The Academy
of Management
and Administration
in Opole

Sergij O. Vambol
Viola V. Vambol
Yana O. Suchikova
Igor V. Mishchenko
Olexandr M. Kondratenko

Monograph

Scientific and practical problems of application of ecological safety management systems in technics and technologies

The Academy of Management and Administration in Opole

Sergij O. Vambol, Viola V. Vambol,

Yana O. Suchikova, Igor V. Mishchenko, Olexandr M. Kondratenko

SCIENTIFIC AND PRACTICAL PROBLEMS OF APPLICATION OF ECOLOGICAL SAFETY MANAGEMENT SYSTEMS IN TECHNICS AND TECHNOLOGIES

Monograph

Opole 2017

ISBN 978-83-62683-42-0

Sergij O. Vambol, Viola V. Vambol, Yana O. Suchikova, Igor V. Mishchenko, Olexandr M. Kondratenko. *Scientific and practical problems of application of ecological safety management systems in technics and technologies.* Monograph. Opole: The Academy of Management and Administration in Opole, 2017; ISBN 978-83-62683-42-0; pp.205, illus. 58; tabs. 17; bibls. 195. Print. In English.

Cover design

Sergij Kovachov

The actual scientific and applied problems of creating of methodological basis of the ecological safety management system of exploitation process of power plants with piston internal combustion engines and the issues of criterial and economic assessment of ecological safety management systems functioning process efficiency have been considered in this monograph. Authors have analysed metrological, technogenic and ecological aspects of experimental researches of ecological safety level indicators and issues of mathematical modelling and calculated researches of technogenic and ecological safety ensuring processes.

The monograph is intended for scientists, engineers and technical employees, graduate and post graduate students, cadets and adjuncts who are studying in specialties «Environmental Protection Technology», «Ecological Safety» and «Civil protection».

Present study was conducted within the framework of the scientific state-funded research project "Nanostructured semiconductors for power efficient ecologically friendly technologies that increase power efficiency and ecological safety of the urbosystem" (State registration number 0116U006961).

Publishing House:
Wyższa Szkoła Zarządzania i Administracji w Opolu
45-085 Polska, Opole, ul. Niedziałkowskiego 18
tel. 77 402-19-00/01
info@poczta.wszia.opole.pl

300 copies

ISBN 978-83-62683-42-0

Академія управління і адміністрації в Ополє

С. О. Вамболь, В. В. Вамболь,

Я. О. Сичікова, І. В. Міщенко, О. М. Кондратенко

НАУКОВО-ПРИКЛАДНІ ПРОБЛЕМИ ЗАСТОСУВАННЯ СИСТЕМ УПРАВЛІННЯ ЕКОЛОГІЧНОЮ БЕЗПЕКОЮ В ТЕХНИЦІ ТА ТЕХНОЛОГІЯХ

Монографія

Ополє 2017

Колектив авторів:

С. О. Вамболь, докт. техн. наук, професор,
В. В. Вамболь, докт. техн. наук, доцент,
Я. О. Сичікова, канд. техн. наук, доцент,
І. В. Міщенко, канд. техн. наук, доцент,
О. М. Кондратенко, канд. техн. наук

Науково-прикладні проблеми застосування систем управління екологічною безпекою в техниці та технологіях : монографія [Текст] / С. О. Вамболь, В. В. Вамболь, Я. О. Сичікова, І. В. Міщенко, О. М. Кондратенко. – Ополє : Академія управління і адміністрації, 2017. – 205 с.

Vambol, S. O. Vambol, V. V., Suchikova, Y. O., Mishchenko, I. V., Kondratenko O. M. (2017), «Scientific and practical problems of application of ecological safety management systems in technics and technologies: Monograph», Publ. Academy of Management and Administration, Opole, Poland, 205 p., Print., In English.

Розглянуто актуальну науково-прикладну проблеми створення методологічних основ систем управління екологічною безпекою процесу експлуатації енергетичних установок з поршневим двигуном внутрішнього згоряння та критеріального й економічного оцінювання ефективності функціонування систем управління екологічною безпекою. Проаналізовано метрологічні й техногенно-екологічні аспекти експериментальних досліджень показників екологічної безпеки та питання математичного моделювання і розрахункових досліджень процесів забезпечення техногенно-екологічної безпеки. Також досліджено питання поліпшення рівня техногенно-екологічної безпеки довкілля з використанням наноструктурованих напівпровідникових фотоперетворювачів.

Для наукових та інженерно-технічних працівників, аспірантів і ад’юнктів, курсантів і студентів, які навчаються за напрямками цивільний захист, технології захисту навколишнього середовища, екологічна безпека.

Дослідження було виконано у межах наукового держбюджетного проекту «Наноструктуровані напівпровідники для енергоефективних екологічно безпечних технологій, що підвищують рівень енергозбереження та екологічної безпеки урбосистеми» (державний реєстраційний номер 0116U006961).

Ил. 58. Табл. 17. Библиогр.: 195 назв.

C O N T E N T S

З М І С Т

P R E A M B L E

Increasing of ecological safety level up to safe or legislative established values of its indicators are relevance scientific, technical and practical problem both for life cycle of technics units and for technologies of production, functioning and utilization of such technics. Complex solution of the problem are possible by the way of creation of ecological safety management systems of various stages of life cycle of such objects based on using of principles of systematic approach, multilevel decomposition, hierarchical structures analysis and decimal division. Team of these monograph authors created methodological basis of such management systems for different types of technics and technologies. Its structures are similar to each other but takes into account of specific features of managed objects, in which is scientific character of created basics, that differ by undoubted *scientific novelty*. *Practical value* of results of research described in these monograph lies in the fact that activities for ensuring of technogenic and ecological safety of technics and technologies was systematized on all levels – strategic, tactical and technical.

First chapter of the monograph dedicated to presentation of methodological basis of creation of ecological safety management systems on examples of functioning process of different technics units and technologies, which form basis of accompany all stages of life cycle of that technics. **Second chapter** contains the results of mathematical modeling and calculated researches of with developed mathematical models of processes of ensuring of ecological safety in technics and technologies.
In monograph **third chapter** presents the analysis results of technogenic, ecological and metrological aspects of experimental researches of values of indicators of ecological safety level as source of initial data for calculated researches and for identification of mathematical models. Base of **fourth chapter** is researches of ensuring of ecological safety of products of nanotechnologies as it is during its life cycle and its application in practice. **Fifth chapter** of these monograph, final in its structure, dedicated to criterial and economical assessment of effectiveness of process of functioning of ecological safety management system, which must be carried out for implementation of feedback in corresponding management system.

These book will be useful for scientists and engineering technical staff, Doctoral and PhD postgraduates, aspirants and adjuncts, students and cadets and also listeners, which studying in areas «Civil Defense», «Technogenic and Ecological Safety», «Technologies of Protection of Environment», «Ecology».

П Е Р Е Д М О В А

Підвищення рівня екологічної безпеки до безпечних чи нормативно встановлених значень показників, що його характеризують, є актуальною науково-технічною і прикладною задачею як для випадку життєвого циклу техніки, так і для технологій, що лежать в основі проектування, виробництва, функціонування й утилізації такої техніки. Комплексне вирішення такої задачі є можливим шляхом створення систем управління екологічною безпекою протягом життєвого циклу таких об'єктів на основі застосування принципів системного підходу, багаторівневої декомпозиції, аналізу ієрархічних структур, десятинного поділу. Авторським колективом створено методологічні основи таких систем управління для різних видів техніки і технологій. Їх структури подібні одна одній, хоча і враховують специфіку об'єктів управління, у чому і виражається науковий характер створених засад, які вирізняються безсумнівною *науковою новизною*. *Практична цінність* результатів досліджень, що наведені у цій монографії, полягає у тому, що заходи щодо забезпечення техногенно-екологічної безпеки техніки і технологій систематизовано на усіх рівнях – стратегічному, тактичному і технічному.

Перший розділ монографії присвячено викладенню методологічних основ створення систем управління екологічною безпекою на прикладах функціонування різної техніки та різних технологій, що складають основу чи супроводжують усі етапи життєвого циклу такої техніки. **Другий розділ** містить результати математичного моделювання та чисельних розрахунків за розробленими математичними моделями процесів із забезпечення рівня екологічної безпеки у техніці й технологіях. У **третьому розділі** монографії наведено результати аналізу техногенно-екологічних і метрологічних аспектів експериментальних досліджень показників рівня екологічної безпеки як джерела вихідних даних для розрахункових досліджень та для ідентифікації математичних моделей. Основою **четвертого розділу** є дослідження щодо забезпечення екологічної безпеки продуктів нанотехнологій як таких протягом їх життєвого циклу та їх застосування на практиці. **П'ятий розділ** цієї монографії, завершальний у її структурі, присвячено критеріальному та економічному оцінюванню ефективності процесу функціонування систем управління екологічною безпекою, що має здійснюватись для зворотного зв'язку у відповідній системі управління.

Монографія буде корисною науковцям та інженерно-технічним працівникам, докторантам, аспірантам, ад'юнктам, студентам, курсантам і слухачам, які навчаються за напрямками «Цивільна безпека», «Техногенно-екологічна безпека», «Технології захисту навколишнього середовища», «Екологія».

INTRODUCTION

Relevance of the study. Results of analysis of modern condition of technogenic and ecological situation in the World and in Ukraine in particular indicates that measures to improve it should not be developed and implemented unsystematically despite the fact that whatever significant positive effects they reached in a particular, narrow, one-sided direction.

Comprehensive and complex nature of processes and technologies which constitute the essence or accompany all stages of the technics life cycle including units of power plants, namely rescue vehicles and equipment, causes a similar character of content, development and implementation of the measures to ensure legislatively established level of the indicators values of ecological safety. To implement this ultramodern approach there is an urgent necessary to develop scientific bases of appropriate methodological support.

Algorithm of solving of this global problem should include management process of development and implementation of such measures step by step, between sequentially following steps must exist cause and effect and hierarchical relations, also this algorithm must to use as the primary initial data values of operational indicators real management objects and being locked by feedback. Such requirements can satisfy only the creation of environmental safety management system on the basis of the principles of a systematic approach, multilevel decomposition, analysis of hierarchical structures decimal division.

As it shown in presents studies, such structured science approach differs with wide universality. It was used as well for ensuring ecological safety of technological processes of uploading, downloading and storing of bulk materials, as for functioning of mines, as for forest fire liquidation processes with using of aerosol dispersed multiphase structures, as for exploitation process of power plants with piston internal combustion engines, as for technological processes of plasma utilization of solid domestic wastes, as for structuring processes of semiconductor nanomaterials and so on. But it should be noted that activities for ensuring of ecological safety in any case require time and money expenses, are scientific and labor capacious. Development of management systems can only optimize these costs, not reduce them to nothing.

That why creating of scientific basics of methodological maintains of ecological safety management systems and whole complex of activities for ensuring of legislative established level of indicators values of ecological safety is extremely promising and relevant area of research in terms of energy and resource costs for scale of country as well as for global scale.

Contact with academic programs, plans, themes. These scientific research reflects main results of performing of scientific work of young scientists that carried out at the expense of state budget of Ukraine of Berdyansk State Pedagogical University «Nanostructured semiconductors for energy efficiency ecological safety technologies which increase level of energy saving and ecological safety of urbanic system» (State Registration № 0116U006961, 2016 – 2018). The research also reflects main results of completed science research work of Applied Mechanics Department of National University of Civil Defense of Ukraine «Theoretical research and development of devices to enhance the operational safety of power plants based on diesel engines» (State Registration № 0115U002040, 2015 – 2016) and two uncompleted science research works – «Hydraulic steams research at the control systems of the enhanceable danger objects ecological safety creation» (State Registration № 0116U002002 2016 – 2017) and «Methodological support for criteria-based assessment of ecological safety management system of power plants of emergency rescue vehicles functioning process efficiency» (State Registration № 0117U002002, 2017 – 2018).

Methods of the study. During carrying out of the research we used following methods. Analysis of scientific and technical literature; synthesis of ecological safety management systems; principals of systematic approach, multilevel decomposition, analysis of hierarchical structures, decimal division; methodics of analysis of data experimentally obtained on engine test bench, calculation of middle exploitation values of technical, economical and ecological operational indicators of piston ICE with standardized stationary testing cycles, calculated assessment of influence of hydraulic resistance of elements of exhaust system of piston ICE of its fuel efficiency; methodics of application of complex fuel and ecological criteria and generalized desirability function; mathematical models of hydraulic resistance and operational efficiency of DPF; mathematical model of motion of two-phase multicomponent dispersed gas-and-drops fluid with taking into account interphase interaction; methods of finite volumes and least squares; methodic of assessment of economical effect of implementation of new technologies; methodics of calculation of geometric parameters of motion trajectory of water jet from manual fire barrel and assessment of influence of measurement errors on it; methodics of analytical, calculated and expetimental assessment of parameters of nanostructured semiconductor materials and operational characteristics of photovoltaic converters.

Purpose of the study. Creation of scientific basis of methodological maintains of ecological safety management systems during life cycle of various types of technics, which based on using of modern ecological safety material and energy saving technologies.

Object of the study. Ecological safety management systems of life cycle of technics and technologies.

Subject of the study. Scientific basis of methodological maintains of ecological safety management systems.

Tasks of the study. During carrying out the research we solved following problems.

1) creation of scientific basis of methodological maintains of ecological safety management systems during life cycle of technics with taking into

account specific features of technologies on which based on its exploitation and utilization;

2) carrying out of mathematical modeling of processes of ensuring of ecological safety as the base of rationalization of technical decisions of construction, exploitation and utilization of technics units;

3) detection and description of technogenic, ecological and metrological aspects of experimental researches of indicators of level of ecological safety of technics and technologies as source of initial data for physical and mathematical modeling and identification of models;

4) detection and studying of features of ways of ensuring of ecological safety of products of nanotechnology during its life cycle as most probability alternative for traditional technologies;

5) creation of scientific basis of methodological maintains of criterial and economical assessment of efficiency of functioning process of ecological safety management systems as basis of monitoring and feedback of such systems;

6) carrying out of SWOT-analysis of results of the study.

Science novelty of results of the study. It is as follows.

1. Was further developed scientific basis of methodological maintains of ecological safety management systems during life cycle of technics with taking into account specific features of technologies on which based on its exploitation and utilization.

2. Was further developed scientific basis of methodological maintains of ecological safety management systems during life cycle of products of nanotechnologies.

3. Was further developed scientific basis of methodological maintains of criterial assessment of functioning efficiency of ecological safety management systems.

Practical value of results of the study. It is as follows.

1. Developed methodological maintains of ecological safety management systems during life cycle of technics and technologies is useful for creation of such systems for new types of management objects.

2. Developed scientific basis of methodological maintains of ecological safety management systems during life cycle of products of nanotechnologies is useful for creation of such systems for new types of management objects.

3. Developed methodological maintains of criterial assessment of functioning efficiency of ecological safety management systems is useful for application with existing and developed systems.

4. Results of analysis of technogenic, ecological and metrological aspects of experimental researches of indicators of level of ecological safety of technics and technologies is useful for development of activities for ensuring of technogenic and ecological safety of experimental researches.

5. Developed ecological safety management systems is useful for implementation in scientific and research works in order of searching of new

ways for ensuring of ecological safety of technics, technologies and its products.

6. Developed methodological maintains of ecological safety management systems was implemented in educational process of National University of Civil Defense of Ukraine and Berdyansk State Pedagogical University.

Material of the research published in 30 scientific articles, namely: 13 articles in professionals scientific journals, including 10 – in journals that is listed in the PAD of Ukraine, 6 – in foreign journals (Republic of Moldova, Republic of Kazakhstan), 8 – in journals, which referred in international scientometric data bases, 1 chapter of handbook and also thesis of 16 scientific reports.

Material of the research passed approbation on 13 international, with international participation, all Ukrainian and regional science, technical and practical conferences and congresses, including on 3 foreign (Republic of Moldova, Republic of Kazakhstan, Russian Federation).

Structure and scope of the research. This monograph presented on 204 pages of main text, consists of preamble, introduction, five chapters, general conclusions and one appendixe on 9 pages. Text of monograph includes 58 figures, 17 tables, bibliography of 195 sources.

Acknowledgements. Team of authors expresses appreciation for consultative and practical help in obtaining scientific data underlying the study, which is reflected in this monograph to following persons: Dr. Sci. (Ped.), Professor *I. T. Bogdanov* (Berdyansk State Pedagogical University), Dr. Sci. (Tech.), Professor *V. M. Shmandiy* (M. Ostrogradsky Kremenchuk National University), Dr. Sci. (Tech.), Professor *M. S. Malyovany* (National University «Lvivska Polytechnica»), Dr. Sci. (Tech.), Professor *V. A. Andronov* (National University of Civil Defense of Ukraine), Dr. Sci. (Tech.), Professor *Y. M. Semchuk* (Ivano-Frankivsk National Technical University of Oil and Gas), Dr. Sci. (Tech.), Professor *I. V. Parsadanov* (National Technical University «Kharkiv Polytechnical Institute»), Dr. Sci. (Tech.), Professor *O. P. Strokov* (Zaporozhye Classical Private University), Cand. Sci. (Tech.), Sr. Researcher *A. M. Levterov* (A. M. Podgorny Institute for Mechanical Engineering Problems of NAS of Ukraine), Cand. Sci. (Econ.), Associate Professor *T. P. Nestorenko* (Berdyansk State Pedagogical University).

ВСТУП

Актуальність дослідження. Результати аналізу сучасного стану техногенно-екологічної ситуації у Світі взагалі та на Україні зокрема свідчать про те, що заходи, спрямовані на її поліпшення, не мають розроблюватися і впроваджуватися безсистемно, яких би суттєвих позитивних ефектів вони не досягали у окремо взятому, вузькому, однобічному напрямку.

Комплексний і складний характер процесів і технологій, які складають сутність чи супроводжують усі етапи життєвого циклу техніки, у тому числі й одиниць енергетичних установок, а саме аварійно-рятувальної техніки, зумовлює аналогічний характер змісту, розробки й впровадження заходів щодо забезпечення законодавчо встановленого рівня значень показників екологічної безпеки. Для реалізації такого надсучасного підходу постає нагальна необхідність у розробці наукових основ відповідного методологічного забезпечення.

Алгоритм вирішення поставленого глобального завдання має передбачати управління процесом розробки і впровадження таких заходів покроково, між послідовно слідуючими кроками мають існувати причинно-наслідкові та ієрархічні зв’язки, такий алгоритм має використовувати у якості початкових вихідних даних значення показників роботи реальних об’єктів управління та замикатися зворотним зв’язком. Такі вимоги може задовольнити лише побудова системи управління екологічною безпекою на основі використання принципів системного підходу, багаторівневої декомпозиції, аналізу ієрархічних структур, десятинного поділу.

Як показано у наведених дослідженнях, такий структурований науковий підхід вирізняється широкою універсальністю – використаний для забезпечення екологічної безпеки технологічних процесів навантаження-розвантаження і зберігання сипких продуктів, функціонування шахт, ліквідації лісових пожеж із застосуванням дисперсних аерозольних багатофазних структур; процесу експлуатації енергетичних установок з поршневим двигуном внутрішнього згоряння; технологічного процесіу плазменої утилізації твердих побутових відходів; процесів структурування напівпровідникових наноматеріалів тощо. Однак слід відмітити, що заходи щодо забезпечення екологічної безпеки у будь-якому випадку потребують часових і грошових витрат, є науко- та працеємними. Розробка систем управління дозволяє лише оптимізувати такі витрати, а не звести їх нанівець.

Тому створення наукових основ методологічного забезпечення систем управління екологічною безпекою та повного комплексу заходів із забезпечення законодавчо встановленого рівня значень показників екологічної безпеки є вкрай перспективним і актуальним напрямком досліджень з точки зору енергетичних і ресурсних витрат як у масштабі країни, так і у всесвітньому масштабі.

Зв'язок з науковими програмами, планами, темами. Дане наукове дослідження відображає основні результати виконання Наукової роботи молодих учених, що виконується за рахунок коштів загального фонду державного бюджету України, Бердянського державного педагогічного університету «Наноструктуровані напівпровідники для енергоефективних екологічно безпечних технологій, що підвищують рівень енергозбереження та екологічної безпеки урбосистеми» (ДР № 0116U 006961 2016 – 2018 рр.). Дослідження також відображає основні результати завершеної НДР кафедри прикладної механіки НУЦЗУ «Теоретичні дослідження і розробка пристроїв для підвищення безпеки експлуатації енергетичних установок на базі дизельних двигунів» (ДР № 0115U002040, 2015 – 2016 рр.), двох виконуваних НДР «Дослідження гідравлічних струменів при створенні систем управління екологічною безпекою об'єктів підвищеного ризику» (ДР № 0116U00 2002, 2016 – 2017 рр.) та «Методологічне забезпечення критеріального оцінювання ефективності функціонування системи управління екологічною безпекою процесу експлуатації енергетичних установок аварійно-рятувальної техніки» (ДР № 0117U 002002, 2017 – 2018 рр.).

Методами дослідження є аналіз науково-технічної літератури; синтез систем управління екологічною безпекою; принципи системного підходу, багаторівневої декомпозиції, аналізу ієрархічних структур, десятинного поділу; методики аналізу даних моторних стендових випробувань, розрахунку середньоексплуатаційних значень техніко-економічних і екологічних показників роботи поршневих ДВЗ за стандартизованими стаціонарними випробувальними циклами, розрахункової оцінки впливу гідравлічного опору елементів випускної системи поршневих ДВЗ на їх паливну економічність; методики застосування комплексного паливно-екологічного критерію і узагальненої функції бажаності; математичні моделі гідравлічного опору і ефективності роботи ФТЧ; математична модель руху двофазного багатокомпонентного дисперсного газо-крапельного середовища з урахуванням міжфазної взаємодії; методи кінцевих об'ємів і найменших квадратів; методика оцінювання економічного ефекту від впровадження нової технології; методика розрахунку геометричних параметрів траєкторії гідравлічного струменя з ручного пожежного ствола і оцінки впливу на них похибок вимірювань; методики аналітичної, розрахункової та експериментальної оцінки параметрів наноструктурованих напівпровідникових матеріалів і робочих характеристик фотоелектричних перетворювачів.

Метою дослідження є створення наукових основ методологічного забезпечення систем управління екологічною безпекою протягом життєвого циклу різноманітних видів техніки, що побудована на використанні сучасних екологічно безпечних матеріало- і енергоощадних технологій.

Об'єктом дослідження є системи управління екологічною безпекою життєвого циклу техніки і технологій.

Предметом дослідження є наукові основи методологічного забезпечення систем управління екологічною безпекою.

Задачами дослідження є такі:

1) створення наукових основ методологічного забезпечення систем управління екологічною безпекою протягом життєвого циклу техніки з урахуванням особливостей технологій, покладених у основу її роботи і утилізації;

2) здійснення метаматичного моделювання процесів забезпечення екологічної безпеки як основи раціоналізації технічних рішень щодо конструкції, експлуатації й утилізації одиниць техніки;

3) виявлення і описання техногенно-екологічних і метрологічних аспектів експериментальних досліджень показників рівня екологічної безпеки техніки і технологій як джерела вихідних даних для фізичного і математичного моделювання й ідентифікації моделей;

4) виявлення і дослідження особливостей шляхів забезпечення екологічної безпеки продуктів нанотехнологій протягом їх життєвого циклу як найімовірнішої альтернативи традиційним технологіям;

5) створення наукових основ методологічного забезпечення критеріального та економічного оцінювання ефективності процесу функціонування систем управління екологічною безпекою як основи моніторингу ефективності функціонування й зворотного зв'язку таких систем управління;

6) виконання SWOT-аналізу результатів дослідження.

Наукова новизна отриманих результатів полягає у такому:

1. Отримали подальший розвиток наукові основи методологічного забезпечення систем управління екологічною безпекою повного життєвого циклу техніки з урахуванням особливостей технологій, покладених у основу її роботи і утилізації.

2. Отримали подальший розвиток наукові основи методологічного забезпечення систем управління екологічною безпекою повного життєвого циклу продуктів нанотехнологій.

3. Отримали подальший розвиток наукові основи методологічного забезпечення критеріального оцінювання ефективності функціонування систем управління екологічною безпекою.

Практична цінність отриманих результатів полягає у такому:

1. Розроблене методологічне забезпечення систем управління екологічною безпекою повного життєвого циклу різних видів техніки та технологій придатне для створення таких систем для нових видів об'єктів управління.

2. Розроблене методологічне забезпечення систем управління екологічною безпекою повного життєвого циклу продуктів нанотехнологій придане для створення таких систем для нових видів об'єктів управління.

3. Розроблене методологічне забезпечення критеріального оцінювання ефективності функціонування систем управління екологічною

безпекою придатне для використання з існуючими та знов розроблюваними системами.

4. Результати аналізу техногенно-екологічних і метрологічних аспектів експериментальних досліджень показників рівня екологічної безпеки техніки і технологій придатні для розроблення заходів щодо забезпечення техногенно-екологічної безпеки експериментальних досліджень.

5. Розроблені системи управління екологічною безпекою придатні для впровадження у науково-дослідну роботу з метою пошуку нових шляхів забезпечення екологічної безпеки техніки, технологій і їх продуктів.

6. Розроблене методологічне забезпечення систем управління екологічною безпекою впроваджено у навчальний процес НУЦЗУ ДСНСУ та БДПУ МОНУ.

Матеріали дослідження опубліковано у 30 наукових працях, а саме: 13 статей у фахових наукових виданнях, з них 10 – у виданнях, що внесені у перелік ДАК України, 6 – у закордонних виданнях (Республіка Молдова, Республіка Казахстан), 8 – у виданнях, реферованих у міжнародних наукометричних базах даних; 1 розділ довідника; тези 16 доповідей.

Матеріали дослідження пройшли апробацію на 13 міжнародних, з міжнародною участю, всеукраїнських і регіональних науково-технічних і науково-практичних конференціях і конгресах, у тому числі на 3 закордонних (Республіка Казахстан, Республіка Бєларусь, Російська Федерація).

Структура та обсяг роботи. Монографія викладена на 204 стор. основного тексту, містить передмову, вступ, п’ять розділів, загальні висновки і один додаток на 9 стор. У тексті монографії присутні 58 рис., 17 табл., бібліографію з 195 джерел.

Слова вдячності. Авторський колектив висловлює вдячність за консультативну й практичну допомогу в отриманні наукових даних, що лягли в основу дослідження, яке відображене у цій монографії, наступним персоналіям: д. т. н., професору *І. Т. Богданову* (Бердянський державний педагоггічний університет), д. т. н., професору *В. М. Шмандію* (Кременчуцький національний університет ім. Михайла Остроградського), д. т. н., професору *М. С. Мальованому* (Національний університет «Львівська політехніка»), д. т н., професору *В. А. Андронову* (Національний університет цивільного захисту України), д. т. н., професору *Я. М. Семчуку* (Івано-Франківський національний технічний університет нафти і газу), д. т. н., професору *І. В. Парсаданову* (Національний технічний університет «Харківський політехнічний інститут»), д. т. н., професору *О. П. Строкову* (Запоріжський класичний приватний університет), к. т. н., с. н. с. *А. М. Лєвтєрову* (Інститут проблем машинобудування ім. А. М. Підгорного НАН України), к. е. н., доценту *Т. П. Нестеренко* (Бердянський державний педагогічний університет).

Chapter 1. METHODOLOGICAL BASIS OF CREATION OF ECOLOGICAL SAFETY MANAGEMENT SYSTEMS

1.1. GENERAL PROVISIONS

Purpose of studies, presented in the chapter, is creation metrological basis of synthesis of ecological safety management systems for examples of various types of technics and different technologies, which form the foundation of its whole life cycle.

Object of studies, presented in the chapter, is ecological safety management systems as a single entity.

Subject of studies, presented in the chapter, is structure and functioning algorithm of ecological safety management systems.

The chapter *includes* materials of three articles.

The **first of these articles** includes material about the results of application of systematic approach for solving the problem of management of ecological safety of process of utilization of solid domestic waste of vital activity with using of plasma technology. Wherewith main structural elements of such system was described by verbal logical formulas.

The **second paper** devoted to issues of conceptual basis of creation of ecological safety management systems, which uses multiphase dispersed structures, namely water-droplet screen for suppression of harmful and explosive aerosols in mines, in enterprises of storing of bulk materials, namely during loading and unloading processes, and also during localization of high and low-level steppe and forest fires by generation of mineralized ground stripes by the way of blasting of hose charges.

Materials of the **third article** consist of results of creation of methodological basis of criterial complex assessment of functioning efficiency of ecological safety management systems of exploitation process of power plants with piston internal combustion engines. Formulated requirements for such criteria, grounded choice units of monetary equivalents of its components, identified possibility of using it criteria for feedback in ecological safety management systems.

Findings of presented in chapter 1 studies is submitted in general conclusions of the monograph.

Bibliographyc description of presented in chapter 1 published scientific articles is submitted in are given in in Appendix A.

Розділ 1. МЕТОДОЛОГІЧНІ ОСНОВИ СТВОРЕННЯ СИСТЕМ УПРАВЛІННЯ ЕКОЛОГІЧНОЮ БЕЗПЕКОЮ

1.1. ЗАГАЛЬНІ МІРКУВАННЯ

Метою досліджень, наведених у розділі, є створення методологічних основ синтезу систем управління екологічною безпекою на прикладах різної техніки та різних технологій, що складають основу чи супроводжують усі етапи життєвого циклу такої техніки.

Об’єктом досліджень, представлених у розділі, є системи управління екологічною безпекою як єдине ціле.

Предметом досліджень, описаних у розділі, є структура і алгоритм функціонування систем управління екологічною безпекою.

Розділ *містить* матеріали трьох статей.

<u>Перша з статей</u> містить матеріали щодо результатів застосування системного підходу до вирішення проблеми управління екологічною безпекою процесу утилізації твердих побутових відходів життєдіяльності за допомогою плазмової технології, при цьому основні структурні елементи такої системи описано вербально-логічними формулами.

<u>Друга стаття</u> присвячена питанням концептуальних основ створення системи управління екологічною безпекою, що використовує багатофазні дисперсні структури, а саме водокрапельні завіси для пригнічення шкідливих та вибухонебезпечних аерозолів у шахтах, на підприємствах зберігання сипких матеріалів, а саме впродовж процесів навантаження і розвантаження, а також під час локалізації верхових і низових степових і лісових пожеж шляхом створення мінералізованих земляних смуг підривом шлангових зарядів.

Матеріали **<u>третьої статті</u>** складають результати створення методологічних основ критеріального комплексного оцінювання ефективності функціонування систем управління екологічною безпекою процесу експлуатації енергетичних установок з поршневим двигуном внутрішнього згоряння. Сформульовано вимоги до критерію для такого оцінювання, обґрунтовано вибір одиниць для вираження вартісних еквівалентів його складових, вказано можливість використання критерію для організації у систем управління екологічною безпекою зворотного зв’язку.

Висновки по результатам досліджень, представлених у розділі 1, винесено у загальні висновки по монографії.

Бібліографічний опис наведених у розділі 1 друкованих наукових праць наведено у Додатку А.

1.2. SYSTEMATIC APPROACH TO SOLVING THE PROBLEM OF MANAGEMENT OF ECOLOGICAL SAFETY DURING PROCESS OF BIOWASTE PRODUCTS UTILIZATION [A.1.1]

Problem statement. Significant negative impact on the balance of the natural environment, for ecological safety have excessive concentration of ecologically dangerous manufactures imperfection of technological processes, technical systems and the unreliability of other human activities. Among the factors of ecological safety in the majority of regions is one of the dominant position occupied by waste. One of the reasons of occurrence of ecologically dangerous waste is a scientific and technological progress in the creation of new kinds of materials [1.1]. In accordance with the Law of Ukraine "Of Wastes" hazardous waste is waste that having such physical, chemical, biological or other dangerous properties that create or could create a significant risk to the environment and human health and which require special methods and means of handling them. An effective solution to the problem of generation and accumulation of dangerous waste is to create a of ecological safety management system (ESMS) at their utilization [1.2, 1.3]. In this case, it is reasonable to use a systematic approach to the development of organizational and technological solutions for utilization. The system approach allows rational formulate and solve the complex problems, by structuring and allocation of their individual tasks as relatively independent parts.

Methods of research. Like any complex system, the management of ecological safety consists of many components that form the basis of their functional characteristics and relationships in the operation of the whole system. This allows presenting the system in the form of model suitable for analytical research and synthesis of components-subsystems of systems as itself and environment. The starting point for the development of such a system is proposed the differentiation of production process on the specific stages. Each of the components of management system of ecological safety during waste utilization is a very complicated and a large target subsystem and characterized by certain functions, methods and mans of their implementation. The main tasks for management system of ecological safety are to prevent (or substantially reduce) the negative impact on the natural environment, mitigate the effects of manifestations of sources of danger, the weakening of the intensity of the action of hazards. In this case the priority management technical solutions are the use of schemes of joint processing of waste of different economic systems.

Results of research. Using the principle of multilevel decomposition [1.4], we have to go to the formalization of solution of the problem of rational management of ecological safety during utilization process of biowaste products. The process of designing of the system is due to the division into hierarchical levels of functionally completed stages of the solution of the complex of subtasks of that level (Fig.1.1).

Initial data for creation of ecological safety management system		Improved and new technologies, which using ecological safety management system		Organization and executing the processes, which using ecological safety management system		Results of using of which using ecological safety management system	
1st level Identification of wastes	**2nd level** Identification of hazards dependently of principals of the formation	**3rd level** Preparing processes	**4th level** Equipment	**5th level** Organization and controlling of management system of ecological safety	**6th level** Manufacturing processes	**7th level** Output results of using of management system of ecological safety	**8th level** Control system

Fig. 1.1 – General scheme of multilevel decomposition (without excessive detailed elaboration)

Formation of the initial data (Fig. 1.2) includes two levels defining the approaches to the identification of wastes and hazards. At the first level are determined by the types of waste for utilization technological process. In this case especially allocated groups promoting the formation of highly toxic substances.

The second level involves detection and identification of hazards with taking into account the characteristic features of the region (each of regions have its own priorities and hierarchy of structures of accumulation of biowaste products and manufacturing), space and time structuring of hazard (set of ecological dangerous wastes of any kind of genesis, which because of interaction and mutually influence are hazard generators), quantitative structuring (involves amiability of statistic data of each of types of biowaste products). That level is finalizing by development of variants of principle technological schemes of utilization with taking into account ensuring of ecological safety.

The stage of new and improving technologies as well as the previous consists of two serial levels (Fig. 1.3) The third level covers the preparatory processes of creating of technological system of utilization, which taking into account ecological safety. It includes the technological process of thermal processing of wastes, pyrolysis; creating the necessary thermochemical process, which prevents formation of highly toxic substances and the process of following possible formation of highly toxic compounds.

On the fourth stage produced technical requirements and developed equipment necessary for utilization process that ensured ecological safety (in gaseous and solid residue). By these we mean servicing of technological processes by main, auxiliary and additional equipment with taking into account safety of staff. The character feature of that level is taking into account volumes and nomenclature of production processes and also dates of performances.

Directly executing of process of utilization of biowaste products presented the third stage (Fig. 1.4). Here is fifth level that characterized by the solution of tasks of control and organization of technological process. If we considering of specificity of the tasks, these level characterized by presence follow components of: organization of sequence of process; organization of shop sections of executing of technological process; and also systems of dispatching and management. The complex solving of tasks of that level must be carried out jointly with solving of tasks of sixth level – manufacturing. That involves the organization of technological and manufacturing processes on Fig. 4, considering ensuring of ecological safety.

1st level	**2nd level**
dentification of wastes	Identification of hazards dependently of principals of the formation
Consuming wastes	Regionalization of hazards
Industrial wastes	Space and time structuring
Domestic wastes	Quantitative structuring of hazard sources
Subsystem of initial data for developing of management system of ecological safety	

Fig. 1.2 – Scheme of initial data formation stage

3rd level	**4th level**
Preparing processes	Equipment
Technological process of thermal processing of wastes	Equipment for preventing formation of highly toxic substances in exhaust gasses
Technological process, which prevent formation of highly toxic substances	
Technological process, which prevent the secondary formation of highly toxic substances	Equipment for preventing formation of highly toxic substances in solid residue
The new and improving ecological safety technologies of utilization	

Fig. 1.3 – Scheme of new and improving technologies stage

The final stage of this algorithm is control of results of application of management system of ecological safety (Fig. 1.5). The seventh level imply obtaining of following parameters of ensuring of ecological safety, which basis on executing utilization process: reducing of volume of wastes on facilities and polygons; obtaining the products of useful purpose (for example, combustible gas, industrial chemical compounds, heat energy, electrical energy, matter for building industry etc.). At the last, eighth level is necessary to organize the system of controlling that allows evaluating efficiency of works for ensuring of ecological safety.

Proposed hierarchic structure implies formalization of solution of the assigned task just in strictly adhering to the basic principles of multilevel decomposition. This implies the following features:

– presents of vertical (between the levels) and horizontal (between the stages) communications;

– priority of action of levels and stages from bottom to top;

– interrelation of levels;
– varieties of choosing and solving of the tasks for each of levels.

The functions of technological system of utilization of biowaste products. The foundation of existing of any system is basis and availability of specific purpose for its operating. It must be assumed that taken separately components of system perform their functions by subordinate its actions to final goal. At the same time, all of components of scheme are in benefiting interrelations and coordination in actions.

5^{th} level	**6^{th} level**
Organization and controlling of management system of ecological safety	Manufacturing stages of technological processes
Organization of sequence of process	High temperature processing of waste
Organization of shop sections of executing of technological process	Decomposition of toxic substances by low temperature plasma
dispatching and management of process	Rapid cooling of exhaust gases
	Methanation
	Purification of exhaust gases
	Separation on products of useful purpose
Organization and executing of processes with using the management system of ecological safety	

Fig. 1.4 – Scheme of organization and executing stage

7^{th} level	**8^{th} level**
Output results of using of management system of ecological safety	Control system
Reducing of volume of wastes on facilities	Ensuring of parameters of ecological safety
Reducing of volume of wastes on polygons	
Obtaining the products of useful purpose	
Results of application of management system of ecological safety	

Fig. 1.5 – Scheme of ensuring of executing stage

The main function of technological system of utilization is to create a technological process of utilization of biowaste products with taking into account ecological safety. We should also mention the ability of obtaining of products of useful purpose for following usage. Form of the function is formally represented as a complex of following three components:

$$F = (A, B, C), \tag{1.1}$$

Here, under our notation should be understood: A – action of system (component) which leads to necessary result; B – designation of object to which directed action; C – formulation of special conditions and limitations under which executed action of the system (components).

Assuming that description of function for proposed technological system of utilization can made by form of formula (1), components of that formula taking following meanings:

F (system of ensuring of ecological safety) = [ecological safety (A)
in operating of technological process of utilization (B)
with rational organization and technical parameters
and application of improved technologies of ensured of safety (C)].

The general approach determines that each of components of the system (component-subsystem, component-element) also is determined by its own function. Functions of system components are dependent on their own properties and on its relations with other components. To formulate the main functions of components of the system we can use a proposed above General multilevel scheme (Fig. 1.1) and schemes of its individual levels (Fig. 1.2 – 1.5).

At the first level in subsystems we must allocate dangerous wastes by their types of formation and identify them by risk of possibility of formation of highly toxic substances in process of utilization.

In process of definition of main regularities of formation of ecological danger in subsystems of second level (Fig. 1.2) the components of Formula (1.1) taking the following meanings:

F^2_1 (regionalization of hazards) = [as a result of analysis industrial and social features of the region (A) allocate priorities of hazard structures (B) in depending on possible development of hazard (C)];

F^2_2 (space and time structuring of hazards) = [as a result of analysis ecological dangerous objects of any kind of genesis, which due to interaction and mutual influence between themselves are generated the hazard (A), positioning its sources (B) with taking into account not only spatial location of that sources in relation to various objects, but also nature of environment in which they are distributing (C)];

F^2_3 (quantitative structuring of sources of ecological danger) = [as a result of analysis of different variants of principal schemes of utilization of biowaste products (A) they classified with taking into account of disposable resources (B) and their kinds (C)].

The functions of subsystem of third level (Fig. 1.3) are following:

F^3_1 (technological process of heat processing) = [choosing of technological processes (A), which create thermodynamic conditions (B) necessary for decomposition of wastes on molecular components (C)];

F^3_2 (technological process, which prevents formation of highly toxic compounds, pyrolysis) = [choosing of technologies (A) for creation of process of pyrolysis (B) and its organization in area (C) where existing highly toxic compounds];

F^3_3 (technological process, which prevents secondary formation of highly toxic compounds) = [choosing of technologies (A) for creation and transportation multiphase structures for realizing of regime of rapid cooling of exhaust gases (B), which prevents secondary formation of highly toxic compounds (C)];

The functions of subsystem of fourth level (Fig. 1.3) are following:

F^4_1 (equipment for preventing formation of highly toxic compounds in atmosphere) = [designing, manufacturing and choosing (A) of equipment (B), which ensured ecological safety process of utilization of wastes that prevent formation of highly toxic compounds (C) at minimal cost of equipment);

F^4_2 (equipment for preventing formation of highly toxic compounds in solid residue) = [designing, manufacturing and choosing (A) of equipment (B), which ensured quality of implementation of technological process of pyrolysis (C) at minimal cost of equipment);

The functions of subsystem of fifth level (Fig. 1.3) are following:

F^5_1 (organization of sequence of process) = [developing (A) of cyclic schedule (B) of forming of thermal utilization, which ensured a minimal spending of resources for ensuring of industrial and ecological safety (C)];

F^5_2 (organization of shop sections of executing of technological process) = = [designing and organization (A) of shop sections for realization of technological process of ecological safety utilization (B) with taking into account features of new and improving technologies (C)];

F^5_3 (management of the process) = [regulation and network planning in time (A) of cyclic schedules of using of technological processes of ecological safety utilization (B) for implementation of manufacturing cycles (C)].

The basic regularities of subsystem of sixth level (Fig. 1.4) we can describe following functions:

F^6_1 (technological process of high temperature processing of wastes) = = [regulation and network planning in time (A) of cyclic schedules of technological processes of burning of biowaste products (B) for implementation of predetermined manufacturing processes (C)];

F^6_2 (technological process of decomposition of toxic substances) = = [regulation and network planning in time (A) of decomposition of highly toxic substances by low temperature plasma (B) for implementation of predetermined task (C)];

F^6_3 (technological process of cooling of exhaust gases) = [regulation and network planning in time (A) of process of cooling of exhaust gases with using of multiphase dispersed structures (B) for implementation of predetermined task (C)];

F^6_4 (technological process of methanation) = [regulation and network planning in time (A) of process of methanation of exhaust gases (B) for implementation of predetermined task (C)];

F^6_5 (technological process of purification of exhaust gases) = [regulation and network planning in time (A) of process of purification of exhaust gases (B) for implementation of predetermined task (C)];

F^6_5 (technological process of separation of exhaust gases) = [regulation and network planning in time (A) of process of separation of exhaust gases on technological gasses and combustible methane (B) for implementation of predetermined task (C)];

The functional dependences for subsystems of seventh and eighth levels (Fig. 5) fit into general dependences for process of utilization of biowaste products with taking into accounts ecological safety.

F (system of ensuring of ecological safety) = [ecological safety (A) in process of operation of technological process of utilization (B) at rational organization and technical parameters with application of improved technologies of ensuring of safety (C)].

Conclusions. Consideration of management system of ecological safety in process of utilization of biowaste products as a complicated technological system, allows complex carrying out the problem of ecological safety. On basis of principle of multilevel decomposition was formalized the task of rational management in utilization biowaste products and described functions of technological system of utilization.

With taking into account of statements of systematic approach of solving of complicated problems and also specific features of creation of management system of ecological safety in utilization of biowaste products, was proposed the methodological scheme for solving of task of management of ecological safety considering obtaining the useful products.

1.3. CONCEPTUAL BASIS AND CREATION OF ECOLOGICAL SAFETY MANAGEMENT SYSTEM OF HARMFUL AEROSOL SUPPRESSION, WHICH USES MULTIPHASE DISPERSED STRUCTURES [A.1.2]

Introduction. The process of multiphase dispersed structures (MDS) formation in the respective statement of the problem may take a worthy place in the creation of ecological safety management system (ESMS) [1.5].

Analysis of recent publications. During the technical preparations for the implementation of management processes must be based on the existing normative and technological documentation and results of carried out experimental researches, perform spatial and temporal structuring of danger and its quantitative indicators. It should take effective schemes of implementation of ESMS [1.6].

On the basis of these materials is being developed technological processes that use MDS, designing and manufacturing funds of equipment of the process, determined the form of organization of the technological processes and also the processes themselves are implemented.

Thus, an integrated model of the processes of ecological safety management, reflecting the variety of factors that affect the content of work for ensuring ecological safety, can be arranged only if its decomposition and the development of relatively independent models of individual complexes of preparation for ensuring the ecological safety.

Since preparations for the implementation of ecological safety technologies requires significant investment of time and resources, the possibility of experimental verification of different options to address specific tasks of development of ESMS practically impossible.

Under these conditions, modeling and definition of the rationality of decisions taken is the only and very effective way to solve problems using computer technology with minimal cost and sufficient accuracy.

Formulation and solving of problem. Based on the conceptual basis of a systematic approach [1.7], we propose the following scheme for solving the problem of formation of a control system (Fig. 1.6).

Taking into account the basis of systematic approach in case of solving of difficult problems as well as the analysis of specific features of a system ecological safety management creation process [1.7, 1.8], we propose using the following sequence when forming a model ecological safety management, which using multiphase dispersed structures:

– determination of problems and analyzing relevant information for final statement of problems;

– elaboration of models in a descriptive, mathematical or other forms of representation;

– selection efficiency criteria or criteria of decision making for rationalization of such systems;

– development of methods and means for resolving identified problems, including the development of computer algorithms and programs to implement them with the help of computer technology;

– experimental studies to verify the results of theoretical developments, including in industrial conditions and real operation conditions;

– development of recommendations and regulatory technical documentation for practical application of proposed and studied method and means and also optimization models of ecological safety management systems.

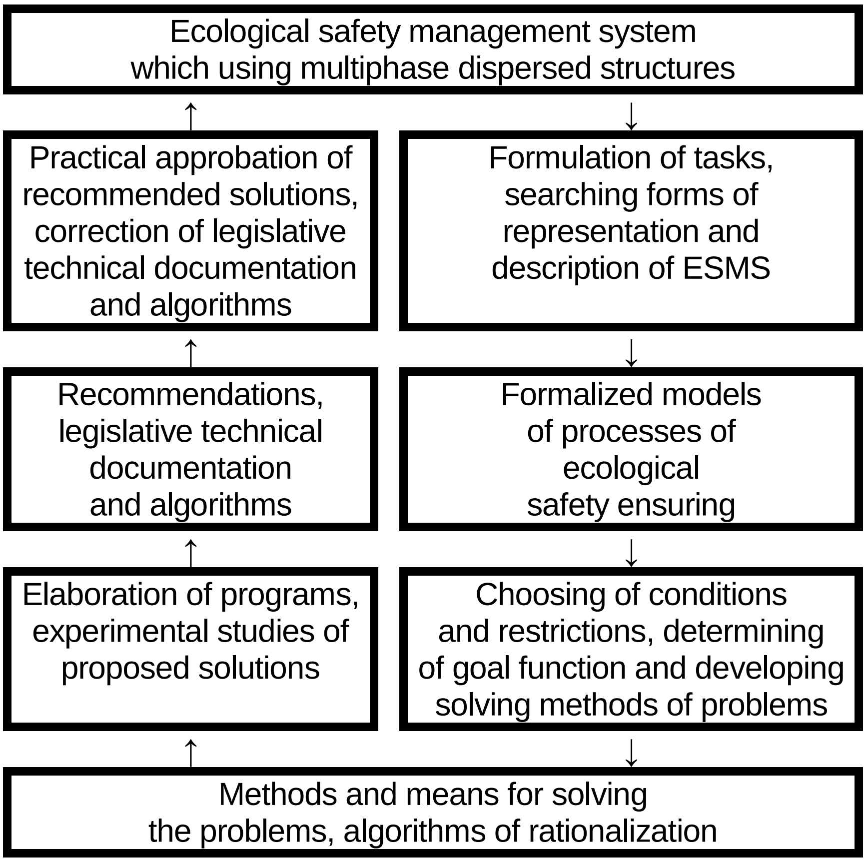


Fig. 1.6 – Scheme of solving of ecological safety management system creation problem

Like any complex system, the management of ecological safety consists of many components that form the basis of their functional characteristics and relationships in the operation of the whole system. This allows presenting the system in the form of model suitable for analytical research and synthesis of components-subsystems of systems as itself and environment. The starting point for the development of such a system is proposed the differentiation of production process on the specific stages.

Each of the components of management system of ecological safety during waste utilization is a very complicated and a large target subsystem and characterized by certain functions, methods and means of their implementation.

The main tasks for management system of ecological safety are to prevent (or substantially reduce) the negative impact on the natural environment, mitigate the effects of manifestations of sources of danger, the weakening of the intensity of the action of hazards. In this case the priority management technical solutions are the use of schemes of joint processing of waste of different economic systems

Results of research. Using the principle of multilevel decomposition [1.7 – 1.9], we have to go to the formalization of solution of the problem of rational management of ecological safety during aerosol suppression process by water-drop curtain generation. The process of designing of the system is due to the division into hierarchical levels of functionally completed stages (of which there are 4) of the solution of the complex of subtasks of that level (of which there are 8 – two for each stage) (Fig. 1.7) [1.9].

The 1st Stage – "Formation of the initial data" – includes two levels defining the approaches to the identification of wastes and hazards.

At the 1st Level – "Identification of hazard aerosols" – are determined by the types of hazard aerosols (of mineral dust, explosive coal dust of combustion smoke in air). In this case especially allocated groups promoting the formation of highly toxic substances (in case of forest fires) or explosive particle-air mixtures (in case of coal mines) of mineral dust and air aerosols (in case of storage facilities) [1.9].

The 2nd level – "Identification of hazards dependently of principals of the formation" – involves detection and identification of hazard aerosols with taking into account the characteristic features of the region (each of regions have its own priorities and hierarchy of aerosol particles kind structures), space and time structuring of hazards (set of ecological dangerous aerosols of any kind of genesis, which because of interaction and mutually influence are hazard generators – coal mine, ports and storage facilities or forest fires), quantitative structuring (involves amiability of statistic data of each of types of hazard aerosol). That level is finalizing by development of variants of principle technological schemes of hazard aerosol suppression by water-drop curtain generation with taking into account ensuring of ecological safety.

The 3rd Stage – "New and improving technologies" – as well as the previous consists of two serial levels.

The 3rd Level – "Preparing processes" – covers the preparatory processes of creating of technological system of hazard aerosol suppression by water-drop curtain generation, which taking into account ecological safety. It includes the technological process of generation and delivery to the desired location of water-drop curtain, which prevents formation of highly toxic substances in environment air.

On the 4th Stage – "Equipment" – produced technical requirements and developed equipment necessary for hazard aerosol suppression process that ensured ecological safety. By these we mean servicing of technological processes by main, auxiliary and additional equipment with taking into account safety of staff. The character feature of that level is taking into account volumes and nomenclature of manufacturing processes and also dates of performances.

The 3rd Stage – "Organization and executing the processes, which using ecological safety management system" – consists of two serial levels.

Here is 5th Level – "Organization and controlling of ecological safety management system" – that characterized by the solution of tasks of control and organization of technological process. If we considering of specificity of the tasks, these level characterized by presence follow components of:

– organization of sequence of process;

– organization of shop sections of executing of technological process;

– systems of dispatching and management.

The complex solving of tasks of that level must be carried out jointly with solving of tasks of 6th Level – "Manufacturing processes". That involves the organization of technological and manufacturing processes on, considering ensuring of ecological safety.

The final, 4th, Stage of this algorithm – "Results of using of which using of ecological safety management system" – is control of results of application of ecological safety management system.

The 7th Level – "Output results of using of ecological safety management system" – imply obtaining of following parameters of ensuring of ecological safety, which basis on executing hazard aerosol suppression by water-drop curtain generation process: reducing of pollutants concentration in environment air, increasing the ecology, fire and explosive safety level of coal mines, ports and storage facilities or forests.

Initial data for creation of ecological safety management system		Improved and new technologies, which using ecological safety management system		Organization and executing the processes, which using ecological safety management system		Results of using of which using ecological safety management system	
1st level	**2nd level**	**3rd level**	**4th level**	**5th level**	**6th level**	**7th level**	**8th level**
Identification of hazard aerosols	Identification of hazards dependently of principals of the formation	Preparing processes	Equipment	Organization and controlling of ecological safety management system	Manufacturing processes	Output results of using of ecological safety management system	Control system

Fig. 1.7 – General scheme of multilevel decomposition
(without excessive detailed elaboration)

At the last, 8th Level – "Control system" – is necessary to organize the system of controlling that allows evaluating efficiency of works for ensuring of ecological safety.

Proposed hierarchic structure implies formalization of solution of the assigned task just in strictly adhering to the basic principles of multilevel decomposition. This implies the following features:

– presents of vertical (between the levels) and horizontal (between the stages) communications;

– priority of action of levels and stages from bottom to top;

– interrelation of levels;

– varieties of choosing and solving of the tasks for each of levels.

Conclusions. In present paper considered conceptual basis of creation of ecological safety management system of executing hazard aerosol suppression by water-drop curtain generation process for coal mines, ports and storage facilities or forest fires, which uses multiphase dispersed structures. That was done on basis of principle of multilevel decomposition and systematic approach by formalization of rational management in executing hazard aerosol suppression task. Also it was proposed the methodological general scheme for solving of task of management of ecological, fire and explosive safety of coal mines, ports and storage facilities or forests.

1.4. METHODOLOGICAL BASICS OF CRITERIAL INTEGRATED ASSESSMENT OF ECOLOGICAL SAFETY MANAGEMENT SYSTEM FUNCTIONING EFFICIENCY OF POWER PLANTS WITH PISTON ICE EXPLOITATION PROCESS [A.1.3]

Relevance of the research. Power plants (PP), a mechanical power source in which is an piston internal combustion engine (PICE), are a powerful source ecological danger, in particular – mass emission of gaseous pollutants with the flow of exhaust gas (EG) [1.11]. Ensuring compliance of PP with PICE with legislatively established ecological safety (ES) indicators is one of the priorities as well for experts in the PICE field as for experts in the ES field. Due to the above it is also possible to ensure urbosystems ES, which should also be based on the appropriate methodological support – ecological safety managing systems (ESMS). For quantitative estimation of measures to ensure the urbosystems ES effectiveness considering anthropogenic impact on them there is a necessary for the relevant criteria. Also, using such criteria, it becomes possible to compare competing designs and individual technical solutions for the same designs. Thus, the development of ESMS effective functioning criteria of the PP with PICE process exploitation as an integral part of their life cycle (LC), characterized by the greatest possible universality and taking into account in this context as much as possible danger factors, is an actual problem with a significant scientific novelty and practical value

Analysis of previous studies. The authors of the study [1.11] have developed a the ESMS of PP with PICE exploitation process. The structure of such ESMS contains Stage 4, entitled "The results of ESMS use" which in their turn contains a Level 8, called "ES level monitoring and control system" is the final in ESMS structure, closes her by feedback through use of the ES indicators monitoring and control of the ESMS effectiveness as itself [1.11 – 1.12]. Functions of the whole ESMS and its Level 8, which we are interested in, can be described by the following verbal and logical formulas [1.11, 1.13]:

F^i_j {N} = [A, B, C] = F {ES ensuring system} = [ES indicators (A) of extracting and processing of waste and pollutants technological process, the source of which are PP with PICE (B), by organization and technical parameters by the way of using of new and improved technologies of ES ensuring (C)]; (1.2)

F^8 {ES level monitoring and ESMS operating control system} = = [monitoring and control of ES of PP with PICE exploitation process indicators level (A) in the appropriate ESMS functioning process of (B), at the rational organization and technical parameters with using of new and improved technologies of ES ensuring (C)], (1.3)

where A – action of the system or its component, which gives necessary result; B – name of the object, on which aimed action of the system or its component; C – formulation of the special conditions and limitations, at which performed action of the system or its component; i – number of the ESMS Level; j – number of the ESMS Level structure element; N – name of the ESMS Level structure element.

Structure of that ESMS is shown on Figure 1.8 [1.11].

Purpose of the study. Purpose of the study is creation of the methodological basis for complex ecological and economical assessment of PP with PICE exploitation process efficiency.

Goals of the study are following:

1. creation of the criteria for complex ecological and economical assessment of PP with PICE exploitation process efficiency;

2. creation of the algorithm for such criteria and selection of its components measurement units;

3. definition of the hierarchical place of such criteria in structure of ESMS, of PP with PICE and of its LC.

Object of the study is the methodological basis for complex ecological and economical assessment of PP with PICE exploitation process efficiency. Subject of the study is the criteria, that gives complex characteristic for object of the study.

Solution of task of the study. The solution of task of creation of methodological support for implementation of that ESMS Stage are proposed by the way of development of its functioning efficiency criteria, which differs as much as possible universality. The proposed conception of that criteria development and its application algorithm involves following sequence of

Steps, which shown in the Table 1.1.

Thus, proposed algorithm is closed with feedback (i.e., cyclic) and is not autonomous regarding ESMS as itself, because it contains Steps B and F, with which is implemented its interaction with the ESMS. Therefore, it can be called integrated in ESMS. Here Step B is the source of the new information in the algorithm and the Step F is a source of information for ESMS.

Stage 1 → Initial data for ESMS creation		**Stage 2** → Improved and new technologies for ES level ensuring which using by ESMS		**Stage 3** → Organization and performing of technological processes for ES level ensuring which using by ESMS		**Stage 4** → Results of ESMS application ↲	
Level 1 →	**Level 2** →	**Level 3** →	**Level 4** →	**Level 5** →	**Level 6** →	**Level 7** →	**Level 8** →↲
Identification of ecological danger factors sources and analysis of low and normative dada base	Classification of ecological danger factors with taking into account its genesis and significance	Development of improved and new preparation technological processes	Development of improved and new equipment for technological processes implementation	Organization and management of ESMS	Manufacturing and technological processes which ensure specified ES level	Output results of ESMS application: values of ES factors and obtaining of designated purpose production	System of monitoring and control of ES level

Fig. 1.8 – Scheme of ESMS of PP with PICE exploitation process [1.11]

For realizing the Step A «Basic version of the object» and Step C «Modernized version of the object» of developed algorithm, taking into account specific features of technical object on which acts ESMS, is proposed using complex fuel and ecological criteria of prof. I.V. Parsadanov [1.14] and other criteria, that is similar to it, developed on its basis or likeness. As a mode initial data for such assessment should be used the results of experimental or computational researches, which based on known, improved or developed methodic, such as in research [1.15]. For obtaining the middle exploitation values of initial data should be used the test methodic, which appropriate exploitation model of PICE or PP and because of it contains stationary, transition or mixed operation modes list with its characteristics (for PICE it is values of crankshaft speed, torque and weight factor etc.) and also appropriate techniques for experimental obtained data processing. In the case of impossibility of carrying out of experimental studies for specific exploitation models and availability data from previous studies for obtaining the necessary initial data can be use mathematical apparatus of approximation (for example, least square or linear regression methods), interpolation or extrapolation [1.13].

For implementation of Step B "Action of ESMS on the object" of the algorithm is proposed to use results of other ESMS Steps described in [1.10, 1.11].

Table 1.1 – Sequence of Steps of the algorithm

Step	Name and gist of the Step
A	«**Basic version of the object**». Quantitative estimation in absolute and relative units of values level of complex technical and economical mode or/and middle exploitation indicators of basic version of PP with PICE, that is before implementation of events for increasing of its ES level.
B	«**Action of ESMS on the object**». Development and implementation of events in the ESMS structure for ensuring of certain ES level of PP with PICE exploitation process.
C	«**Modernized version of the object**». Quantitative estimation values level of such indicators complex for modernized version of PP with PICE, that is after implementation of events for increasing of its ES level based on new or improved methods and means.
D	«**Response of the object to ESMS action**». Definition of absolute and relative difference of values such indicators complex for basic and modernized versions of PP with PICE, that is offered to consider the ESMS functioning efficiency criteria.
E	«**Normalization of the ESMS functioning efficiency criteria**». Comparison of obtained difference of such indicators complex values with its legislative limited values or developed scale and conclusion of certain findings based on a comparison of that results.
F	«**Correction of action of ESMS on the object**». Correction of kind or sequence of events for ES level ensuring in the ESMS structure and also intensity or nature of impact of individual event.
G	«**Feedback**». Rationalization of ESMS functioning efficiency criteria value in iteration process with variation of parameters values of technological processes and executive organs, that ensure necessary ES level.

For implementation of Step D "Response of the object to ESMS action" of the algorithm is proposed the difference of complex of technical, economical and ecological indicators values for basic and modernized versions of PP with PICE actually considered the criteria of ESMS operation efficiency of PP with PICE exploitation process – Ω_{ESMS} [1.14]. Composition of complex of technical, economical and ecological PICE operational indicators, that can be taking into account by such criteria, must be as comprehensive as possible, what determines criteria universality level. For that it must be in accordance with paragraphs of ecological danger factors classification, that created in research [1.11] and presented on Fig. 1.9. In this case that criteria of ESMS operation efficiency of PP with PICE exploitation process defined by formula [1.13]:

$$\Omega_{ESMS} = \left(\mathrm{E}_M - \mathrm{E}_B\right) / \mathrm{E}_B, \quad (1.4)$$

where E_M and E_B – accordingly monetary expenses for modernized and basic versions of PP with PICE, $.

Justification of measurement units choice for Ω_{ESMS} criteria – US Dollars ($) – presented in [1.13]. This decision is due to the following circumstances.

Firstly, by definition, money is the commodity of maximum liquidity and the universal equivalent of the value of goods and services [1.16].

Secondly, the presence of the successful experience of applying well-known approach to assessment of technical, economic and ecological indicators of PICE developed by prof. I.V. Parsadanov as part of the methodology of calculation of the fuel and ecological criteria K_{FE} [1.14].

Thirdly, not all of monetary expenses components is possible to bring to form the dimensionless quantity β and, moreover, give them a physical meaning of average operational efficiency specific mass hour fuel consumption $g_{e.av.exp}$, as in the case K_{FE} [1.14].

In research [1.14] monetary expenses, which included in K_{FE} criteria structure, expressed in Ukrainian Hryvnia (₴). But in this case there is the problem of assessing the effectiveness of measures to ensure the ES level of PP with PICE which are in operation for a long time. So, for the case of raising the ES level of diesel 2Ch10,5/12 by equipping it exhaust system with DPF, developed in Piston Power Plants Dept. of A.M. Podgorny Institute for Mechanical Engineering Problems of NAS of Ukraine with the participation of staff members of the Applied Mechanics Dept. of Technogenic and Ecological Safety Faculty of National University of Civil Defense of Ukraine [1.15, 1.17 – 1.19], a direct comparison of K_{FE} criterion values for the basic (diesel without DPF) and modernized (diesel with DPF) version to perform in the Ukrainian Hryvnia difficult.

This is due to the following circumstances.

Firstly, diesel 2Ch10,5/12 (D21A1), which was used as a generator of aerosol of PM in the EG in these studies, released in the middle of the 80-years of the XX century, modern its modification produced by the Vladimir Tractor Plant (Russian Federation) and has significant constructive differences (e.g., electronic fuel supply control system). In this case to accurately estimate total operating time and the residual motoresource, prehistory and features of its exploitation, maintenance and repair measures and also, accordingly, its current technical condition and correlate it with any value indicator is extremely difficult.

Secondly, at the time of its release, such monetary unit as the Ukrainian Hryvnia didnt exist, and the unit in which to express it cost parameters – USSR Ruble – do not exist at present; monetary unit in which its cost was estimated at the time when motor test bench was equipped with this diesel engine – Ukrainian Coupon-Karbovanets, also no longer exists; and the current modification of this diesel engine is estimated in Russian Rubles.

Thirdly, for some reason the Ukrainian Hryvnia exchange rate against major freely convertible (so-called hard) currencies is very unstable. So, at the time of introduction into circulation Ukrainian Hryvnia (1996), its rate against the US Dollar ($) amounts to less than 2 ₴/$, at the beginning of development of DPF concept (2008) – about 5 ₴/$, at the time of obtaining experimental data for the study [1.15] (2013) – about 8 ₴/$, at the time of mathematical models [1.17 – 1.19] creation (2014) – about 12 ₴/$, at the moment (October 2016) – about 26.5 ₴/$. To predict behavior of this macroeconomic indicator with reasonable accuracy for at least six months in advance is impossible, not to mention the longer term.

In connection with the above considerations, it seems rational to express the monetary expenses values E in the formula (3), that forming Ω_{ESMS} criteria value, in one of the widely used in Ukraine freely convertible world reserve currencies – Euro or US Dollar. However, only the last one has a history, that completely covering the PICE history from birth of the idea (1807 de Rivas engine, 1860 Lenoir engine, 1863 two-stroke Otto engine,1876 four-stroke Otto engine, 1880 Kostovich engine, 1897 Diesel engine) and to the present day.

In this case should take into account that purchasing capacity of the US Dollar throughout its existence since the creation of the first PICE to the present day was not constant too due to manifestations of inflation phenomenon, which can be accounted by applying the Consumer Price Index CPI [1.16].

In order to enable comparative studies of different energy sources for PP, such as PICE and separately photoelectric converter (PEC) based on nanostructured semiconductors [1.20], or a complex of PEC and supercapacitor or a complex of PEC, supercapacitor and electric motor, in the structure of the developed criterion Ω_{ESMS} monetary expenses for fuel must be converted into energy or power units.

It should also be noted that the equipping diesel by the DPF affects the value of K_{FE} criteria as a part of Ω_{ESMS}, both positively – by reducing the PM mass emissions from the EG flow (and corresponding money expenses for compensation for impact of that ecological danger factor on environment or urbosystem), and negative – due to fuel consumption increase to overcome the DPF hydraulic resistance [1.13, 1.15, 1.19].

To implement Step E "Normalization of the ESMS functioning efficiency criteria" of the algorithm is proposed to use the data of regulatory legal acts that are in force in the territory, where PP operation is carried out, such as the UNECE Regulation number 49 or 96 [1.11].

To implement Step F "Correction of action of ESMS on the object" of developed algorithm is proposed to be based on specific characteristics of the particular measures to ensure the ES level of PP with PICE process exploitation or complex of such measures.

To implement Step G "Feedback" of developed algorithm is proposed to use experiment planning method [1.21], mathematical apparatus of multi-criteria optimization [1.22], as well as the mathematical apparatus of fuzzy logic, namely Harrington generalized desirability function using psychophysical scales [1.23, 1.24].

When developing Ω_{ESMS} criteria must take into account the following aspects of the hierarchical structure of ESMS, PP and its LC.

The whole LC of PP with PICE is traditionally divided into sequential chain of phases, a division into which found no common approach among researchers. In the light of specifics of this problem and the above considerations it makes sense to them combined in blocks given in Fig. 1.10.

When developing Ω_{ESMS} criteria is also necessary take into account the features of PP as is and PICE as they energy sources.

Firstly, one and the same PICE can be used as actuator for different types of PP (for example, autotractor diesel engines), that is used by various exploitation models.

Secondly, one PP can contain more than one PICE (e.g., mobile concrete mixer with a drive mixer by a separate PICE, articulated lorry consisting of tractor and power unit with electric generator, water pump or air compressor on board, etc.) that can be exploited simultaneously, separately and with some overlap of each other's time.

Thirdly, PP as itself, excluding the presence in its composition PICE and aggregates of its systems, made outside the engine compartment, are also sources of ecological and technogenic danger, and must be both qualitatively and quantitatively characterized by its own factors, the criteria for which evaluations also require development or modifications.

Fourthly, in some PP there is PICE, what is not the primary or main source of mechanical energy, or produces such energy discontinuously (e.g., hybrid vehicles), that is its operation model is fundamentally different from a conventional as well by the structure, as by parameters of individual modes of PICE exploitation modes.

Due to above, especially it should be noted that the proposed Ω_{ESMS} criteria in the proposed formulation takes the following hierarchical place in the structures of LC and the composition of PP: firstly, characterizes only Block II of PP with PICE LC "exploitation"; secondly, characterizes ES level only of part PP, namely PICE and systems units that its service, as shown in Fig. 1.11.

In Fig. 4 there are the following notation: indices I, II and III are marked Ω_{ESMS} criteria for the Block I, Block II and Block III of LC, respectively, while the index ES and EC is designated Ω_{ESMS} criterion for PP energy sources (e.g., PICE and units of its systems, made by outside the engine compartment) and its energy consumers (PP all executive organs, parts of its skeleton, control and measuring equipment, etc.), respectively.

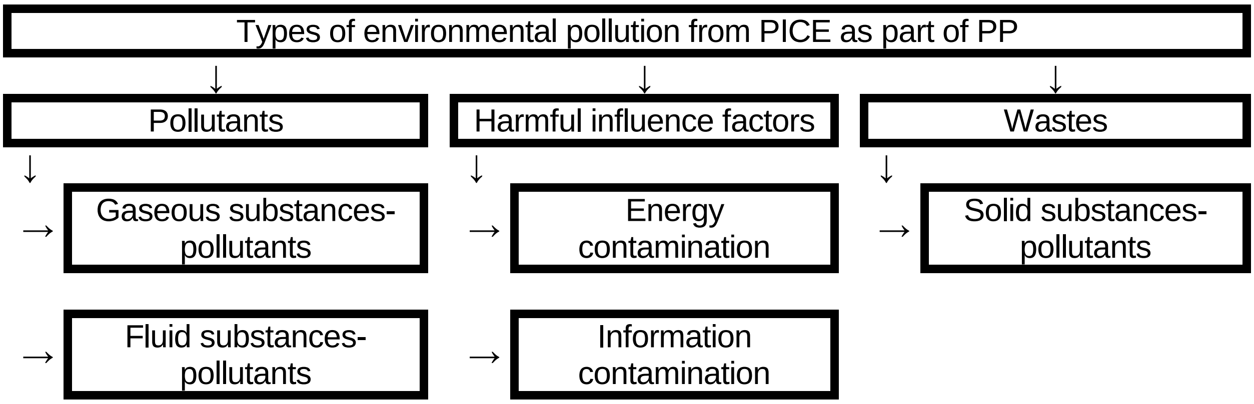


Fig. 1.9 – Classification of Types of environmental pollution from PICE as part of PP [1.11]

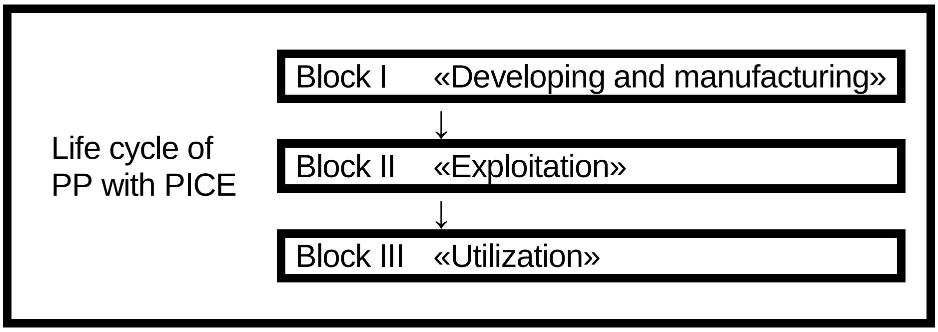


Fig. 1.10 – Dividing the PP with PICE life cycle into blocks suitable for use in the development ESMS process

Therefore, for the ESMS of the PP with PICE exploitation process its functioning efficiency criterion can be expressed by the following formula.

$$\Omega^{PP}_{ESMSII} = f\left(\sum_{j=1}^{m}\Omega^{ES}_{ESMSII};\ \sum_{k=1}^{n}\Omega^{EC}_{ESMSII}\right), \qquad (1.5)$$

where f – some mathematical function, that linking components of Ω_{ESMS} criteria with each other; j and m – number and quantity of energy source in the PP structure; k and n – number and quantity of energy consumer in the PP structure.

Summing up the above arguments, the structure of the algorithm of estimation the efficiency of ESMS of PP with PICE exploitation processes and its place in the ESMS structure shown in Fig. 1.12.

Conclusion. Thus, in the study developed methodological basis of the criteria for evaluating the ESMS functioning effectiveness of PP with PICE operation process, what consists the scientific novelty of the study results. It is equal to the difference between the values of the complex technical, economic and ecological indicators of basic and modernized versions of such objects.

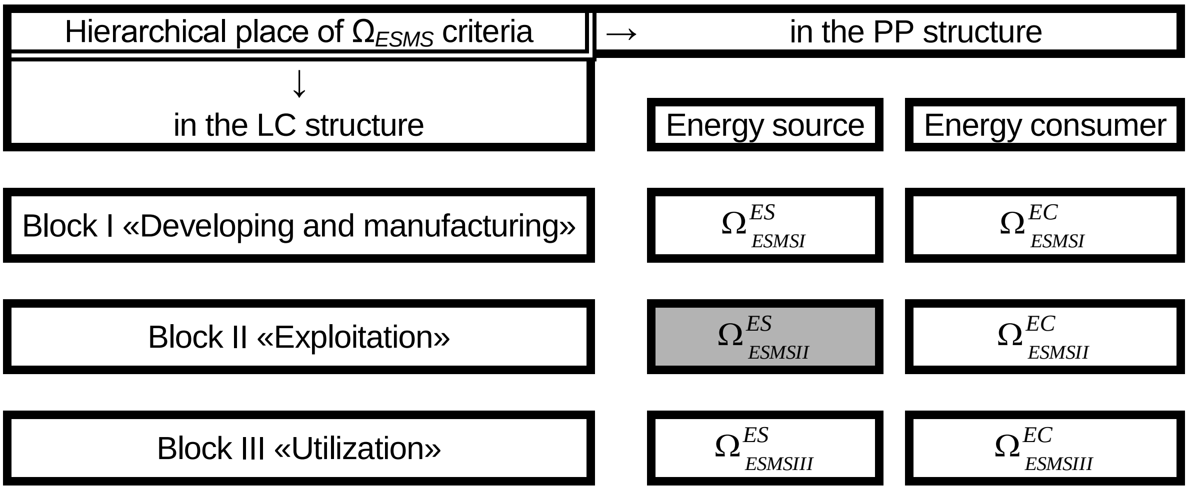


Fig. 1.11 – Hierarchical place of Ω_{ESMS} criteria

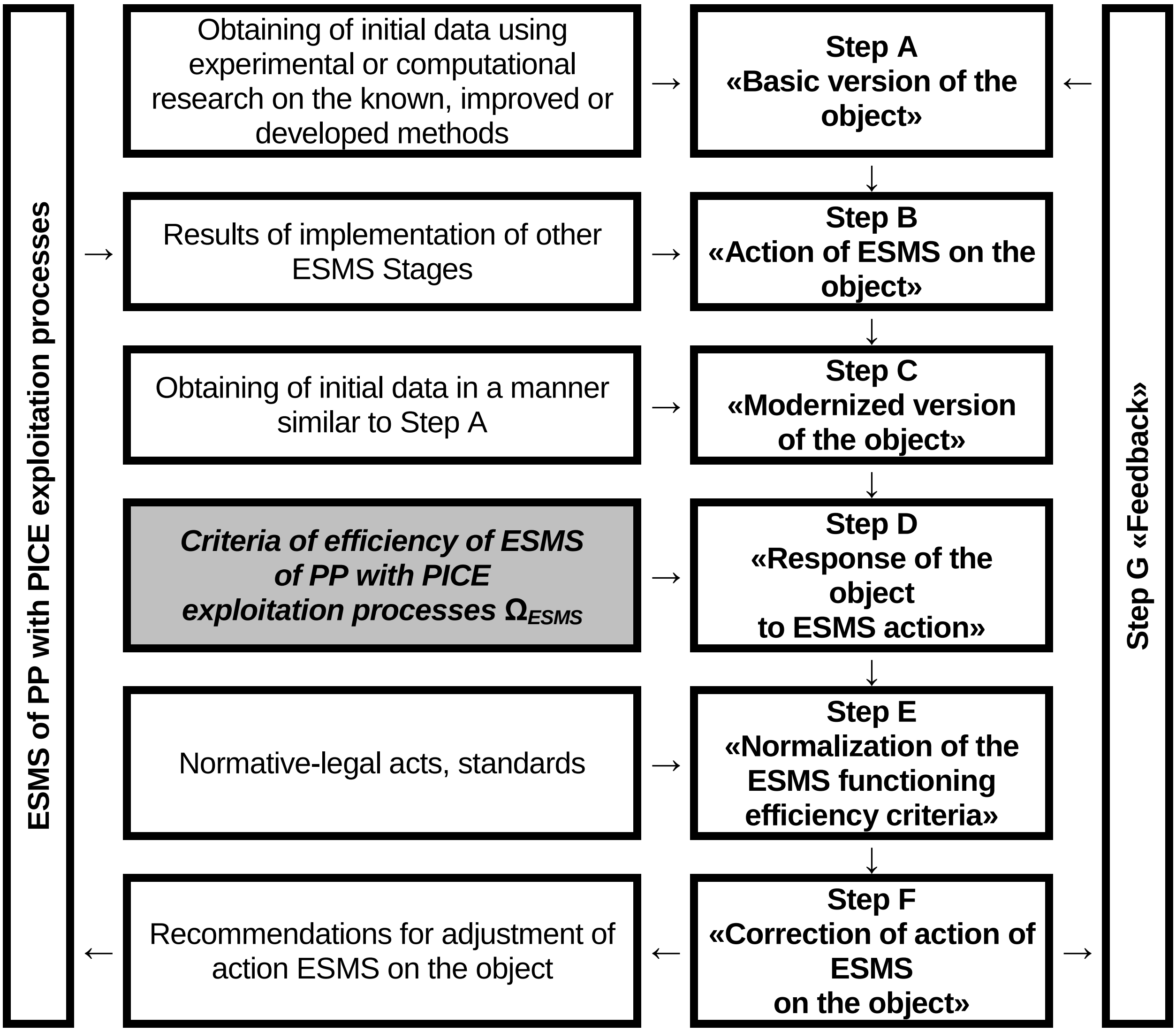


Fig. 1.12 – Algorithm of estimation the efficiency of ESMS of PP with PICE exploitation processes

It is the final in the structure of ESMS, closes it with feedback through the use of monitoring ES indicators and monitoring the effectiveness of the ESMS as itself, what consists the practical value of the study results. Determined hierarchical place of such a criterion in the structure of ESMS, PP and its life cycle. Confirmed by calculated studies results hypothesis about the necessity of expressing the value equivalent of components of integrated fuel and ecological criteria in terms of global reserve freely convertible currency.

1.5. REFERENCES

1.1. Shmandij, V.M., Klymenko, M.O., Golik, Ju.S., Pryschepa, A.M., Bakharev, V.S., Kharlamova, O.V. (2013), Ecologichna bezpeka: pidruchnyk [Ecological safety: textbook], Oldi-plus, Kherson, Ukraine.

1.2. Shmandij, V.M. (2001), Upravlenije ekologicheskoj bezopasnost'ju urbosistemy na stadii obrazovanija i postuplenija othodov v okruzhajuschuju sredu: monografija [Management of technogenic safety of urban system at the stage of formation and admission of wastes in environment: monograph], KhDPU, Kharkov, Ukraine.

1.3. Kobrin, V.N., Nechyporuk, N.V., Vambol', V.V. (2014), "System of management of ecological safety in utilization of solid domestic and industrial wastes", Ecological Safety, no. 2 (18), pp. 24 – 29.

1.4. Saati, T.L. (1989), Prinjatije reshenij. Metod analiza ijerarhij: monografija [Making decisions. Method of analysis of hierarchies: monograph], Radio i Svjaz', Moscow, USSR.

1.5. Shmandij V.M., Nekos V.Ju. (2008), "Ekologichna bezpeka: pidruchnyk" [Ecological safety: Textbook] [Text], Kharkiv: Publ. V.N. Karasin KhNU, 436 p. [in Ukranian].

1.6. Shmandij V.M. (2001), "Teoreticheskije i prakticheskije osnovy upravlenija tehnogennoj bezopasnost'ju na regional'nom urovne" [Theoretical and practical basis of management of technogenical safety on regional level] [Text], Environmental protection from anthropogenic loading, issue 4 (6), Kremenchuk, Publ. KrNU, pp. 95 – 100. [in Russian].

1.7. Vambol' S.O., Metelev A.V. (2013), "Sistemnyj podhod k upravlenijy ekologicheskoj bezopasnost'ju, ispol'zujuschij mnogofaznyje dispersnyje struktury" [Systematic approach for management of ecological safety which uses multiphase dispersed structures] [Text], Firefighting, problems, technologies, innovations: materials of International science and practical conference, Moscow, Publ. Academy of GPS MChS of Russia, pp. 347 – 351. [in Russian]

1.8. Vambol' S.O. (2013), "Sistemy upravlenija ekologicheskoj bezopasnost'ju, kotoryje ispol'zujut mnogofaznyje dispersnyje struktury" [Systems of management of ecological safety that using multiphase dispersed structures: Monograph] [Text], Kharkiv, Publ. National Aerospace University named after N.E. Zhukovsky "Kharkiv Aviation Institute", 204 p. [in Rus.].

1.9. Vambol' V.V., Shmandij V.M., Vambol' S.O., Kondratenko O.M. (2015), "The systematic approach to solving the problem of management of ecological safety during process of biowaste products utilization" [Text], Science Journal "Ecological Safety", Kremenchuk, Publ. KrNU, no 1 (19), pp. 7 – 11.

1.10. Vambol' S.A., Strokov A.P., Vambol' V.V., Kondratenko O.M. (2015), "Metodologicheskij podhod k postrojeniju sistemy upravlenija ekologicheskoj bezopasnost'ju ekspluatacyi energeticheskih ustanovok" [Methodological approach to development of management system of ecological safety of exploitation of power plants] [Text], Internal Combustion Engines: all-Ukrainian scientific and technical journal, Kharkiv, Publ. NTU "KhPI", no. 1, pp. 48 – 52.

1.11. Vambol S.O., Strokov O.P., Vambol V.V., Kondratenko O.M. (2015), "Modern methods for improving the ecological safety of power plants exploitation: monograph" [Suchasni sposoby pidvyshchenn'a ekologichnoi' bezpeky ekspluatacii energetychnykh ustanovok: Monografija] [Text], Kharkiv, Publ. Styl-Izdat, 212p. [in Ukrainian].

1.12. Kondratenko O.M., Vambol S.O., Vambol V.V. (2015), "Functions of management system of ecological safety of power plants exploitation" [Funkcyi sistemy upravlenija ekologicheskoj bezopasnost'ju ekspluatacyi energeticheskih ustanovok] [Text], Kharkiv, Bulletin of KhNAHU. Col. of sci. works, Publ. KhNAHU, Issue 69, pp. 95 – 100 [in Russian].

1.13. Kondratenko O.M. (2016), "Effectiveness evaluation concept of ecological safety management of power plants with piston ice exploitation process" [Koncepcyja ocenki effektyvnosti upravlenija ekologicheskoj bezopasnost'ju processa ekspluatacyi energetycheskih ustanovok s porshnevym DVS] [Text], Kharkiv, Scientific journal «Internal Combustion Engines», Publ. NTU "KhPI", № 2, pp. 68 – 72. [in Russian].

1.14. Parsadanov I.V. (2003), "Improving the quality and competitiveness of diesel fuel in an integrated and ecological criteria: monograph" [Pidvyshhennja jakosti i konkurentospromozhnosti dyzeliv na osnovi kompleksnogo palyvno-ekologichnogo kryteriju: monografija] [Text], Kharkiv, Publ. NTU "KhPI", 244 p. [in Ukrainian].

1.15. Kondratenko O.M. (2013), "Reduction of emissions of the particularte matter of vehicle diesel engines under operating conditions: a thesis for degree of Candidate of Science: specialty 05.05.03 – engines and power plants" [Snizhenie vybrosa tverdyh chastic transportnyh dizelej, nahodjashhihsja v ekspluatacii: dys... kand.tehn. nauk: 05.05.03 – dvyguny ta energetychni ustanovky] [Manuscript], Kharkiv, Podgorny Institute for Mechanical Engineering Problems, 288 p. [in Russian].

1.16. Matveeva T.Ju. (2004), "Introduction to macroeconomics" [Vvedenye v makroekonomyku] [Text], Moscow, Publ. GU-VShE, 512 p. [in Russian].

1.17. Kondratenko O.M. (2014), "Mathematical model of the hydraulic resistance of the diesel particulate matter filter. Part 1: adjusting coefficient"

[Matematicheskaja model' gidravlicheskogo soprotivlenija fil'tra tverdyh chastic dizelja. Chast' 1: nastroechnyj kojefficient] [Text], Kharkiv, Herald of NTU "KhPI". Series: Mathematical modeling in engineering and technology, Publ. NTU “KhPI”, № 18 (1061), pp. 68 – 80 [in Russian].
1.18. Kondratenko O.M., Strokov O.P., Vambol S.O., Avramenko A.M, (2015), “Mathematical model of efficiency of diesel particulate matter filter” [Matematychna model' efektyvnosti roboty fil'tra tverdyh chastynok dyzelja] [Text], Dnipropetrovs’k, Scientific Bulletin of NMU, Publ. NMU, Issue 6 (150), pp. 55 – 61 [in Ukrainian].
1.19. Kondratenko O.M., Strokov O.P., Vambol S.O. (2014), “Estimation of influence of hydraulic resistance of DPF on the fuel efficiency of diesel engine” [Ocinka vplyvu gidravlichnogo oporu FTCh na palyvnu ekonomichnist' dyzelja] [Text], Kharkiv, Herald of NTU "KhPI". Series: Transport Machine building, Publ. NTU “KhPI”, № 14 (1057), pp. 57 – 66 [in Ukr.].
1.20. Deyneko N.V., Sychikova Ja.O. (2013), “Hybrid device for ensuring of using solar energy efficiency” [Gibrydnyj prystrij dlja zabezpechennja energoefektyvnosty vykorystannja sonjachnogo vyprominennja] [Text], Materials for XXIV International scientific and practical conference MICROCAD “Information technology, science, engineering, technology, education, health”, Part 2 (18 – 20 may 2016), Kharkiv, Publ. NTU “KhPI”, p. 14 [in Ukrainian].
1.21. Adler Ju.P., Markova E.V., Granovskij Ju.V. (1976), “Planning experiment in the search for optimal conditions” [Planirovanie eksperimenta pri poiske optimal'nyh uslovij] [Text], Moskow, Publ. Nauka, 279 p. [in Russian].
1.22. Akhnazarova S.L., Kafarov V.V. (1985), “Methods of experiment optimization in Chemical Technology” [Metody optimizacii jeksperimenta v himicheskoj tehnologii] [Text], Moscow, Publ. Vysshaja shkola, 327 p. [in Russian].
1.23. Harrington E.C.Jr. The Desirability Function [Text] / E.C. Harrington // Industrial Quality Control. – 1965. – № 21 (10). – P. 494 – 498.
1.24. Pichkalev A.V. (2012), “Generalized Harrington desirability function for comparative analysis of technical equipment” [Obobshhennaja funkcija zhelatel'nosti Harringtona dlja sravnitel'nogo analiza tehnicheskih sredstv] [Text], Sci. journal “Issledovanija Naukograda”, № 1, pp. 25 – 28. [in Russian].

Chapter 2. MATHEMATICAL MODELING OF TECHNOGENIC AND ECOLOGICAL SAFETY ENSURING PROCESSES

2.1. GENERAL PROVISIONS

Purpose of studies, presented in the chapter, is achieving of mathematical models of processes of providing of acceptable or legislative established levels of ecological safety indicators and also results of calculated assessment of it values.

Object of studies, presented in the chapter, is fundamental relationships between main influencing factors and values of indicators in processes of providing ecological safety.

Subject of studies, presented in the chapter, is mathematical description of processes of providing ecological safety.

The chapter *includes* materials of four articles, one of them (the first one) combines the contents of two reports.

The **first of these articles** described the background of beta-distribution mathematical apparatus application in numerical simulation of ecological safety ensuring process. The study carried out for examples of ensuring the localization of forest fires by creates a protective ground strips by using the explosion and practical reduce the ecological danger of rescuers during these works as well as for case of numerical simulation of ecological safety ensuring process, namely for describing distribution low of certain characteristics particulate matter as dispersed phase of aerosol diesel engine exhaust gases.

The **second** and the **third articles** includes materials about the description of relationship between regulatory and real manufacturing precision of fire nozzle and its water jet trajectory geometric characteristics with metrology mathematical apparatus as well as results of calculated assessment of values of this influence.

In the **fourth paper** discussed issues of numerical integration of cooling process of gas, formed by thermal recycling of domestic solid waste with development of physical model of gas-dynamic processes of interfacial interactions in viscous multiphase aerosol in the evaporative heat exchanger with centrifugal water nozzles. That provides a sharp cooling of the exhaust gases and therefore ensure improvement of ecological safety level in the thermal wastes utilization process by preventing the formation of highly toxic substances in the generator gas.

Findings of presented in chapter 2 studies is submitted in general conclusions of the monograph.

Bibliographic description of presented in chapter 2 published scientific articles is submitted in are given in in Appendix A.

Розділ 2. МАТЕМАТИЧНЕ МОДЕЛЮВАННЯ ПРОЦЕСІВ ЗАБЕЗПЕЧЕННЯ ЕКОЛОГІЧНОЇ БЕЗПЕКИ

2.1. ЗАГАЛЬНІ МІРКУВАННЯ

Метою досліджень, наведених у розділі, є розробка математичних моделей процесів забезпечення прийнятних чи законодавчо встановлених рівнів показників екологічної безпеки, а також результатів розрахункового оцінювання їх значень.

Об'єктом досліджень, представлених у розділі, є фундаментальні взаємозв'язки між основними впливаючими факторами та значеннями показників в процесах забезпечення екологічної безпеки.

Предметом досліджень, описаних у розділі, є математичне описання процесів забезпечення екологічної безпеки.

Розділ *містить* матеріали чотирьох статей, одна з яких – перша – поєднує вміст тез двох доповідей.

Перша з статей описує передумови застосування математичного апарату бета-розподілу для чисельного моделювання процесів забезпечення екологічної безпеки. Дослідження виконано на прикладах забезпечення локалізації лісових пожеж шляхом створення вибухом захисних земляних смуг та зниження екологічної небезпеки рятівників впродовж цього процесу, а також для випадку чисельного моделювання процесів забезпечення екологічної безпеки, а саме описання закону розподілу основних характеристик твердих частинок як дисперсної фази аерозолю відпрацьованих газів дизельних двигунів.

Друга і третя статті містять матеріали щодо описання взаємозв'язку між нормативною і реальною точністю виготовлення ручного пожежного ствола та геометричних характеристик струменя води з нього за допомогою математичного апарату метрології, а також щодо результатів розрахункового оцінювання значень такого впливу.

У **четвертій статті** обговорено питання чисельного інтегрування процесу охолодження газів, що утворились під час термічної утилізації твердих побутових відходів, з побудовою фізичної моделі газодинамічних процесів між фракційної взаємодії у в'язкому багатофазному аерозолі у випарному теплообміннику з відцентровими водяним форсунками. Такі процеси забезпечують підвищення рівня екологічної безпеки у процесі термічної утилізації відходів шляхом попередження формування високотоксичних речовин у генераторному газі.

Висновки по результатам досліджень, представлених у розділі 2, винесено у загальні висновки по монографії.

Бібліографічний опис наведених у розділі 2 друкованих наукових праць наведено у Додатку А.

2.2. BACKGROUND OF APPLICATION OF BETA-DISTRIBUTION IN NUMERICAL SIMULATION OF ECOLOGICAL SAFETY ENSURING PROCESS [A.2.1, A.2.2]

These article is based on materials of two reports at All-Ukrainian science and technical conferences [A.2.1, A.2.2].

Relevance of the study exhaustive manner characterized by title of the publication.

Purpose of the study is describing and substantiate the basic prerequisites of application of mathematical apparatus of beta-distribution for numerical simulation of ecological safety ensuring process.

Object of the study is features of numerical simulation of ecological safety ensuring process.

Subject of the study is substantiation of application of mathematical apparatus of beta-distribution for object of the study.

Tasks of the study is:

1. definition of background of application of beta-distribution mathematical apparatus for case of ensuring the localization of forest fires and reduce the ecological danger during these works rescuers practically creates a protective ground strips by using the explosion;
2. definition of background of application of beta-distribution mathematical apparatus for case of numerical simulation of ecological safety ensuring process, namely for describing distribution low of certain characteristics particulate matter as dispersed phase of aerosol diesel engine exhaust gases.

2.2.1. Background of application of beta-distribution mathematical apparatus for case of ensuring the localization of forest fires and reduce the ecological danger during these works rescuers practically creates a protective ground strips by using the explosion.

To ensure the localization of forest fires and reduce the ecological danger during these works rescuers practically creates a protective ground strips by using the explosion. Together with the simplicity of use, low cost and high efficiency, there are certain drawbacks associated with the use of explosives.

Proposed by A.M. Grishin etc. version of the fuel-air mixture formation by using the explosive charge, first used in ammunition of volume blast, does not reuce the risks during the operation of such charges.

The bulk of the detonation-capable mixture is distributed along the periphery of the cloud, which reduces the impact action with a corresponding increase in fuel consumption. It is known that the three-dimensional mathematical modeling of volume blast hose-charge action on the forest phytocenosis and vegetation carried out using non-stationary gas dynamics equations for compressed gas in the Cartesian coordinate system.

The existing software complex allows calculating the density, velocity, pressure, temperature of mixture, the concentration of mixture components (fuel, air and combustion products), and the rate of heat release within the limits each control volume mixture on each discrete time step.

From the metrological point of view in this situation we formally carry indirect measurement accuracy of which substantially dependent on the accuracy of measurement (or calculation) of variables included in the calculation formula. In the case where distribution of individual variables errors can be considered a normal, error distribution of output value in principle is different from normal. In practice for testing of these distributions normality used visual methods, such as histograms, normal probability graphs or numerical methods by using of estimation of asymmetry and excess coefficients.

But in case of inconsistency of the empirical distribution to the normal, which is usually presented as a histogram, becomes the question of searching or selection of the distribution, according to certain criteria and more accurately describes the empirical distribution.

The authors proposed approach to building the universal family of distributions, including approximation based on families of Pearson distributions that is one that covers a broad class of probability distributions, not close to normal.

Final thesis speaks about a variability and flexibility in solving the problem of approximation that under verification and substantiation the possibility of using beta-distribution allows use the proposed in the mathematical apparatus for determining parameters specified distribution when conducting research [2.1].

2.2.2. Background of application of beta-distribution mathematical apparatus for case of numerical simulation of ecological safety ensuring process, namely for describing distribution low of certain characteristics particulate matter as dispersed phase of aerosol diesel engine exhaust gases.

The ecological safety management system (ESMS) of exploitation process of power plants (PP) with piston internal combustion engines (ICE) contains individual stages, the implementation of which involves quantitative and qualitative identification of sources and factors of ecological danger, theoretical and experimental investigation of their characteristics, development or selection methods and means to bring them to the normative established levels and monitoring of the ESMS operation [1.11]. In the case of PP equipped with diesel ICE during their normal operation the main factors of ecological danger are emissions of nitrogen oxides and particulate matter (PM) from exhaust gases (EG) [1.11, 1.18, 2.2, 2.3]. PM is dispersed phase of EG aerosol consisting of adsorbent particles (soot cores) and adsorbate (unburned hydrocarbon of fuel and motor oil), coagulated together. At that the basic characteristics of PM in their ensemble (mass, counting number, adsorbing surface area, hydraulic radius) vary in a wide range as in individual sample and along the diesel exhaust tract, and also depend on diesel mode parameters [1.11, 2.3, 2.4]. Thus, typical (obtained by averaging the results of experimental and theoretical studies for various types of diesel engines operating under different conditions) distribution of weighted values of mass, counting number and adsorbing surface area in the PM ensemble on values of PM equivalent projection diameter within individual EG sample has the form presented in the studies [2.2, 2.3] and shown in Fig. 1.

As shown in Fig. 2.1, distribution curves of these random variables have the form with three modes and have a character which much different from the normal distribution law. Mathematical expectation and values of similar modes for the different characteristics of PM not match. Characteristics of the distribution curve, which includes the central moments 2nd ... 4th order (dispersion asymmetry coefficient, excess) for modes of the same PM characteristics also not match.

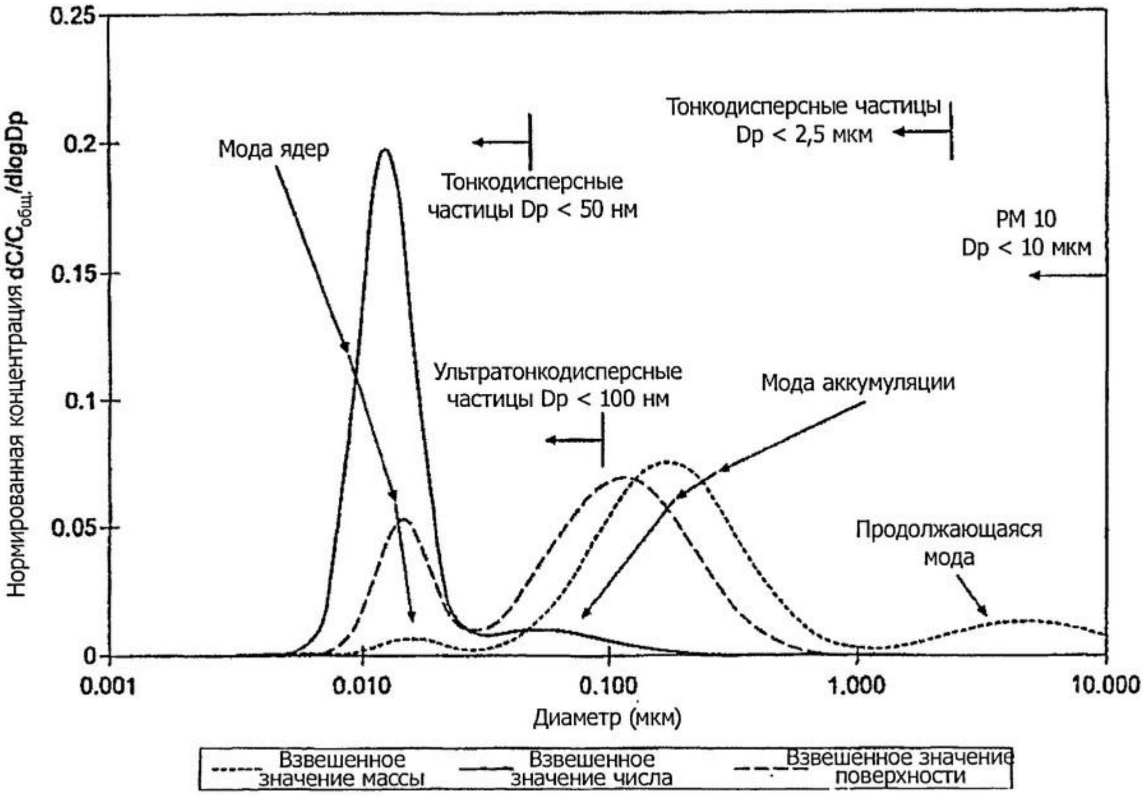


Fig. 2.1 – Averaged dispersed fractional composition of diesel PM (in original language – Russian) [2.2]

In connection with foregoing there is some interest of scientific character in getting the mathematical description of the PM distribution laws. The results of such description (distribution law and its numerical characteristics) also have practical value and can be used in computational studies of EG aerosol motion laws in diesel exhaust tract and in aggregates of EG reducing the toxicity system at forming of initial and boundary conditions. Features of beta distribution mathematical apparatus detail discussed by the same authors by the example of geometric characteristics of typical details of mechanical engineering constructions (rolling bodies of bearings) in the study [2.4 – 2.6]. The feasibility and application algorithm of beta distribution mathematical apparatus for the geometric characteristics of construction elements of typical objects of fire and rescue equipment (manual fire barrels) by the same authors reviewed in the study [2.7].

Conclussions. Thus, in present paper described dackground of application of beta-distribution mathematical apparatus for case of ensuring the localization of forest fires and reduce the ecological danger during these works rescuers practically creates a protective ground strips by using the explosion.

Also in the paper described background of application of beta-distribution mathematical apparatus for case of numerical simulation of ecological safety ensuring process, namely for describing distribution low of certain characteristics particulate matter as dispersed phase of aerosol diesel engine exhaust gases.

2.3. RELATIONSHIP BETWEEN REGULATORY MANUFACTURING PRECISION OF FIRE NOZZLE AND ITS WATER JET TRAJECTORY GEOMETRIC CHARACTERISTICS [A.2.3]

Introduction. From the main provisions of the hydraulics is known that the geometric parameters of trajectory of water jet from a convergent conical nozzle, what is the manual fire nozzle (MFN), depends on diameter of its outlet hole [2.8 – 2.12]. In approximate calculations of these water jet parameters are used the nominal value of the MFN outlet hole diameter [2.10 – 2.12]. However, this parameter is conditional and characterized by a certain value of the precision [2.13, 2.14]. Analysis and evaluation of the accuracy of manufacture of fire fighting equipment components, as well as any technical object, is the subject of research of metrology [2.8, 2.9]. Since the MFN is the product of mass production, the basic requirements to it are reflected in GOST 9923-93 [6] and other normative legal acts, which are set including the precision requirements of its manufacturing. From the main provisions of hydraulics are also known, and other factors affecting the geometric characteristics of the water jet from the nozzle of this type, as the MFN [2.10 – 2.12]. Therefore, study of the impact of MFN regulatory manufacturing precision on the geometric parameters of a water jet from it are allocated a significant scientific and practical interest.

Statement of the problem and its solution. The purpose of study is justification for the need to consider the regulatory established values of MFN output hole size deviation in the calculation of its water jet trajectory geometric characteristics and the calculated estimation the value of this impact. The object of study is the geometric characteristics of the trajectory of MFN water jet. The subject of study is the influence of MFN regulatory manufacturing precision as a mass-produced product on the object of study.

From described in [2.15] the list of geometric characteristics of the outlet opening MFN the most simple (basic) is its diameter d_0. To describe the effect of the value d_0 on the geometric characteristics of the trajectory of the water jet from MFN is possible to use the method of approximate calculation of these characteristics from [2.10, 2.12]. Also we can use the assessment methodology of influencing factors measurement errors on the MFN jet trajectory geometric characteristics from [2.9, 2.10, 2.12]. The main geometric characteristics of the MFN water jet trajectory are its flight length l and lifting height h. In the approximate calculation (i.e. without taking into account air resistance), these values are determined by the formulas (2.1) and (2.2) in meters [2.9, 2.10, 2.12].

$$l = \left(V_0^2 \cdot \cos\theta_0 / g\right) \cdot \left(\sin\theta_0 + \sqrt{\sin^2\theta_0 + 2 \cdot g \cdot h_0 / V_0^2}\right), \tag{2.1}$$

$$h = V_0^2 \cdot \sin^2\theta_0 / (2 \cdot g) + h_0, \tag{2.2}$$

where V_0 – average initial velocity of water flow in a living cross section matching with the MFN outlet hole, m/s; g – acceleration of gravity, m/s^2; h_0 – height of MFN outlet hole center placement relative to an arbitrary horizontal plane, which is directed along the x axis, m; Θ_0 – inclination angle of MFN axis to the horizon, degree.

The trajectory of MFN water jet and its geometric characteristics and also the factors influencing on it are illustrated in Fig. 2.2. [2.10, 2.12].

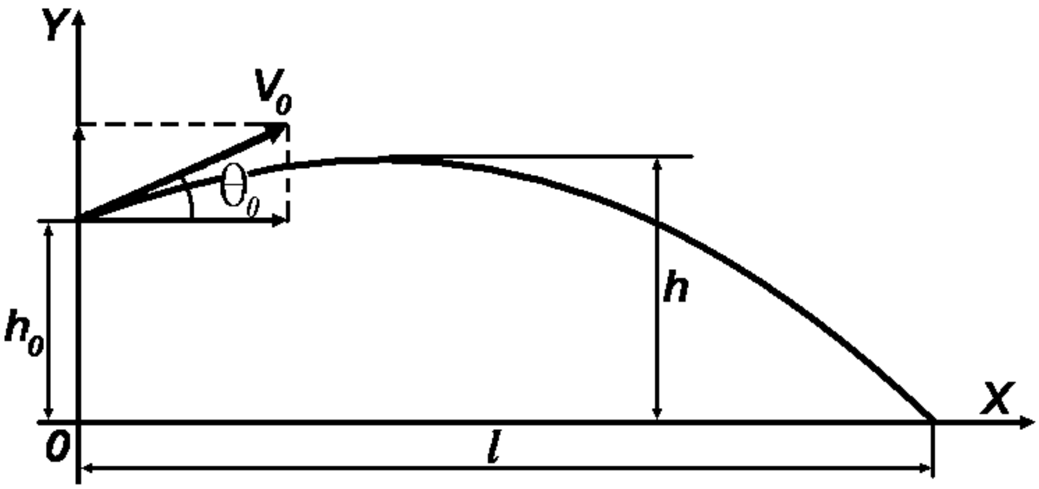


Fig. 2.2 – Motion trajectory of water jet from MFN [2.10, 2.12]

In the such problem statement on the value of l and h is influenced only following factors: V_0, h_0, Θ_0, of which with MFN outlet hole geometric characteristics is directly related value of V_0 only. Moreover, this relationship can be described by the continuity equation of fluid flow from the formula which binds the volumetric water flow rate through any MFN normal cross section Q_0 (in m^3/s) and the area of its outlet hole ω_0 (in m^2) by the formulas (2.3) and (2.4).

$$V_0 = Q_0 / \omega_0, \tag{2.3}$$
$$\omega_0 = \pi \cdot d_0^2 / 4. \tag{2.4}$$

The value h_0 we will conventionally assumed to be constant both for case of nozzle placed in rescuer hands, and for case of its fixed on carriage. Accordingly, the setting and accounting the precision level of determination of this values in such problem statement does not make sense. Accounting of precision of Θ_0 value in such problem statement is also meaningless, since during the fire extinguishing MFN axis inclination angle dynamically and randomly changing personally by rescuer for adjusting of jet impact point on the burning object, that is, $\Theta_0 = 0... 90°$. The same applies to the Q_0 value, which depends on the unpredictable changes in the parameters of the pump and hose lines. Then the value of l in this problem statement is a function of one independent variable – V_0. Because the task of setting of absolutely exact value of V_0 is impossible in principle, the impact of error of its determination ΔV_0 on jet length error value Δl may be described by the formulas (2.5) and (2.6) from references [2.10, 2.12] (since there is only one influence factor in these formulas, it is possible to use of partial derivatives algebraic values), adding them by formulas (2.7) – (2.12).

$$\Delta l \approx \left| \partial l / \partial V_0 \right| \cdot \Delta V_0, \tag{2.5}$$
$$\Delta h \approx \left| \partial h / \partial V_0 \right| \cdot \Delta V_0, \tag{2.6}$$
$$\frac{\partial l}{\partial V_0} = \frac{1}{g}\left(\sin(2\theta_0)\cdot V_0 + 2\cdot\cos\theta_0 \frac{V_0^2 \cdot \sin^2\theta_0 + g\cdot h_0}{\sqrt{V_0^2\cdot\sin^2\theta_0 + 2\cdot g\cdot h_0}} \right), \tag{2.7}$$
$$\partial h / \partial V_0 = \sin^2\theta_0 \cdot V_0 / g, \tag{2.8}$$
$$\Delta V_0 \approx (\partial V_0 / \partial\omega_0)\cdot\Delta\omega_0, \tag{2.9}$$
$$\partial V_0 / \partial\omega_0 = -Q / \omega_0^2, \tag{2.10}$$
$$\Delta\omega_0 \approx (\partial\omega_0 / \partial d_0)\cdot\Delta d_0, \tag{2.11}$$
$$\partial\omega_0 / \partial d_0 = \pi\cdot d_0 / 2. \tag{2.12}$$

In the normative documents (for example, GOST 9923-93 [2.13]) and in the specialized literature (for example, [2.10, 2.12]) established a series of MFN outlet hole nominal diameters d_{0n} and precision qualitet and type of tolerance field for this parameter. Thus, for the nozzle RS-50A with d_{0n} = = 13 mm set accuracy of H11, that according to the data given in [2.14], means that the value of this parameter should be in the range 13.00...13.11 mm, and the diameter indicated the drawings as Ø13H11 or Ø$13^{+0,11}$, and the parameter is changed by regulatory requirements by amount Δd_{0r} = = +0,84 % relative to values $d_{0n} = d_0$.

For the nozzle RS-50A with outlet hole having a maximum possible value of diameter within the these requirements, and typical case described in [2.10, 2.12], h_0 = 1 m (when MFN placed in the rescuer hands), and V_0 = = 20 m/s (a value close to the maximum possible for these conditions). Then we have the following results of the application the formulas (2.9) – (2.12): $\partial\omega_0/\partial d_0$ = 0,0204 m, $\Delta\omega_0$=2,246·10^{-6} m^2, $\partial V_0/\partial\omega_0$ = –1,507·10^{-5} $(m·s)^{-1}$, ΔV_0 = –0,338 m/s (ΔV_{0r} = –1,692 %). For different Θ_0 values have the following results of formulas (2.1) – (2.8) application, they are shown in Table. 2.1 and Fig. 2.3 – Fig. 2.5. Dependences of the values of *l* and *h* (in m) from the Θ_0 value are shown in Fig. 2.3. Dependences of the absolute Δl (in m) and relative Δl_r (in %) values of *l* from value of Θ_0 are shown in Fig. 2.4. Dependences of the absolute Δh (in m) and relative Δh_r (in %) values of *l* from value of Θ_0 are shown in Fig. 2.5.

Table 2.1 – Parameters of the water jet trajectory from fire manual nozzle RS-50A, which are in compliance with regulatory requirements, depending on the inclination angle of its axis to the horizon

Parameter	Unit	Value of parameter at h_0 = 1 m, V_0 = 20 m/s, d_0 = 13.0 mm, Δd_0 = +0.11 mm, ΔV_0 = –0.338 m/s										
Θ_0	degree	0	10	20	30	40	45	50	60	70	80	90
l	m	9.030	18.274	28.717	36.967	41.314	41.751	40.977	35.880	26.568	14.120	0.000
h	m	1.000	1.615	3.385	6.097	9.424	11.194	12.964	16.291	19.003	20.773	21.387
$\partial l/\partial V_0$	s	0.452	1.477	2.641	3.538	4.019	4.080	4.017	3.532	2.621	1.395	0.000
Δl	m	-0.153	-0.500	-0.894	-1.198	-1.360	-1.381	-1.360	-1.195	-0.887	-0.472	0.000
Δl_r	%	-1.692	-2.736	-3.113	-3.240	-3.292	-3.307	-3.318	-3.332	-3.339	-3.343	-3.345
$\partial h/\partial V_0$	s	0.000	0.061	0.238	0.510	0.842	1.019	1.196	1.529	1.800	1.977	2.039
Δh	m	0.000	-0.021	-0.081	-0.173	-0.285	-0.345	-0.405	-0.518	-0.609	-0.669	-0.690
Δh_r	%	0.000	-1.289	-2.385	-2.829	-3.025	-3.082	-3.124	-3.177	-3.207	-3.222	-3.226

As can be seen from Table. 1 and Fig. 3 at Θ_0 = 45° the value of *l*, $\partial l/\partial V_0$ and Δl reaching maximums: 41.751 m, 4.08 s and –1.381 m accordingly, and therefore $l = 41.751_{-1.381}$ m, or 40.370 ≤ *l* ≤ 41.751 m, the value Δl_r amounts to –3.31 %, and the actual value of *l* in this case is determined with an accuracy of ±0.691 m or ±1.66% relative to the value corresponding to the influencing parameter middle of the tolerance field. The value of Δl_r reaching its maximum equal to –3.345 % at Θ_0 = 90°. When Θ_0 = 0°, these values are not equal to zero: *l* = 9.030 m, $\partial l/\partial V_0$ = 0.452 s and Δl = –0.153 m, Δl_r = –1.692 %.

In contrast to the flight length of MFN water jet as is seen from Table. 2.1 and Fig. 2.5, the values of *h*, $\partial h/\partial V_0$, Δh и Δh_r reaching maximums at Θ_0 = 90° – accordingly: 21.387 m, 2.04 s, –0.690 m and –3.23 % and therefore 2.0697 ≤ *h* ≤ 21.387 m or $h = 21.387_{-0.69}$ m, and the actual value of *h* in this case is determined with an accuracy of ±0.691 м или ±1.66 % relative to the value corresponding to the influencing parameter middle of the tolerance field. When Θ_0 = 0° the values of $\partial h/\partial V_0$, Δh и Δh_r are equal to zero and $h = h_0$.

Also from the data shown in Fig. 2.3 and 2.4 and Table. 2.1 implies that the values of the relative errors in determining the values of *l* and *h* (Δl_r and Δh_r) significantly modified by changing the value of Θ_0 between 0 and

45°. After reaching values of Θ_0 45° and down to the 90° they "go on the shelf", asymptotically approaching the value of –3.5 %. At the same time influence factor (d_0) changed only by the amount of Δd_{0r} = +0,846 %, being in inverse correlation with desired values.

Let us get dependences describing research results analytically. Dependences for the absolute values of Δl and Δh, received by transforming the formulas (2.5), (2.6) taking into account the formulas (2.3), (2.4), (2.7) – (2.12) (in m) have the form of formulas (2.13) and (2.14), where Δd_{0r} – relative change of diameter value d_0, %; A and B – substitution values for facilitate the calculation, determined by the formulas (2.15) – (2.17). Dependences for the relative values of Δl_r and Δh_r, obtained by ratio of formulas (2.13) and (2.14) with formulas (2.1) and (2.2) (in %) have the form of formulas (2.18) and (2.19).

$$\Delta l = -\frac{\sqrt{A} \cdot ctg\Theta_0 \cdot \Delta d_{0r} \cdot \left(\sqrt{A} + \sqrt{B}\right)^2}{50 \cdot g \cdot \sqrt{B}}, \quad (2.13)$$

$$\Delta h = -\frac{A \cdot \Delta d_{0r}}{50 \cdot g}. \quad (2.14)$$

$$\Delta d_{0r} = \Delta d_0 / d_0 \cdot 100; \quad (2.15)$$

$$A = V_0^2 \cdot \sin^2 \theta_0; \quad (2.16)$$

$$B = A + 2 \cdot g \cdot h_0. \quad (2.17)$$

$$\Delta l_r = \frac{\Delta l}{l} \cdot 100 = -\frac{2 \cdot \Delta d_{0r} \cdot \left(\sqrt{A} + \sqrt{B}\right)}{\sqrt{B}}, \quad (2.18)$$

$$\Delta h_r = \frac{\Delta h}{h} \cdot 100 = -\frac{4 \cdot \Delta d_{0r} \cdot A}{B}. \quad (2.19)$$

Thus, from the analysis of the above results of performed estimation it follows that impact of changes of MFN of the model RS-50A outlet hole diameter, located within the regulatory established tolerance field, has a significant impact on the geometric parameters of its water jet motion trajectory, in particular on its flight length and lifting height.

The above confirms and illustrates the feasibility of using the mathematical apparatus of the beta distribution to describe distribution law of physical value having a non-linear effect on the other physical values, even if the condition of precise description empirical distribution of such physical value by the normal law [2.4, 2.15]. In this case, such an influence quantity is d_0, which is a mathematical expression for: ω_0 at 2[nd] degree (see formula (2.4)), V_0 at –2 degree (see formula (2.3)), l and h at –2 and –4 degrees (see formulas (2.1) and (2.2)).

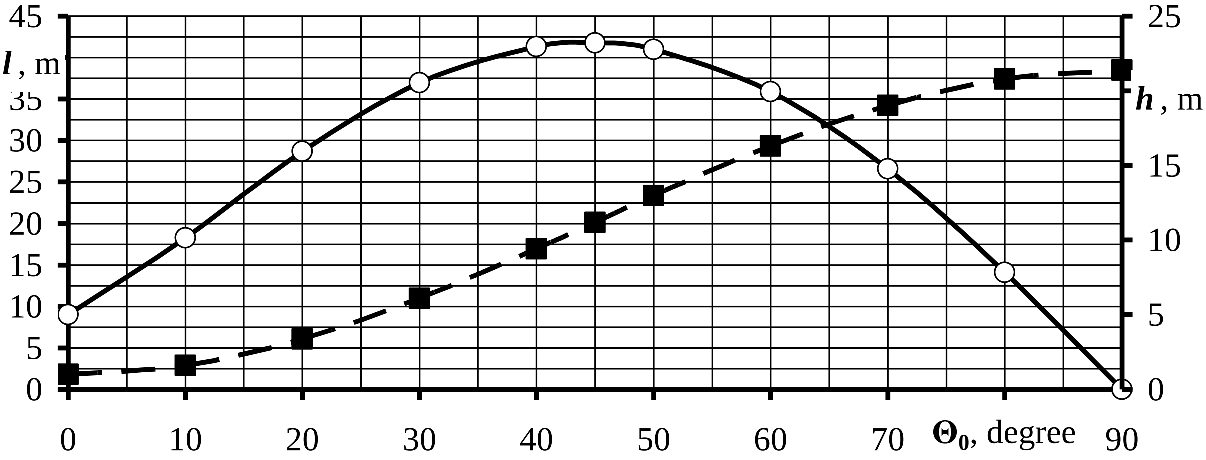


Fig. 2.3 – Dependences of the values of MFN water jet flight length and lifting height from the value of inclination angle of its axis to the horizon:
○ – *l*, m; ■ – *h*, m

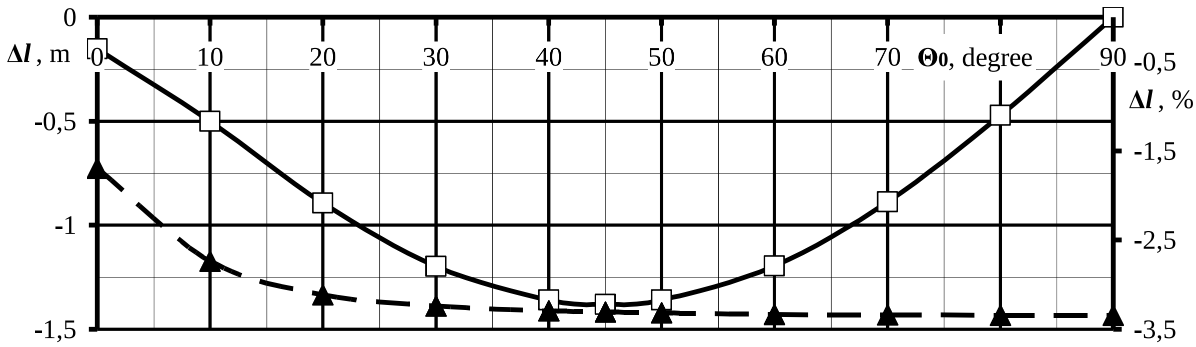


Fig. 2.4 – Dependences of the absolute and relative changes of flight length of water jet from MFN which corresponding to the requirements of GOST from the value of inclination angle of its axis to the horizon:
□ – Δ*l*, m; ▲ – Δl_r, %

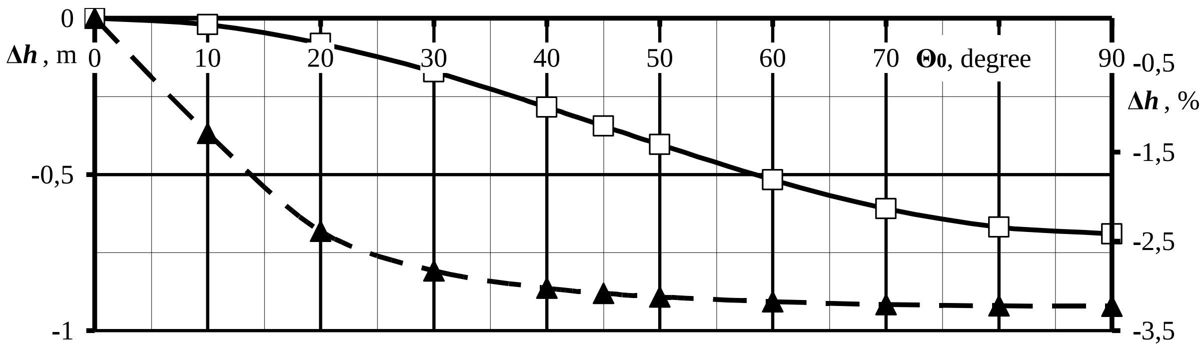


Fig. 2.5 – Dependences of the absolute and relative changes of lifting height of water jet from MFN which corresponding to the requirements of GOST from the value of inclination angle of its axis to the horizon:
□ – Δ*h*, m; ▲ – Δh_r, %

Conclusions. Thus, this study shows the methodology, substantiated, estimated, illustrated and described by analytical formulas the impact of manufacturing precision of manual fire nozzle diameter outlet hole, which corresponds with regulatory established requirements, on the trajectory geometric parameters of water jet from it, in particular its flight length and lifting height, for various values of nozzle axis inclination angle to the of the horizon, in both absolute and relative terms. It found that such an impact is significant.

Also in the study was substantiated the expediency of using the beta distribution for description of these variables taking into account non-linearity of their mutual influence.

2.4. RELATIONSHIP BETWEEN REAL MANUFACTURING PRECISION OF FIRE NOZZLE AND ITS WATER JET TRAJECTORY GEOMETRIC CHARACTERISTICS [A.2.4]

Introduction. Geometric parameters of trajectory of water jet from a manual fire nozzle (MFN) depends on diameter of its outlet hole. In approximate calculations of these parameters are used the nominal value of the diameter [2.8–2.12], which is conditional and characterized by a certain normative established (GOST 9923-93) value of the precision [2.13,2.14]. However, as practice shows, on combat duty of subdivisions of the State Emergency Service of Ukraine there is some number of MFN that do not meet the standards for manufacturing precision, in particular the outlet hole diameter. Moreover, such deviations have value within ±5 % from both tolerance field limits. Therefore, study of the impact of MFN real manufacturing precision on the geometric parameters of its water jet from are allocated a significant scientific and practical interest.

Statement of the problem and its solution. The purpose of study is justification for the need to consider the real, which differs from normative established, values of MFN output hole size deviation in the calculation of its water jet trajectory geometric characteristics (in particular its flight length and lifting height) and the calculated estimation the value of this impact. The object of study is the geometric characteristics of the trajectory of MFN water jet. The subject of study is the influence of MFN real manufacturing precision as a mass-produced product on the object of study.

In study [2.16] evaluated influence of the of MFN RS-50A outlet hole diameter Δd_0 (in mm), which meets requirements of GOST 9923-93 [3.13] and GOST 25347-2013 [2.14] (i.e. for its manufacturing precision), on absolute and relative value determination error of MFN water jet geometric characteristics (its flight length Δl (in m) and lifting height Δh (in m)). In these case using the data of study [2.4] was choused the basic MFN outlet hole geometric characteristic – its diameter d_0 (in m). In study [2.15] was used the method of approximate estimation (i.e. excluding air resistance) of MFN water jet geometric characteristics (its flight length l (in m) and lifting height h (in m)) from [2.10, 2.12] in function of influencing factors changes – diameter d_0 and MFN axis to horizon inclination angle Θ_0 (in degrees). Also in that study was used the method for errors determination (manufacturing, measuring, estimation) choused influencing factor (Δd_0) on determination errors water jet geometric characteristics (Δl and Δh) from references [2.9, 2.10, 2.12], where the following partial derivatives are used: $\partial\omega_0/\partial d_0$(in m), $\partial V_0/\partial\omega_0$ (in $(m\cdot s)^{-1}$), $\partial l/\partial V_0$ (in s), $\partial h/\partial V_0$ (in s), where ω_0 – MFN outlet hole area (in mm^2).

The above described evaluation was performed on the assumption that on the values of Δl and Δh affect only the values Δd_0 (changes discretely from one MFN unit to another) and Θ_0 (changes continuously in the firefighting process). Other influencing factors (average initial velocity of water flow motion through life cross section which coinciding with MFN outlet hole V_0 (in m/s), height of MFN outlet hole center placement relative to an arbitrary horizontal plane h_0 (in m), volumetric water flow rate through any MFN normal cross section Q_0 (in m^3/s)) are not independent (according to continuity of fluid flow low $V_0 \sim \omega_0 \sim d_0^2$ at Q_0 = const) or changes unpredictable (in significant range, for example Q_0 depending on the extinguishing fluid properties, on pump and a hose line parameters), or randomly (in insignificant range, for example h_0 both for manual and lafet fire nozzle) and therefore assumed constant (h_0 = const, Q_0 = = const).

In GOST 9923-93 [2.13] established a series of MFN outlet hole nominal diameters d_{0n} and precision qualitet and type of tolerance field for this parameter. Thus, for the nozzle RS-50A with d_{0n} = 13 mm set accuracy of H11, that according to the data given in GOST 25347-2013 [2.14], means that d_0 = [13.00… 13.11] mm, d_{0n} are minimum allowable value of d_0 and the diameter indicated the drawings as Ø13H11 or $Ø13^{+0,11}$. That is, the parameter is changed by the regulatory requirements by amount Δd_{0r} = +0.84 % relative to value $d_{0n} = d_0$.

Results of the study [2.16], carried out for nozzle RS-50A with maximum available within GOST 9923-93 requirements limits d_0 value and the typical case h_0 = 1 m (when MFN placed in the rescuer hands) and V_0 = 20 m/s (a value close to the maximum possible for these conditions), shows that partial derivatives have the following values: $\partial\omega_0/\partial d_0$ = const = 0.0204 m, $\partial V_0/\partial\omega_0$ = const = $-1.507\cdot10^{-5}$ $(m\cdot s)^{-1}$, $\partial l/\partial V_0$ and $\partial h/\partial V_0$ are functions of Θ_0 (see Table 2.2).

But nozzles RS-50A with which are equipped two research installations of hydraulic laboratory of Applied Mechanics Dept. of Technogenic and Ecologic Safety Faculty of National University of Civil Defense of Ukraine characterized by the d_0 values which differs from normative established. For them the d_0 values were determined by averaging the results of eight times direct measurement using vernier caliper ShTs-I-150-0.02. Thus for the first one d_0 = 12.6 mm and for the second d_0 = 13.7 mm that differs from the nominal value of d_0 on Δd_0 = = –0.40 mm and +0,70 mm or Δd_{0r} = –3.1 % and +5.4 % respectively. For comparison was chosen the nominal value of d_0 because it is used for MFN water jet trajectory calculation. Thus, from the practice of study it becomes clear that in exploitation are certain number of MFN items which for various reasons do not comply with GOST requirements for d_0 value. Exact number of such MFN items is difficult to evaluate, as noted in introduction.

Results of that study are also summarized in Table 2.2 and presented on Fig. 2.6. Dependences of the absolute changes of flight length Δl and lifting height Δh values (both in m) of water jet from nozzle RS-50A with varying degrees of compliance with GOST 9923-93 from the value of inclination angle of its axis to the horizon Θ_0 (in degrees) is shown on Fig. 2.6, a, b. Same dependences for the relative values (Δl_r and Δh_r, both in %) is shown on Fig. 2.6, c, d.

As we can see from the data of Table 2 and Fig. 2.6 (where also presented results of study [2.16] for comparison) for nozzle RS-50A with outlet hole having a maximum possible value of diameter within the these requirements values of l, $\partial l/\partial V_0$ and Δl reaching maximums (41.751 m, 4.08 s, –1.381 m respectively) at Θ_0 = 45°, than l = [40,370…41,751] m or $l = 41.751_{-1.381}$ m, Δl_r = 3.31 %, and the actual value of l in this case is determined with an accuracy of ±0.691 m or ±1.66% relative to the value corresponding to the influencing parameter middle of the tolerance field (13.055 mm). The value of Δl_r reaching its maximum equal to –3.345 % at Θ_0 = 90°. It should be noted that when Θ_0 = 0°, these values are not equal to zero: l = 9.030 m, $\partial l/\partial V_0$ = 0.452 s and Δl =–0.153 m, $\Delta\ l_r$ = = –1.692 %. The values of h, $\partial h/\partial V_0$, Δh & Δh_r reaching maximums at Θ_0 = 90° (21.387 m, 2.04 s, –0.690 m and –3.23 % accordingly) and therefore $h = 21.387_{-0.69}$ m, or 2.0697 ≤ h ≤ 21.387 m, and the actual value of h in this case is determined with an accuracy of ±0.691 м или ±1.66 % relative to the value corresponding to the influencing parameter middle of the tolerance field. When Θ_0 = 0° the values of $\partial h/\partial V_0$, Δh и Δh_r are equal to zero and $h = h_0$ [2.16].

Also from the data of Table 2 and Fig. 2.6 we can see, that the values of l, $\partial l/\partial V_0$, h and $\partial h/\partial V_0$ for all three investigated cases are not different from the case of MFN with nominal value of diameter d_0 from the study [2.16].

Results of such evaluation for the first one of MFN with Δd_0 = = –0.40 mm are following. Absolute values of Δl and Δh reaching maximums (5.021 m and 2.509 m respectively) when Θ_0 = 45° and 90°. Than l = [41.751…46.772] m or $l = 41.751^{+5.021}$ m. Relative values of Δl_r & Δh_r reaching maximums (+12.162 % & +11.732 %) when Θ_0 = 90°. Than $h = 21.387^{+2.509}$ m or h = [21.387…23.896] m. Should be noted that when Θ_0 = 0° Δl = +0.556 m, Δl_r = +6.154 %, Δh = 0 m.

Results of such evaluation for the first one of MFN with Δd_0 = +0,70 мм are following. Absolute values of Δl and Δh reaching maximums

(–8.787 m and –4,391 m respectively) when Θ_0 = 45° and 90°. Than l = = [32.964…41.751] m or $l = 41.751_{-8.787}$ m. Relative values of Δl_r & Δh_r reaching maximums (–21.284 % and –20.531 %) when Θ_0 = 90°. Than $h = 21.387_{-4.391}$ m or h=[16.996…21.387] m. Should be noted that when Θ_0 = 0° Δl = –0.973 m, Δl_r= –10.769%, Δh = 0m.

Thus, from the data of Table 2 and Fig. 2.6 are follows that the values of Δl_r and Δh_r significantly changing when the value of Θ_0 vary in limits 0…45°. After Θ_0 reaching values of 45° and down to the 90° they "goes on the shelf", asymptotically approaching the value of +12.5 % for the first one manual fire nozzle with Δd_0 = –0.40 mm and –22.0 % for the second MFN with Δd_0 = +0.70 mm.

At the same time influence factor (d_0) changed at a much lower value Δd_{0r} (–3.1 % and +5.4 % respectively) being in inverse correlation with the desired values. The above described is presented in Fig. 2.7.

On Fig. 2.7 are showed influence of absolute (Δd_0 in mm) and relative (Δd_{0r} in %) values of nozzle RS-50A outlet hole diameter (d_0) changing on absolute (Δl and Δh in m) and relative (Δl_r and Δh_r in %) values of flight length (l) and lifting height (h) of its water jet in all possible combinations.

As follows from the analysis of data contained in Fig. 2.7, these dependencies are linear, influencing factor and the desired effect are inversely correlated for the absolute values of Δl and Δh and also these dependencies on Δd_0 and Δd_{0r} are different (see Fig. 2.8, a, b), and for the relative values Δl_r and Δh_r they are identical (see Fig. 2.8,b,c). Linearity of these relationships follows from the analysis of the formulas (13)–(19) in study [2.16] with constant values of Θ_0.

They described by the method of least squares (for all dependencies R^2 = 1,0) and can be represented by the formulas (2.20) – (2.25).

$$\Delta l = -12{,}553 \cdot \Delta d_0 \text{, m;} \tag{2.20}$$

$$\Delta h = -6{,}273 \cdot \Delta d_0 \text{, m;} \tag{2.21}$$

$$\Delta l_r = \Delta h_r = -3{,}953 \cdot \Delta d_{0r} \text{, \%;} \tag{2.22}$$

$$\Delta l = -1{,}6319 \cdot \Delta d_{0r} \text{, m;} \tag{2.23}$$

$$\Delta h = -0{,}8155 \cdot \Delta d_0 \text{, m;} \tag{2.24}$$

$$\Delta l_r = \Delta h_r = -30{,}4063 \cdot \Delta d_{0r} \text{, \%.} \tag{2.25}$$

So, from the above evaluation results analysis it follows that the nozzle RS-50A outlet hole diameter value deviation, going beyond the tolerance field according to GOST 9923-93 in both directions, has a significant impact on its water jets motion trajectory geometric parameters under otherwise equal conditions. In practice, the magnitude of such influence would not be as significant due to the influence of unaccounted factors.

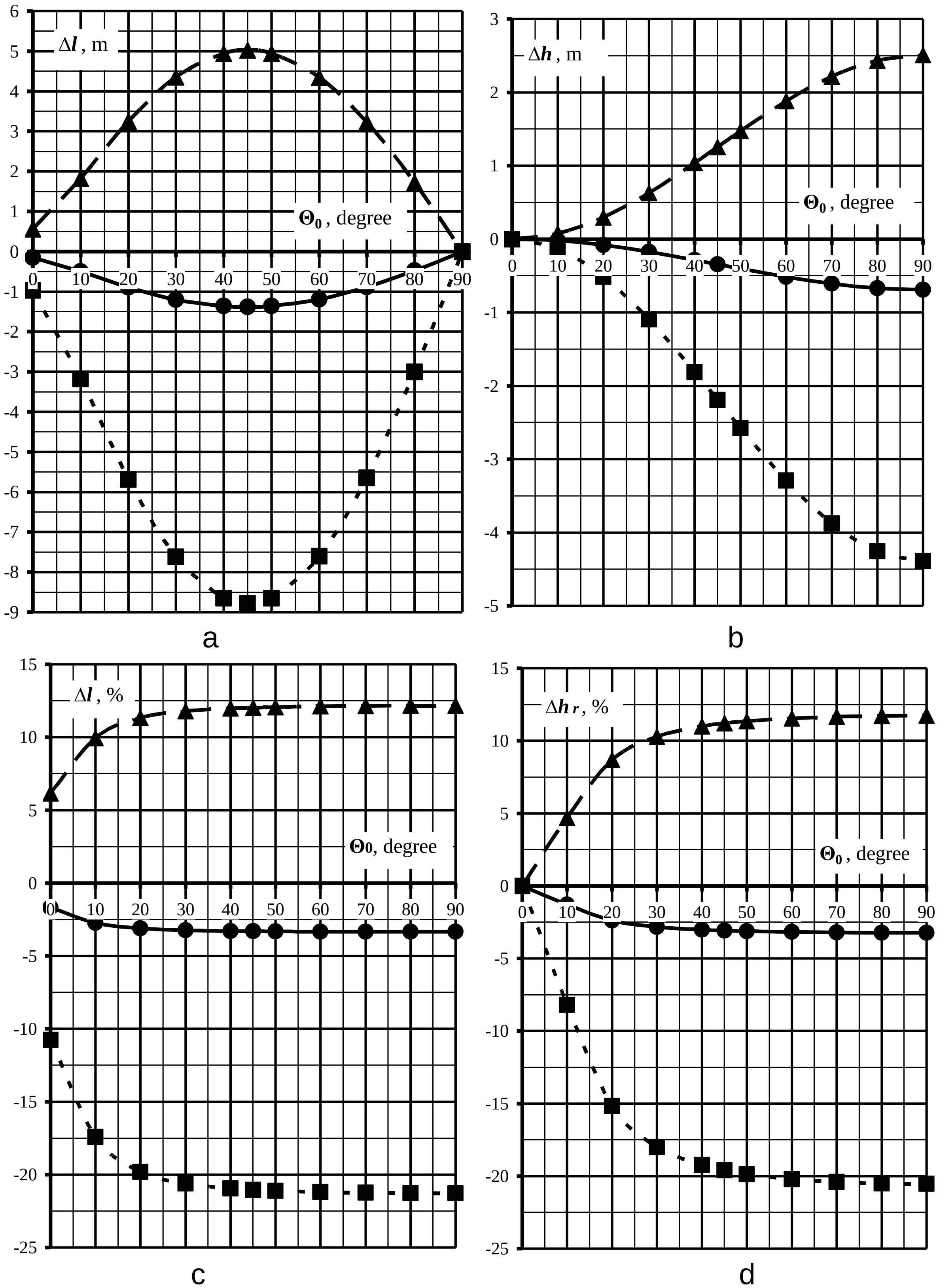


Fig. 2.2 – Dependences of the absolute (a, b) and relative (c, d) changes of flight length (a, c) and lifting height (b, d) of water jet from nozzle RS-50A with different degrees of compliance with GOST 9923-93 from the value of inclination angle of its axis to the horizon:
■ – Δd_0 = +0.70 mm; ▲ – Δd_0 = –0.40 mm; ● – Δd_0 = +0.11 mm

Table 1 – Parameters of the water jet trajectory from fire manual nozzle RS-50A, with different degrees of compliance with GOST 9923-93, depending on the inclination angle of its axis to the horizon

Parameter	Unit	Value of parameter at $h_0 = 1$ m, $V_0 = 20$ m/s, $d_0 = 13.0$ mm $\Delta d_0 = 0.0$ mm (nominal value)										
Θ_0	degree	0	10	20	30	40	45	50	60	70	80	90
l	m	9.030	18.274	28.717	36.967	41.314	41.751	40.977	35.880	26.568	14.120	0.000
h	m	1.000	1.615	3.385	6.097	9.424	11.194	12.964	16.291	19.003	20.773	21.387
$\partial l/\partial V_0$	s	0.452	1.477	2.641	3.538	4.019	4.080	4.017	3.532	2.621	1.395	0.000
$\partial h/\partial V_0$	s	0.000	0.061	0.238	0.510	0.842	1.019	1.196	1.529	1.800	1.977	2.039
		$\Delta d_0 = +0.11$ mm (within the requirements of GOST)										
Δl	m	-0.153	-0.500	-0.894	-1.198	-1.360	-1.381	-1.360	-1.195	-0.887	-0.472	0.000
Δl_r	%	-1.692	-2.736	-3.113	-3.240	-3.292	-3.307	-3.318	-3.332	-3.339	-3.343	-3.345
Δh	m	0.000	-0.021	-0.081	-0.173	-0.285	-0.345	-0.405	-0.518	-0.609	-0.669	-0.690
Δh_r	%	0.000	-1.289	-2.385	-2.829	-3.025	-3.082	-3.124	-3.177	-3.207	-3.222	-3.226
		$\Delta d_0 = -0.40$ mm (deviation from the GOST requirements in the smaller side)										
Δl	m	0.556	1.818	3.251	4.355	4.946	5.021	4.944	4.347	3.226	1.717	0.000
Δl_r	%	6.154	9.951	11.319	11.780	11.972	12.026	12.066	12.116	12.144	12.158	12.162
Δh	m	0.000	0.076	0.294	0.627	1.037	1.255	1.472	1.882	2.216	2.434	2.509
Δh_r	%	0.000	4.686	8.672	10.289	11.002	11.208	11.358	11.552	11.660	11.715	11.732
		$\Delta d_0 = +0.70$ mm (deviation from the GOST requirements in the greater side)										
Δl	m	-0.973	-3.182	-5.689	-7.621	-8.656	-8.787	-8.652	-7.608	-5.646	-3.004	0.000
Δl_r	%	-10.769	-17.414	-19.809	-20.616	-20.951	-21.046	-21.115	-21.203	-21.251	-21.276	-21.284
Δh	m	0.000	-0.132	-0.514	-1.098	-1.814	-2.196	-2.577	-3.293	-3.877	-4.259	-4.391
Δh_r	%	0.000	-8.200	-15.175	-18.006	-19.253	-19.614	-19.877	-20.216	-20.405	-20.502	-20.531

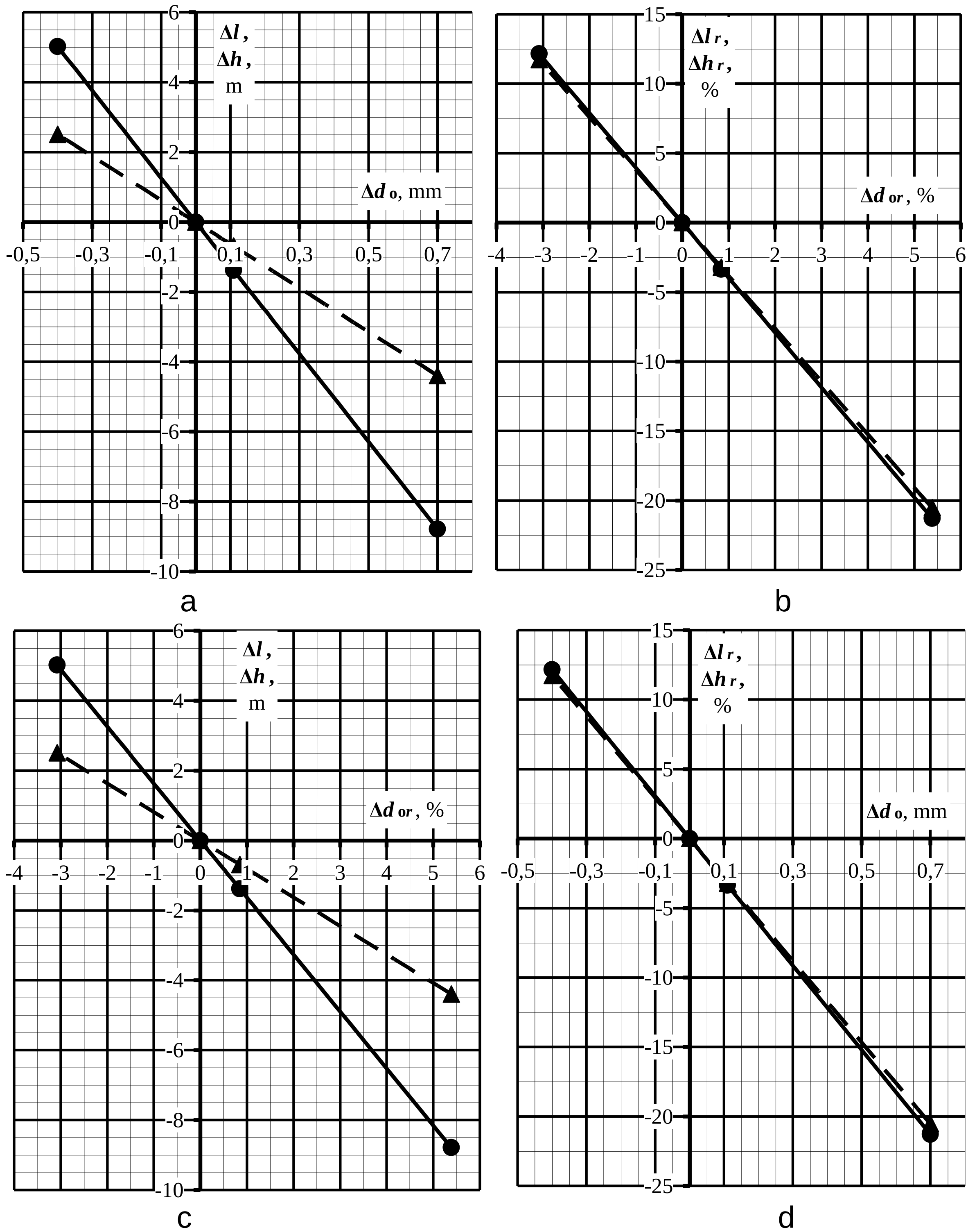


Fig. 2.3 – Dependences of the maximum values of absolute (a, b) and relative (c, d) changes of flight length (a, c) and lifting height (b, d) of water jet from nozzle RS-50A with different degrees of compliance with GOST 9923-93 from the absolute (a, d) and relative (b, d) value of change of its outlet hole diameter:

● – Δl (при Θ_0 = 45°) и Δl_r (при Θ_0 = 90°); ▲ – Δh и Δh_r (при Θ_0 = 90°)

This is the following factors: water jet motion air resistance, deviation from roundness (deviation of the surface shape) of the MFN outlet hole and distribution of this deviation on hole perimeter (beating of the radius), changes of parameters of the pump and hose lines, presence of lateral wind and (or) headwind, varying the type and composition of the fire-extinguishing liquid, changes of resistance, velocity and flow rate coefficients of MFN as a conical converging nozzle, environmental parameters (temperature, pressure, humidity) etc.

The above as well as the results of studies [2.4, 2.15, 2.17], confirms and illustrates the feasibility of using the mathematical apparatus of the beta distribution to describe distribution law of physical value having a non-linear effect on the other physical values, even in case when condition of precise description empirical distribution of such physical value by the normal law [2.4].

Conclusions. Thus, this study includes the methodology, substantiated, estimated, described by formulas and illustrated by graphs the impact of manufacturing precision of manual fire nozzle diameter outlet hole, which does not meet the regulatory established requirements of GOST 9923-93 in varying degrees, on the trajectory geometric parameters of water jet from it, in particular its flight length and lifting height, for various values of nozzle axis inclination angle to the of the horizon, in both absolute and relative terms. It found that such an impact under certain assumptions, and other conditions being equal is significant. Also in the study was substantiated the expediency of using the beta distribution for description of these variables taking into account non-linearity of their mutual influence.

2.5. NUMERICAL INTEGRATION OF GAS COOLING, FORMED BY THERMAL RECYCLING OF WASTE [A.2.5]

2.5.1. Introduction

Relevance of the permanent increasing of wastes amount problem is obviously. That situation is escalates by significant increasing of unsanctioned storage places for danger wastes. Paces of various substances decomposition in general wastes mass are not same and impact of individual fractions on filtrate generation are different. Since the time period from dump formation starting till filtrate in groundwater pervasion beginning are not known, than at the moment of dump detection the harmful consequences for environmental components from filtrate impact can be significant. That’s why such objects substantially decreasing the ecological safety level [2.18] and must be eliminated as quickly as possible.

Serious attention requires waists of medical institutions, which are quite epidemiological dangerous because contains helminth eggs and pathogenic microorganisms and also may contain radioactive or toxic substances [2.19]. No less a danger to the environmental components are polymer materials wastes [2.20]. They contain carbon and its compounds and also are secondary material and energetic resources, as it shown in references [2.21, 2.22]. Wide application of plastics and polymeric materials in various industrial sectors as well as in consumer goods manufacturing causing to increasing of carbon part in waists and carbon containing compounds, that during its thermal treatment causing increasing of various pollutants amounts, including such super toxic as dioxins.

2.5.2. Analysis of published data and problem statement

At the current stage for waists utilization apply thermal methods with using plasma generators [2.23], whereby in high temperature conditions (over 1200 °C) ensured decomposition of dioxin, cumulative poison, which belonging to the danger xenobiotics group, into simple fragments [2.24]. However, exist the mechanism for recrudescent dioxin forming, or "de novo", which observed in exhaust gases in temperature range from 300 till 450 °C. To the number of its forming factors includes gases cooling speed in the specified temperature diapason and presents in it chlorine and oxygen [2.25]. Therefore we can affirm, that maximal ecological efficiency of wastes utilization process can be obtained by the way of prevention the dioxin forming not only at the stage of wastes processing in plasma reactor, but at its outlet at the stage of generator gas cooling. Thus, most important and relevance from a scientific point of view are searching of technical solution for ecological safety ensuring at solid wastes thermal utilization.

Existing different methods for cleaning of hot smoke gases. In the study [2.26] authors shows dioxin forming process during wastes thermal treatment, at the same time in studies [2.27, 2.28] scientifically grounded the effectiveness of dealing with them in conditions of using relevant cleaning systems. But in these case raises the question of following handling with used filters. So, the best way is prevent highly toxic substances. In the study [2.29] authors presented wide enough review of modern methods for dealing with dioxins, which basing on catalytic reactions. Comparative analysis of these methods allowed to reveal deficiencies, the main ones are:

– urgency of controlling of wastes chemical composition to reduce the amount of chlorine [2.30], which is quite difficult tusk, because composition of municipal wastes is not constant through time;

– urgency of controlling of catalyst condition for ensuring of catalytic process high efficiency;

– high level of investments and exploitation costs, which limits application of these methods in full.

One of rational variants of these problem solution are fast exhaust gases cooling, whereby not create conditions for dioxin formation. But to realize that cooling in broad temperature range is pretty difficult.

Therefore, in present paper proposed investigation of possibility of applying evaporate heat exchanger with centrifugal nozzles, which provides dispersed liquid injection in hot gas flow from plasma reactor.

2.5.3. Purpose and task of the study

Purpose of the study is increasing of ecological safety level during wastes thermal utilization by the way of high toxic substances formation prevention in generator gas.

For setting purpose obtaining we solve following tasks:

– analysis of actions of gas and dispersed phases during generator gas irrigating cooling for decreasing probability of dioxin formation in wastes utilization process;

– investigation of influence of interphase interaction on efficiency of proposed cooling system for generator gas with liquid, which dispersed with centrifugal nozzles;

– efficiency estimation by numerical modeling for different operational modes of proposed technological plant for generator gas irrigating cooling for temperature speed reduction until safety value.

2.5.4. Materials and methods of the study of efficiency different operation modes of proposed technological plant for generator gas irrigating cooling

2.5.4.1. Analysis of actions of gas and dispersed phases and influence of interphase interaction on efficiency of proposed cooling system

Issues of ecological safety with using of multiphase dispersed structures for other tasks described in references [2.31, 2.32].

Such irrigating systems using for ecological safety ensuring during fire fighting, dust control at loading and unloading of granular materials etc. [2.33]. In references [2.34, 2.35] by authors reviewed mathematical models and performed calculated studies of that processes. But, it necessary to note, that during executing of these tasks considered specific technical conditions and requirements. At present moment exist the general approach to physical and mathematical statement of that class tasks, which based on classical gas dynamic equations.

In conditions of costs reduction on research and development of promising technologies, one of the most economical and convenient methods for detailed analysis of complex processes in gas-dispersion environments are numerical experiment. For its implementation and visualization of generator gas cooling processes results we have to use the mathematical apparatus, which adequately reflex complex gas dynamic processes. Since water drops in high temperature gas flow will be vaporized, then we have studied two-phased multi-component environment with phase transformations. Actions of single drop in gas dynamic field describes by system of ordinary differential equations (ODE) [2.36], in which part of parameters functionally associated with independent variables. For closure and solution of ODE is necessary to taking into account bilateral interaction by the way of alternately solution of equations of dispersed and continuous phases until solution for both phases becomes steady in time.

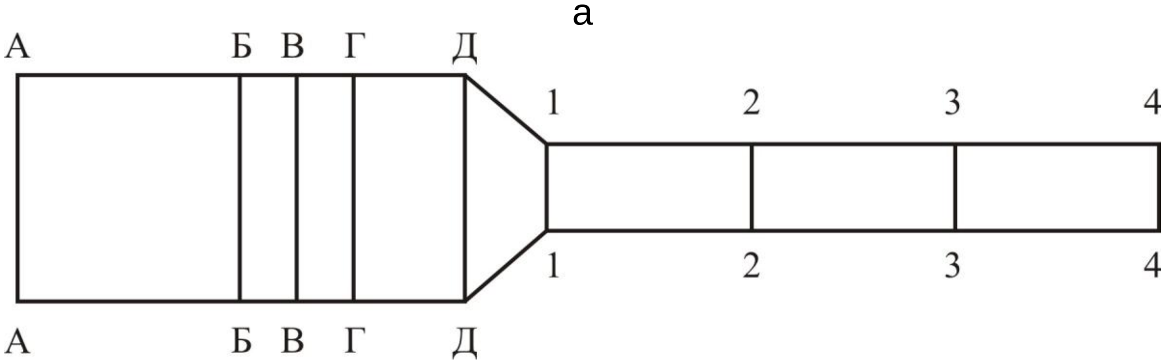
Effectiveness of water curtain for generator gas cooling in evaporative heat exchanger depends on structure and parameters of gas-drop flow. One of operational effectiveness indicators is value of water supplying parameters, which ensure certain water spraying dispersion and its nozzle leakage velocity. So, it is necessary water supply variant with centrifugal nozzles in high temperature gas flow, that can be recognized as satisfactory, that is, provide fast gas cooling until gas temperature reaches safety value close to about 300 °C. Physical and mathematical description of that process can be provide based on classical approach for two-phase flow movement [2.36–2.38]. During the modeling of generator gas cooling process by the way of water injection centrifugal nozzles in a hot gas flow was investigated computational domain, that includes a piece of space bounded by the heat exchanger walls, its input/output section (Fig.2.4).

Mathematical model of gaseous phase of generator gas cooling process described in references [2.36, 2.37]. It allows to describe the features of three-dimensional flow in the heat exchanger and shows the impact on the disperse phase. To analyze the action of the dispersed phase in relation to it were accepted some assumptions, described in [2.38], which allowed to examine its action in Lagrangian description.

Interaction between phases taken into account using the discrete model "particle – source in the cell," according to which the presence of a drop in the gas flow manifests itself through additional sources in the equations of the law of conservation of continuous phase [2.39]. During the calculating of drops trajectories monitored the values of impetus, mass and heat that is gained or lost by "package" of drops, that move along this trajectory. Then these values were included in the calculation of the gas phase in the form of source members S_m, S_q, S_{fi} in the gas dynamics equations. Thus, as the gas phase are influences on disperse phase, than opposite effect of dispersed phase on continuous phase is also taken into account [2.38].

The obtained mathematical models of gas and dispersed phases is the basis for numerical experiments to investigate effectiveness of proposed generator gas cooling system in order to improve ecological safety level of wastes utilization process. Using the method of numerical integration of obtained equations of gas phase [2.36, 2.37], we can determine gas parameters at any point of the settlement area. This will allow to control the temperature of gas flow in required sections of the heat exchanger and speed of its change.

a



b

Fig. 2.4 – Evaporated heat exchanger:
a – irrigating system for gas cooling (evaporated heat exchanger);
b – control sections

However, we can determine the most rational parameters of water supply with nozzles, which provide a sharp decrease of temperature of gas flow and, consequently, increased ecological safety level of wastes utilization process.

2.5.4.2. Numerical integration of gaseous phase equations

Numerical integration of differential equations in partial derivatives with a given boundary conditions involves their discretization. Discretization of equations in space performed by the method of control volumes [2.40] with the unstructured (disordered) calculating net, which is composed of polyedrical elementary volumes – cells.

Allocation of drops volumes in the spray jet is based on data from [2.35] and is well described by the Rozin-Rammler formula. The numerical values of nozzle water supply parameters, determined with the method described above, for three water supply variants, that differs water spray dispersion and speed of its discharge from the nozzle, provided in Table. 2.3. Irregular calculated net includes 77087 polyedrical cells. We consider that elementary volume of gas at initial time located in the center of cross-sectional flow part of heat exchanger, which precedes area of water injection (section "B – B" variants in the № 1 and № 2, section "A – A" version № 3).

Table 2.3 – Numerical values of nozzle water supplying parameters

Parameter name	Variant number		
	1	2	3
d_0, m	0,0006	0,0009	0,0011
$A_f/(D_s d_0)$	0,75	1,3	1
C_D	0,43	0,56	0,50
v, m/s	10	3	3
Δp, Pa	48228	5650	3189
Re_e	3858	2257	1957
n	3,77	3,99	3,6

In the process of gas cooling dispersed liquid drop temperature change until it reaches the boiling point under the heat balance, which is defined by the equation:

$$m_p c_p \frac{dT_p}{dt} = \alpha A_v \left(T_\infty - T_p\right) + L\frac{dm_v}{dt}, \tag{2.26}$$

where c_p – drop heat capacity; α – heat transfer coefficient between drop and gas, which defined by experiment; A_v – drop surface area; L – latent heat of vaporization; T_p – drop temperature; T_∞ – local gas temperature.

The results of experimental studies is usually served as a criterion dependences Nu = f (Re, Pr), where Nu – Nusselt number. In view of equations (14) and (20) [2.38] of equation (2.26) can be written as:

$$\frac{dT_p}{dt} = \frac{\left(T_\infty - T_p\right)}{\Theta} + \frac{Q_L}{\Theta} \tag{2.27}$$

$$Q = \frac{LSh\rho D\left(c_s - c_\infty\right)}{Nu\lambda} \tag{2.28}$$

$$\Theta = \frac{\rho_p d_p^2 c_p}{6Nu\lambda} \tag{2.29}$$

When the drop temperature reaches of boiling point, we can apply the boiling speed equation:

$$\frac{d(d_p)}{dt} = -\frac{4\lambda}{\alpha\rho_p c_{p\infty} d_p}\left(1 + 0{,}23\,\mathrm{Re}_p^{0,5}\ln\left[1 + \frac{c_{p\infty}(T_\infty - T_p)}{L}\right]\right) \quad (2.30)$$

where $c_{p\infty}$ – gas heat capacity.

In considering of gas elementary volume movement in the flowing part of heat exchanger, we generate control squirt of gas flow for three variants of dispersed liquid supplying (Fig. 2.5) and graph of dependence for gas elementary volume Z coordinates and time τ (Fig. 2.6).

Determined from the graph Z(τ) time points τ_i, in which gas elementary volume crossing the control section *i*. Defined as the average gas temperature t_{av}, coefficient of uniformity of temperature distribution in gas γ_T control cross sections *i*, residence time Δτ and average cooling rate Δt/Δτ of gas elementary volume between adjacent cross sections *i* and (*i*–1) (Table. 2.3, 2.4).

Table. 2.4 shows, that the total residence time of gas elementary volume in the flow part of heat exchanger for the investigated variants of is respectively 1.32 s, 6.42 s and 2.37 s. The coefficient of uniformity γ_T shows how temperature of gas-vapor mixture changes in the control section. If there are no changes (i.e. reached the maximum uniformity of distribution) $\gamma_T = 1$.

The residence time Δτ and average cooling rate Δt/Δτ for gas elementary volume in areas between control cross sections are necessary parameters on basis of which it is possible to decide which flow rate of the coolant are need.

2.5.5. Results of study of gas dynamic processes in evaporated heat exchanger during generator gas irrigating cooling

Maximum cooling of gas occurs during his contact with droplets of dispersed liquid, that evaporates:

– for variant № 1 gas temperature decreased to 472 °C at 0,47 s of it presents between cross sections C and E;

– for variant № 2 gas temperature decreased to 436 °C at 1,0 s of it presents between cross sections C and E;

– for variant № 3 gas temperature decreased to 454 °C at 1,6 s of it presents between cross sections A and E.

The maximum speed of the cooling in all variants takes place between the crossings C and D (Fig. 2.7), reaching for variants № 1, 2 and 3 values of 1919, 1269 and 975 °C/s, respectively (Fig. 2.8). The rest of the time it takes mixing of gas with water vapor.

Best quality of mixing takes place in variant № 2 (uniformity coefficient equal to 0.997) due to the great stay duration of gas between the crossings G and D because of the presence of circulating currents in there.

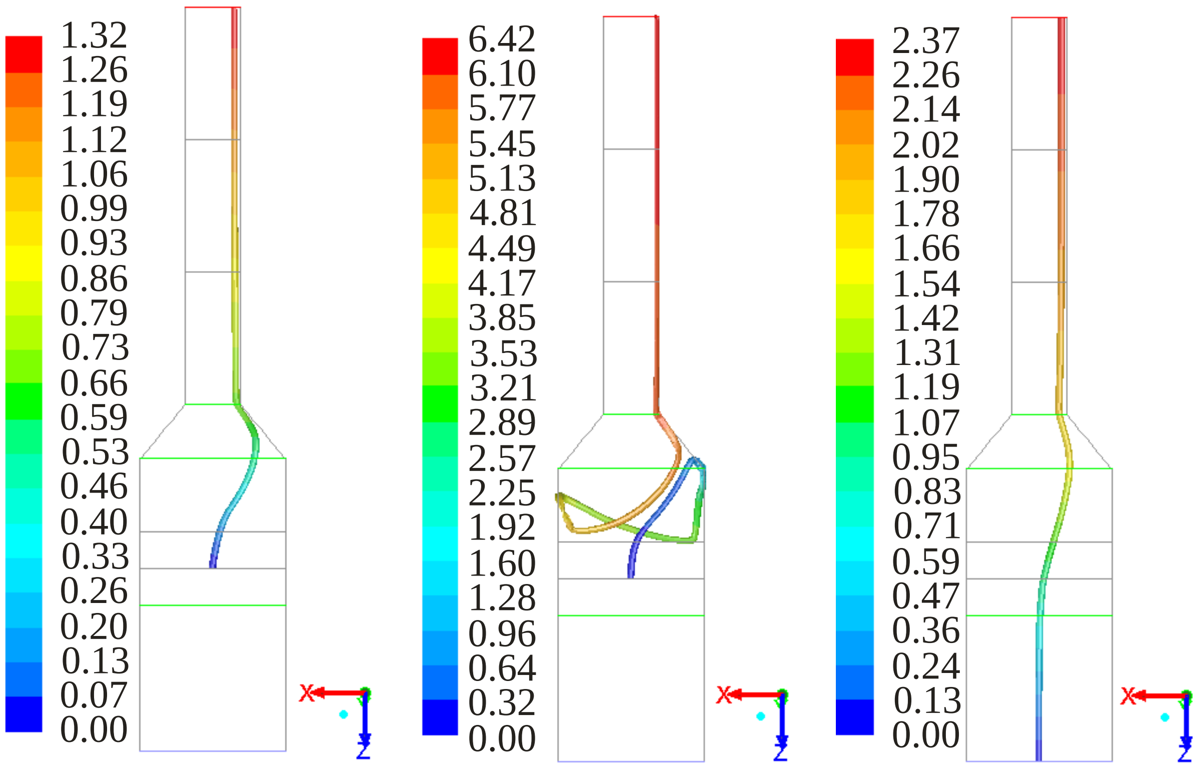
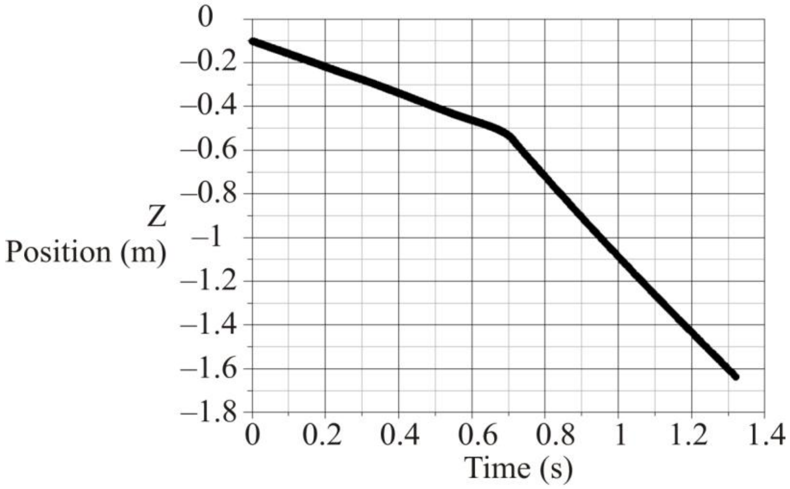


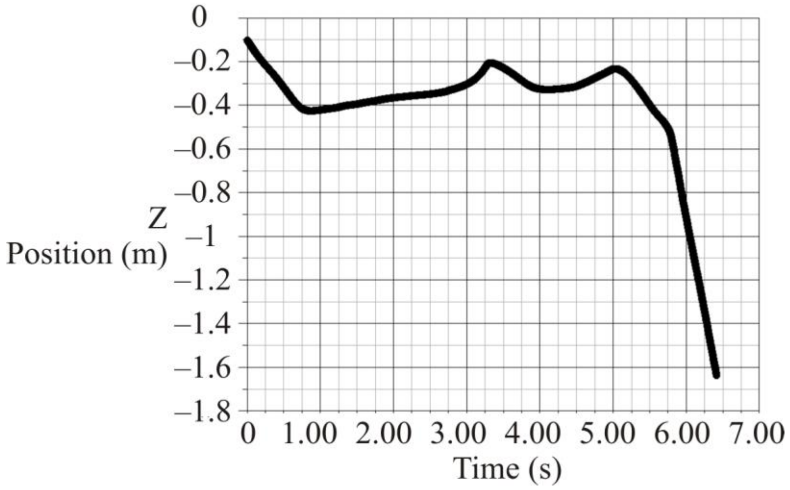
Fig. 2.5 – Movement trajectory of elementary gas volume (control squirt of gas flow): *a – c* – variants of dispersed liquid supplying

Table 2.4 – Parameters of gas elementary volume, which controls in cross sections *i*

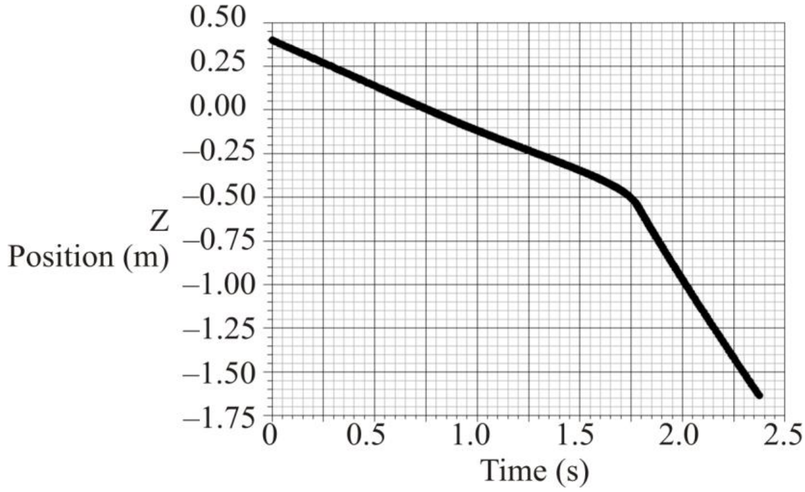
Parameter	Controls cross section								
	A	B	C	D	E	1	2	3	4
Variant of dispersed liquid supplying № 1									
τ, s	–	–	0	0,17	0,48	0,72	0,9	1,1	1,32
t_{av}, °C	1200	1199,8	1180,4	854,2	472,2	408,6	364,7	357,6	305,8
γ_T	1	0,999	0,985	0,792	0,728	0,815	0,899	0,938	0,961
Variant of dispersed liquid supplying № 2									
τ, s	–	–	0	0,25	1	5,8	6,0	6,2	6,42
t_{av}, °C	1200	1200	1200	882,8	436,0	356,9	354,4	354,4	354,4
γ_T	1	1	1	0,813	0,839	0,964	0,992	0,995	0,997
Variant of dispersed liquid supplying № 3									
τ, s	0	0,75	0,95	1,15	1,6	1,76	1,96	2,16	2,37
t_{av}, °C	1200	1053,7	891,8	696,8	454,0	418,2	393,3	382,0	375,0
γ_T	1	0,985	0,970	0,947	0,885	0,917	0,951	0,972	0,984



a



b



c

Fig. 2.6 – Dependence gas elementary volume Z coordinates of time:
a – variant № 1; b – variant № 2; c – variant № 3

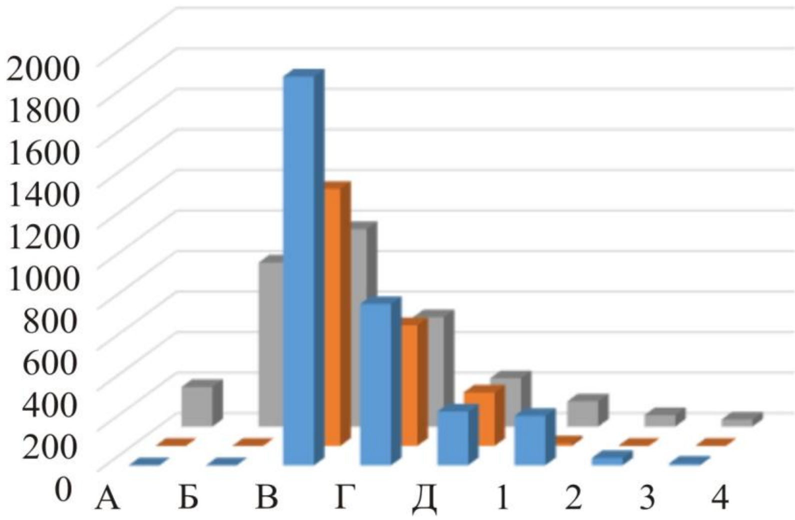


Fig. 2.7 – The average cooling rate of gas (°C/s):
● – variant № 1 of dispersed water supplying; ● – variant № 2; ● – variant № 3

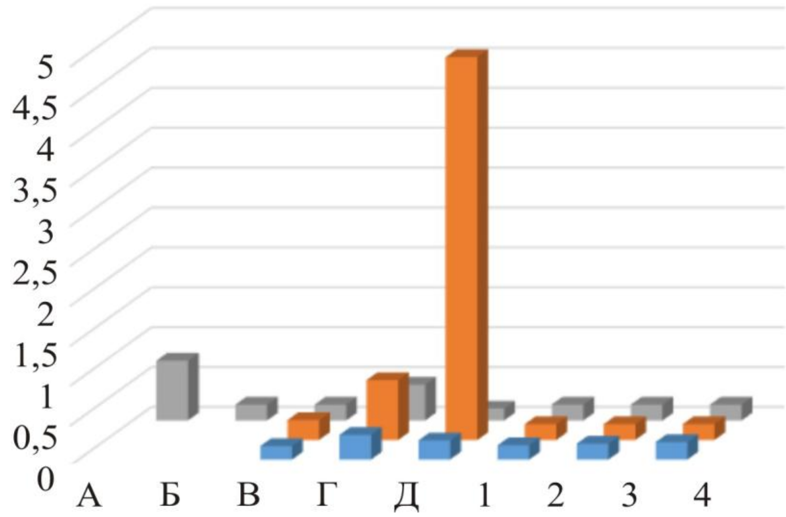


Fig. 2.8 – The gas residence time (s) between control cross sections:
● – variant № 1 of dispersed water supplying; ● – variant № 2; ● – variant № 3;
А, Б, В, Г, Д, 1, 2, 3, 4 – control cross sections

2.5.6. Discussion of the results of numerical integration of equations describing gas-dynamic processes in the studying heat exchanger

These paper is a part of scientific research for creation ecological safety wastes utilization technology. Beginning of the study is [2.32, 2.36 – 2.38], where created the mathematical model of three-dimensional flow of gas-dispersion fluid with phase transformation (evaporation) and inter-phace interaction, that qualitatively and clearly defines the main features of generator gas cooling process with injection in it dispersed liquid. This mathematical model of study of drops in coolant trajectory allows us to monitor changing impulse, mass and heat of set of drops and the temperature of gas-vapor mixture at different time points of gas in the heat exchanger. The advantages of this method of ensuring ecological safety during thermal waste utilization is to prevent the creation of temperature conditions for the dioxins formation, unlike other methods, which use complex filters or catalytic reactions.

The results of numerical experiments indicates that the second variant of supply dispersed coolant characterized by shortest time of establishing equilibrium in vapor mixture, that reduces the coolant expenditure and eliminates its accumulation in the heat exchanger. But in terms of ecological safety ensuring it can be considered the most satisfactory is first variant, because the time of gas flow cooling with a temperature of 1200 °C to a temperature, which close to safe, i.e. 305.8 °C, is 1.32 s. It is clear, that the proposed mathematical models of processes, which occurring in the heat exchanger, satisfactory within the task of study and show the possibility of its implementation. The research does not exclude the possibility of determining the most effective variant, to find which subsequently can formulate and solve relevant optimization problem.

2.5.7. Conclusions

1. Scientifically reasonable possibility of technical devices application, the use of which provides a sharp cooling of exhaust gases, thus are not created temperature conditions for dioxins formation and thereby increasing the ecological safety level. Wherewith cooling physical model is based on cooling liquid injection with centrifugal nozzles in the gas flow.

2. In order to following optimization the parameters of proposed technological plant for generator gas irrigation cooling in present research through numerical simulations provided evaluation of its effectiveness by temperature decrease speed parameters up to a safe value in a given segment of space, limited by heat exchanger walls in different modes. This numerical simulation provided on the basis of developed in previous publications [2.36 – 2.38] mathematical models of interfacial interactions gas-dynamic processes in evaporating heat exchanger, which describe the change of impulse, mass and heat of drop set and also temperature gas-vapor mixture at different time points of gas in the heat exchanger.

3. The numerical experiment shows that as a result of plant using gas temperature can be reduced by 895 °C in 1.32 sec by using a nozzles with a spray diameter 0.6 mm and the coolant injection velocity 10 m/s. The maximum gas cooling occurs during its contact with evaporating dispersed fluid droplets. However, variant, which used nozzles with a spray diameter 0.9 mm and the coolant injection velocity 3 m/s characterized by distribution of a gas temperature uniformity coefficient γ_T = 0.997 (compared to γ_T = 0.961) at the outlet of the heat exchanger, due to less time of stabilization of equilibrium in vapor-gas mixture and also ensure less coolant consumption and excludes its accumulation in the heat exchanger.

2.6. REFERENCES

2.1. Vambol' S.O., Mischenko I.V., Kondratenko O.M., Burmenko O.A. (2015), "Aproksymacija zakonu rozpodilu eksperymental'nyh danyh za dopomogoju beta-rozpodilu. Chastyna 1" [Approximation of the experimental data distribution law using the beta distribution. Part 1], Herald of NTU "KhPI". Collection of scientific works. Series: Mathematical Modeling in Technique and Technologies, no. 18 (1127), pp. 36 – 44. [in Ukrainian].

2.2. Zvonov V.A., Kornilov G.S., Kozlov A.V., Simonova E.A. (2005), "Evaluation and control particulate matter emissions from the exhaust gases of diesel engines" [Otsenka i kontrol' vybrosov dispersnyh chastits s otrabotavshymi gazami dizelej] [Text], Moscow, Publ. Prima-Press-M, 312 p. [in Russian].

2.3. Twigg M.V., Phillips P.R. (2009), "Cleaning the Air We Breathe – Controlling Diesel Particulate Emissions from Passenger Cars" [Text], Platinum Metals Review, № 53 (1). – pp. 27 – 34.

2.4. Vambol S.O., Mishchenko I.V., Kondratenko O.M., Burmenko O.A. (2015), "Approximation of the experimental data distribution law using the beta distribution. Part 1" [Aproksymatsiya zakonu rozpodilu eksperymental'nykh danykh za dopomohoyu beta-rozpodilu. Chastyna 1] [Text], Kharkiv, Herald of NTU "KhPI". Series: Mathematical modeling in engineering and technology, Publ. NTU "KhPI", Publ. NTU"KhPI", № 18 (1127), pp. 36 – 44 [in Ukrainian].

2.5. Vambol S.O., Mishchenko I.V., Vambol V.V. , Kondratenko O.M. (2015), "Approximation of the experimental data distribution law using the beta distribution. Part 2" [Aproksymatsiya zakonu rozpodilu eksperymental'nykh danykh za dopomohoyu beta-rozpodilu. Chastyna 2] [Text], Kharkiv, Herald of NTU"KhPI". Series: Mathematical modeling in engineering and technology, Publ. NTU "KhPI", Publ. NTU"KhPI", № 41 (1150), pp. 11 – 16 [in Ukrainian].

2.6. Vambol S.O., Mishchenko I.V., Vambol V.V. , Kondratenko O.M. (2015), "Approximation of the experimental data distribution law using the beta distribution. Part 3" [Aproksymatsiya zakonu rozpodilu eksperymental'nykh danykh za dopomohoyu beta-rozpodilu. Chastyna 3] [Text], Kharkiv, Herald of NTU"KhPI". Series: Mathematical modeling in engineering and technology, Publ. NTU "KhPI", Publ. NTU"KhPI", № 41 (1150), pp. 16 – 21 [in Ukrainian].

2.7. Vambol S.O., Mishchenko I.V., Kondratenko O.M., Burmenko O.A. (2015), "The algorithm of distribution law constructing for data of nonlinear values empirical indirect definition by the example of outlet hole manual fire barrel geometric characteristics" [Algorytm pobudovy empirychnoho zakonu rozpodilu danykh nepryamoho vyznachennya neliniynykh velychyn na prykladi geometrychnyh harakterystyk vykhidnoho otvoru ruchnogo pozhezhnogo stvola] [Text], Kyiv, Publ. IDUZC, Materials of the 17th All-Ukrainian scientific conference of rescuers "The current state of civil defense of Ukraine: prospects and ways to European space" which held at the XIV International Exhibition Forum "Protection Technologies / Fire Tech-2015", pp. 16 – 21 [in Ukrainian].

2.8. Toybert P. (1988), “Evaluation of precision the measurement results: Translated from the German” [Otsenka tochnosti rezul'tatov izmerenij: Per. s nem.] [Text], Moscow, Publ. Energoizdat, 88 p. [in Rus.].

2.9. Mishchenko I.V., Vambol S.O., Kurs’ka T.M. (2006), “Metrology and standardization. Abstract of lectures” [Metrolohiya ta standartyzatsiya. Konspekt lektsiy] [Text], Kharkiv, Publ. NUCDU, 137 p. [in Ukr.].

2.10. Ol’shanskij V.P., Halypa V.M., Dubovyk O.A. (2004), “Approximate methods for calculation of hydraulic fire jets” [Priblizhennye metody rascheta gidravlicheskih pozharnyh struj] [Text], Kharkiv, Pupl. Mytets’, 166 p. [in Russian].

2.11. Lojtsjanskij L.G. (2003), “Fluid and gas mechanics: A Textbook for universities” [Mehanika zhydkosti i gaza: Uchebnik dlja vuzov] [Text], Moscow, Publ. Drofa, 840 p. [in Russian].

2.12. Halypa V.M., Vambol S.O., Mishchenko I.V., Prokopov O.V. (2012), “Technical mechanics of liquid and gas. Course of lectures. The second edition, revised and supplemented” [Tehnichna mehanika ridyny i gazu. Kurs lektsij. 2 vydannja, vyp. ta dop.] [Text], Kharkiv, Publ.NUCDU, 224 p. [in Ukrainian].

2.13. GOST 9923-93 “Manual fire nozzle. Technical conditions” [Text], Moscow, Publ. Standartinform, 1993, 11 p. [in Russian].

2.14. GOST 25347-2013 “Basic norms of interchangeability. Product geometric features. System of the tolerances for linear dimensions. A number of tolerances, limit deviations of holes and shafts” [Text], Moscow, Publ. Standartinform, 2015, 54 p. [in Russian].

2.15. Vambol S.A., Mishchenko I.V., Kondratenko A.N., Burmenko A.A. (2015), “Algorithm for constructing the empirical data distribution law indirect definition of non-linear values on the example of the geometric characteristics of a manual fire nozzle outlet hole” [Algorytm postroenija empiricheskogo zakona raspredelenyija dannyh kosvennogo opredelenija nelinejnyh velichin na primere geometricheskih harakteristik vyhodnogo otverstija ruchnogo pozharnogo stvola] [Text], "Fire safety: problems and prospects": a collection of articles of the Proceedings of the VI All-Russian scientific-practical conference with international participation (23 – 24 sept. 2015), Voronezh, Publ. FSEI of HPE Voronezh Institute of SFS of EMERCOM of Russia, pp. 126 – 129.

2.16. Mischenko I.V., Kondratenko O.M. (2016), “Relationship between regulatory manufacturing precision of fire nozzle and its water jet trajectory geometric characteristics” [Text], Kokshetau, Herald of Kokshetau Technical Institute of KES of MIA of RK, issue № 3 (23), Publ. KTI of KES of MIA of RK, pp. 31 – 38.

2.17. Kondratenko O.M., Burmenko O.A., Vambol’ S.O., Mischenko I.V. (2015), “Application of beta-distribution in numerical simulation of environmental safety ensuring process” [Text], Kharkiv, Materials of the All-Ukrainian scientific conference of students and young scientists "Metrological aspects of decision-making in terms of work on technologically dangerous objects" (28 – 29 oct. 2015), Publ. KhNADU, pp. 243 – 244.

2.18. Shmandiy, V. M., Kharlamova, E. V., Ryhas, T. YE. (2015). Issledovaniye proyavleniy ekologicheskoy opasnosti na regional'nom urovne. Gigiyena i sanitariya: nauchno-prakticheskiy zhurnal, 94 (7), 90 – 92.

2.19. Treatment and Disposal of Regulated Medical Waste (2015). Healthcare Environmental Resource Center. Available: http://www. hercenter.org/ rmw/treatment.cfm.

2.20. Hopewell, J., Dvorak, R., Kosior, E. (2009). Plastics recycling: challenges and opportunities. Philosophical Transactions of the Royal Society, 364 (1526), 2115 – 2126. doi: 10.1098/rstb.2008.0311

2.21. Vambol, S. A., Shakhov, YU. V., Vambol, V. V., Petukhov I. I. (2016). Matematicheskoye opisaniye protsessov razdeleniya gazovykh smesey, obrazuyushchikhsya pri termicheskoy utilizatsii otkhodov. Vostochno-Yevropeyskiy zhurnal peredovykh tekhnologiy, 1/2 (79), 35 – 41. doi: 10.15587/1729-4061. 2016.60486

2.22. Vambol, S. A., Shakhov, YU. V., Vambol, V. V., Petukhov I. I. (2016). Matematicheskoye opisaniye protsessov v ustanovke razdeleniya gazovykh smesey pri utilizatsii otkhodov. Tekhnologicheskiy audit i rezervy proizvodstva, 3/3 (29), 62 – 67. doi: 10.15587/2312-8372.2016. 70688

2.23. Bernadiner I.M. (2010). Obezvrezhivaniye opasnykh otkhodov: vybor optimal'noy tekhnologii. Tverdyye bytovyye otkhody, 9, 18 – 26.

2.24. Slenkin, M. V., Zhovmir, N. M., Drozd K. A. (2006). Obrazovanie dioksinov pri termicheskoi utilizatsii tverdyh bytovyh othodov. Materialy II Mezhdunar. konf. "Sotrudnichestvo dlia resheniia problemy othodov", 9 – 10 fevralia 2006 g., 253 – 255.

2.25. Milosh, V. V. (2013). Dioksiny i ih potentsial'naia opasnost' v ekosisteme «chelovek – okruzhaiushchaia sreda». Available: http:// crowngold.narod.ru/articles/dioxini.htm.

2.26. Shibamoto, T., Yasuhara, A., Katami, T. (2007). Dioxin formation from waste incineration. Rev Environ Contam Toxicol, 190, 1 – 41.

2.27. Lee, W. S., Chang–Chien, G. P., Chen, S. J. and etc. (2004). Removal of polychlorinated dibenzo–p–dioxins and dibenzofurans in flue gases by Venturi scrubber and bag filter. Aerosol and Air Quality Resear, 4, 27 – 37.

2.28. Kim, B.H., Lee, S., Maken, S. and etc. (2007). Removal characteristics of PCDDs/Fs from municipal solid waste incinerator by dual bag filter (DBF) system Fuel. Gas. Procedia Environmental Sciences, 86, 813 – 927.

2.29. Mukherjee, A. A., Debnath, B., Ghosh, S. K. (2016). Review on Technologies of Removal of Dioxins and Furans from Incinerator. Flue.

Gas. Procedia Environmental Sciences, 35, 528 – 540. doi: 10.1016/ j.proenv.2016.07.037.

2.30. Yan, J. H., Chen, T., Li, X. and etc. (2006). Evaluation of PCDD/Fs emission from fluidized bed incinerators co-firing MSW with coal in China. Journal of Hazardous Materials, 135 (1), 47 – 51.

2.31. Vambol, S. A., Skob, YU. A., Nechiporuk N. V. (2013). Modelirovaniye sistemy upravleniya ekologicheskoy bezopasnost'yu s ispol'zovaniyem mnogofaznykh dispersnykh struktur pri vzryve metanovozdushnoy smesi i ugol'noy pyli v podzemnykh gornykh vyrabotkakh ugol'nykh shakht. Vestnik Kazan. tekhnol. un-ta, 16/24, 168 – 174.

2.32. Kostyuk, V. Ye., Kirilash, Ye. I., Kobrin, V. N., Vambol, S. A. (2013). Matematicheskaya model' povedeniya dispersnykh struktur v atmosfere. Tekhnologii tekhnosfernoy bezopasnosti: nnternet-zhurnal, 4 (50). Available: http:// academygps.ru/img/UNK/asit/ttb/2013-4/07-04-13.ttb.pdf.

2.33. Vambol, S. A. (2013). Sistemy upravleniia ekologicheskoi bezopasnost'iu, kotorye ispol'zuiut mnogofaznye dispersnye struktury. Kh.: Nats. aerokosm. un-t im. N. E. Zhukovskogo «Har'k. aviats. in-t», 204.

2.34. Launder, B. E., Spalding, D. B. (1972). Lectures in Mathematical Models of Turbulence. London: Academic Press, 458.

2.35. Schmidt, D. P., Corradini, M. L., Rutland, C. J. (2000). A Two-Dimensional, Non-Equilibrium Model of Flashing Nozzle Flow. Proceedings of the 3rd ASME•JSME Joint Fluids Engineering Conference, July 18–23, 1999, San Francisco, Calif. American Society of Mechanical Engineers, 1322.

2.36. Vambol, V. V. (2014). Matematicheskoye modelirovaniye gazovoy fazy okhlazhdeniya generatornogo gaza ustanovki utilizatsii otkhodov zhiznedeyatel'nosti. Ekologichna bezpeka, 6 (89)/1, 148 – 152.

2.37. Vambol, V. V. (2015). Modelirovanie gazodinamicheskih protsessov v bloke ohlazhdeniia generatornogo gaza ustanovki dlia utilizatsii othodov. Tehnologii tehnosfernoi bezopasnosti: internet-zhurnal, 1(59). Available: http:// ipb.mos.ru/ttb/ index.html.

2.38. Vambol, V. V. (2015). Matematicheskoye opisaniye protsessa okhlazhdeniya generatornogo gaza pri utilizatsii otkhodov zhiznedeyatel'nosti. Tekhnologicheskiy audit i rezervy proizvodstva, 2/4 (22), 23 – 29. doi: 10.15587/ 2312-8372.2015.40467

2.39. Crowe, C. T., Sharma, M. P., Stock, D. E. (1977). The Particle-Source-In Cell (PSI-CELL) Model for Gas-Droplet Flows. Journal of Fluids Engineering, 99 (2), 325 – 332. doi: 10.1115/1.3448756

2.40. Fletcher, K. (1991). Vychislitel'nyye metody v dinamike zhidkostey. M.: Mir, v.1, 504.

Chapter 3. TECHNOGENIC AND ECOLOGICAL ASPECTS OF EXPERIMENTAL RESEARCHES OF ECOLOGICAL SAFETY LEVEL INDICATORS

3.1. GENERAL PROVISIONS

Purpose of studies, presented in the chapter, is to analyze technogenic, ecological and metrological aspects of experimental researches of indicators of ecological safety level as an source of initial data for calculated researches and also for mathematical models identification.

Object of studies, presented in the chapter, is technogenic and ecological safety of carrying out of experimental researches on highly energetic testing installations of high-risk.

Subject of studies, presented in the chapter, is analysis of technogenic and ecological safety factors of carrying out of experimental researches of ecological safety level indicators and also its metrological aspects.

The chapter *includes* materials of four articles, two of them (the first one and the third one) combines the contents of 9 and 5 reports respectively.

The **first of these articles** dedicated to general issues of ecological safety ensuring of exploitation process of power plants with piston internal combustion engine, namely: analyzed global trends over the past 25 years, structure of vehicle park of Ukraine, application of alternative fuels of renewable sources, units of exhaust gas neutralization system, namely particulate matter filters.

The **second article** includes materials about the grounding of urgency of researching of factors of industrial, ecological, fire and explosion safety of experimental studies on the engine test bench. Described the features of construction, composition, and shows a diagram of the bench.

The **third article** describes the results of analysis of general problems of experimental determination of mass emissions of legislative normalized pollutants with diesel engine exhaust gas flow, namely particulate matters, classification of methods and instruments for such determination, aspects of fire, technogenic and ecological safety of engine bench tests.

In the **fourth paper** discussed issues of relevance of researching of metrological aspects of experimental studies on the engine test bench. Described the features of composition and features of measurement instruments of the bench.

Findings of presented in chapter 3 studies is submitted in general conclusions of the monograph.

Bibliographic description of presented in chapter 3 published scientific articles is submitted in are given in in Appendix A.

Розділ 3. ТЕХНОГЕННО-ЕКОЛОГІЧНІ АСПЕКТИ ЕКСПЕРИМЕНТАЛЬНИХ ДОСЛІДЖЕНЬ ПОКАЗНИКІВ РІВНЯ ЕКОЛОГІЧНОЇ БЕЗПЕКИ

3.1. ЗАГАЛЬНІ МІРКУВАННЯ

Метою досліджень, наведених у розділі, є аналіз техногенно-екологічних і метрологічних аспектів експериментальних досліджень показників рівня екологічної безпеки як джерела вихідних даних для розрахункових досліджень та для ідентифікації математичних моделей. *Об'єктом досліджень*, представлених у розділі, є техногенно-екологічна безпека проведення експериментальних досліджень на високорнергетичних дослідницьких установках підвищеного ризику. *Предметом досліджень*, описаних у розділі, є аналіз факторів техногенно-екологічної безпеки проведення експериментальних досліджень показників рівня екологічної безпеки, а також їх метрологічні аспекти.

Розділ *містить* матеріали чотирьох статей, дві з яких – перша і третя – поєднують вміст тез 9 та 5 доповідей відповідно.

Перша з статей присвячена загальним питанням забезпечення екологічної безпеки процесу експлуатації енергетичних установок з поршневим двигуном внутрішнього згоряння, а саме: про аналізовано загальні тенденції за останні 25 років, структуру парку автотранспортних засобів України, застосування альтернативних палив з відновлювальних джерел, агрегатів систем нейтралізації відпрацьованих газів, зокрема фільтрів твердих частинок.

Друга стаття містить матеріали щодо обґрунтування необхідності дослідження факторів виробничої, екологічної, пожежної та вибухової безпеки експериментальних досліджень на моторному випробувальному стенді. При цьому наведено опис особливостей конструкції, складу і схеми стенду.

Третя стаття описує результати аналізу загальних проблем експериментального визначення масових викидів законодавчо нормованих полютантів з потоком відпрацьованих газах дизелів, зокрема твердих частинок, класифікації методів і засобів для визначення масових викидів таких полютантів, аспектів пожежної та техногенно-екологічної безпеки стендових моторних випробувань

У **четвертій статті** обговорено питання щодо обґрунтування актуальності дослідження метрологічних аспектів експериментальних досліджень на моторному випробувальному стенді. При цьому наведено опис особливостей складу і характеристик засобів вимірювальної техніки стенду.

Висновки по результатам досліджень, представлених у розділі 3, винесено у загальні висновки по монографії. *Бібліографічний опис* наведених у розділі 3 друкованих наукових праць наведено у Додатку А.

3.2. GENERAL ISSUES OF ENSURING OF ECOLOGICAL SAFETY OF EXPLOITATION PROCESS OF POWER PLANTS WITH PISTON ICE [A.3.1 – A.3.9]

These article is based on materials of 9 reports at science and technical conferences, including 7 International [A.3.1 – A.3.9]. **Relevance of the study** exhaustive manner characterized by title of the publication. **Purpose of the study** is describing of general issues of ensuring of ecological safety of exploitation process of power plants with piston internal combustion engines. **Object of the study** is ecological safety of exploitation process of power plants with piston internal combustion engines. **Subject of the study** is general issues of ensuring of object of the study.

Tasks of the study is:

1. analysis of development of scientific thought and global trends in questions of ensure compliance with legislative established norms of vehicle exhaust gas toxity between 1991 and 2010; 2. analysis of main pollutantes in diesel exhaust gases; 3. analysis of structure of vehicle fleet of Ukraine as a factor of ecological safety; 4. analysis of prospects of using petrol and alcohol mixtures by PICE; 5. analysis of aspects of using of emulators of exhaust gas cleaning system of PICE. 6. analysis of diesel particulate matter filter on engine test bench as a source of technogenic danger; 7. analysis of aspects of using diesel particulate matter filters as a spark arrestor for fire and rescue vehicles; 8. analysis of basis of classification of methods of regeneration of diesel particulate matter filters; 9. analysis of aspects of technogenic and ecological safety of the diesel particulate matter filters regeneration process.

3.2.1. Development of scientific thought and global trends in questions of ensure compliance with legislative established norms of vehicle exhaust gas toxity between 1991 and 2010

Purification of exhaust gases (EG) of diesel piston internal combustion engines (PICE) from their harmful components, in particular of particulate matter (PM), especially appropriate for vehicles and special machines (including one that is used by the State Emergency Service of Ukraine (SESU)), which operates in conditions of limited air exchange, in public places and areas in towns, where there are established special regulations for toxicity of vehicles, that harder for operating outside of these areas, and also for vehicles, which took part in the military celebrations. Diesel engines is a PICE with mixed heat supply in the working process, compression ignition of the fuel-air mixture (with excess air ratio equal 1.3 ... 8.0), qualitative power regulation and external mixture formation, consuming diesel oil as motor fuel. PM is all substances, which have settled on a special filter of teflon fiber during passing through it a mixture of air and exhaust gas in certain proportions at a temperature, not higher than 52 °C and are not water [3.1].

Analysis of publications and reports of sections of the World Congress of the Society of Automotive Engineers (SAE), which devoted to questions of ecological compatibility of PICE, for the period from 1991 to 2010 shows, that during this time in these issues sphere following trends were observed [3.2–3.18]:

– dieselization of global and Ukrainian vehicle fleets;

– environmental regulations cover new types of vehicles, and their PICE with them;

– introduction of ecological standards in new countries of the world and strengthening of already existing requirements;

– transition from rationing smoke of EG to rationing of mass emissions of PM from EG;

– focusing on the fractional composition of PM – by weight, by the active surface area and by counting;

– focusing on the chemical composition of PM and their internal structure;

– transition from technology of EG simple filtration and their catalytic oxidation to the application of reducing EG toxicity complex systems;

– commitment to modularity and compactness of systems of reducing EG toxicity and their units;

– solving the problem of cold start of PICE;

– improving the ceramic substrate material of catalytic converters (CC) and DPF;

– transition from the solid ceramic filter elements (FE) to FE with the cellular structure and channels of gas-permeable walls, that drowned out in a checkerboard pattern;

– depth study of the catalytic properties of platinum group metals and their combinations;

– search, research and manufacturing application of FE materials, which alternative to ceramic – fibrous, granular, wound, woven and non-woven steel mesh, membranes;

– development and application of various variants of realization complex approach to reduction the toxicity of EG, that provides not only improve of EG purification system, but also systems that are involved in the work process organization of PICE, and improve the quality of motor fuels and oils;

– development and implementation of measures to bring the of toxicity indicators of vehicles, that are in exploitation, to the level of the newly introduced regulations;

– integration of the system of reduction toxicity of EG of PICE to the system of electronic control of ICE or of vehicle;

– mathematical modeling of the mechanisms of formation of toxic components of EG, including PM, in the workflow of PICE;

– mathematical modeling of the processes occurring in EG during their movement of PICE exhaust tract;

– mathematical modeling of the processes occurring in DPF during regeneration process of 1st kind.

Thus, the scientific capacity of the above trends and spectrum of scientific and technical problems in ecological compatibility matters of vehicles and of PICE, that of their component, indicate that this subject is very important.

3.2.2. Main pollutantes in diesel exhaust gases.

The main legislative normalized pollutants in EG of PICE with compression ignition, working on a Diesel cycle, are follow substances: nitrogen oxides NO_x and particulate matters PM because they account for up to 95% of reduced toxicity, and their formation in the diesel combustion chamber lead antagonistic factors. PM by definition is all substances in sample of mixture of EG and pure air in a certain ratio that settled on a special teflon filter during the passage of the sample through it, with temperature less than 52 °C and aren't water. That means PM is a product of uncompleted combustion of motor fuel and oil and structurally is a liquid unburned hydrocarbons C_nH_m, which adsorbed on surfaces of coagulated soot cores (porous amorphous carbon). PM conditionally divided on oxidizable (C_nH_m and soot cores) and non-oxidizable (products of wearing of diesel parts, mineral dust of environment air, ash of combustion of additives in motor fuel and oil, sulfates) fractions. NO_x on the contrary are a product of completed combustion of air-fuel mixture – nitrogen-containing fractions and additives in motor fuel and oil and atomic nitrogen on air. NO_x in chemical reaction with vapor of water of EG and environmental air generated an acid rains, and in chemical reaction with polycyclic aromatic hydrocarbons of EG and PM gives its nitroderivatives which has a mush greatest carcinogenic and mutagenic effect on human. NO_x generates at high temperatures in combustion chamber of diesel engine and a fullness of combustion promotes it process. Since to the notion of fullness of combustion is closely related notion of fuel efficiency of PICE, usually its constructive and adjusting parameters optimize to achieve its maximum value of that indicator, and therefore as an undesirable side effect is increase in emissions of NO_x in EG flow. The exhaust of gasoline PICE with spark ignition, working on an Otto cycle, there is a reverse situation. Of these legislatively normalized pollutants main contribution to the toxicity of the EG is made unburned hydrocarbons motor fuel and oil C_nH_m and carbon monoxide CO, that is, products of incomplete combustion. This is due to the fact that such ICE operating in a narrow range of air-fuel ratio near its stoichiometric value $\alpha = 1.0$, and the maximum capacity is achieved with a deficiency of oxygen, that is at $\alpha = 0.8...0.9$. In EG of forced petrol supercharged PICE is also present a significant amount of nitrogen oxides NO_x. This is caused by high temperature combustion of fuel-air mixture in the combustion chamber [1.11].

3.2.3. Structure of vehicle fleet of Ukraine as a factor of ecological safety

Ecological parameters of vehicles, which equipped with PICE in general, and in particular of PICE themselves, largely formed by qualitative and quantitative composition of their EG. For PICE, which working on a diesel cycle, the main pollutants in the EG are nitrogen oxides and PM. In this case, the formation of these pollutants in the working process of a diesel engine caused by antagonistic factors. Their emissions with the flow of the EG of diesel PICE legislatively standardized [3.19].

All of the above relates to novel PICE. The technical level of PICE being in operation, corresponded to the level of development of the industry at the time of release, but does not meet modern requirements for fuel efficiency, production costs and reliability. Growth of radical modernization of these characteristics can not be achieved. However, the requirements for ecological characteristics irrelative to term of operation of PICE and vehicle with such type of engine are allowed for exploitation only together with the introduction of economic sanctions of their owners. For owners of vehicle, which satisfying the these standards, on the contrary, granted preferences to the payment of taxes and fees, benefits for payment of fuel and parking spaces. This leads to the need to develop of methods to bring ecological performance of vehicles of earlier years of manufacture to the requirements of modern standards [3.19].

Vehicle fleet of Ukraine is characterized by a significant number of units of machinery that has reached a high degree of moral and physical wear, but, nevertheless, can not be put out of operation for various reasons. That is PICE of agricultural and military hardware, of building and road machines, as well as locomotive, marine and aircraft PICE. The same situation is observed in the operation of vehicles on private property of citizens of Ukraine. And their forced removal from operation is possible only when the technical condition of their critical levels, hazardous to the lives of other citizens [3.19 – 3.22].

The average service life a vehicle in the European Union is 8 years, in Ukraine this index for domestic brands is at a level 14 – 16 years, and for foreign cars – 10 – 12 years. Vehicle fleet of Ukraine in terms of age of vehicles in 2009 consisted of such segments: up to 5 years – 22 %, 6 – 8 years – 10 %, more than 9 years – 68 % [3.20, 3.22].

Ukrainian car market is far from saturation. The average rate of motorization in Ukraine is 130 cars per 1000 inhabitants (in the European Union it is 400 – 600 cars per 1000 inhabitants). The volume of primary car market in Ukraine in 2009 amounted to 162291 cars, and secondary – twice as much because the price of the car with a run in 2–3 times lower than the price of a new car [3.21].

Trends in the car market of Ukraine in the time interval from 2008 to 2009 for its different segments were as follows: new car registrations 59,5 % in 2008 and 32,2 % in 2009, the resale of used cars in the domestic market – 40 and 67,2 % respectively, registration of imported used cars – 0,5 and 0,6 % [3.21].

As of 2009 the value of the vehicle fleet in Ukraine amounted to about 6 million vehicles. From them about 70 % were cars of domestic brands (VAZ – 37 %, ZAZ – 15 %, Moskvich – 13 %, GAZ – 5 %), and on the cars of the brands Opel, Daewoo, Volkswagen, Chevrolet, Ford, Toyota, Mitsubishi, Skoda, Nissan, Mercedes, Mazda, Hyundai, Audi had 5 – 2 % of the units of vehicle fleet, respectively, on the other – 10 %[3.21].

In the secondary market in Ukraine in 2009 from solded cars 45 % were cars produced in CIS countries, of which 38 % were for cars of mark the VAZ, and best-selling car model in the market has become a Daewoo Lanos [3.21].

Brand structure of sales of commercial vehicles with mileage (cargo, vans, trucks) on a car market of Ukraine as of 2008 and 2009 was as follows: GAZ – 14 and 18 % respectively, Volkswagen – 17,5 and 17,7 %, Mersedes-Benz – 19 and 17 %, Ford – 8 and 7,5 %, Renault – 9 and 8 %, Fiat – 6,5 and 6 %, ZAZ– 2,5 and 3,5 %, Peugeot – 3,3 and 3,2 %, Izh – 2 and 3 %, UAZ – 2,7 and 2,9 %, Citroen – 3 and 2,7 %, Opel – 2,9 and 2,6 % others – 9 and 8 % [3.21].

Average service life of vehicles in vehicle fleet of Ukraine as of the 01.01. 2001 was 17,1 years, as of the 01.01.2006 – 18,5 years (historical maximum), as of 01.01. 2011 – 18,2 years. Thus, the average statistical car on the ukrainian road is car of 1993 release, predominantly the VAZ [3.21, 3.22].

All of these data confirm what was said in the beginning of this thesis: the structure of the vehicle fleet in Ukraine is such that there is an urgent need to develop a tools of bringing the ecological performance of vehicles to the current level of legislatively established standards.

3.2.4. Prospects of using petrol and alcohol mixtures by piston internal combustion engines

The problem of use of alternative fuels in PICE in recent years is the most relevant in relation to the situation that has arisen in the world to date – a decreasing of reserves and increasing in the price of fossil fuels. The potential of production of ethanol for passenger transport around the world is estimated at about 32 % of the consumed gasoline when using E85 (85 % alcohol) [3.23]. The possibility of substitution of such a level of traditional fuels draws attention to the problem of use of renewable resources and collateral damage to environment in the form of seizure of agricultural land, pollution of water sources by pesticides, widely used in the production of raw materials for biofuels. One of the important technical requirements related to the use of ethanol in composition of benzoethanol (petrol and alcohol mixture) for ICE, is to increase its aggregate stability. When the temperature drops and increase the amount of water in the benzoethanol fuel occurs its delamination with the formation of two liquid phases. Tendency of the gasoline and alcohol mixtures to separation depends on the petrol composition, water and alcohol content in the composition. With increasing concentration of aromatic compounds in petrol and with increasing alcohol fraction contained in a mixed fuel, its cloud point temperature reduce [3.23]. The modern system of preparation of mixed fuels are used, as a rule, hydrodynamic, vortex and ultrasonic cavitators. A promising direction of researches is the development of small-dimension hydrodynamic cavitators which enable to maintain the benzoethanol stability on board the vehicle [3.24]. One of the drawbacks of this type of alternative fuel is its high corrosion activity [3.25].

This subject of research is one of the basic directions of work of Piston Power Plants Dept. (DPPP) of A.N. Podgorny Institute for Problems in Machinery of NASU (IPMash NASU) [3.24 – 3.27]. The DPPP Laboratory is equipped with the engine test bench (ETB), in which the object of research is the transport piston engine MeMZ-307.1 (automobile, gasoline, four-in-line vertical arrangement of cylinders and liquid cooling) [3.26, 3.27]. Given the decline of net calorific value of benzoethanol fuel the engine has been primarily adapted to ensure efficient operation on gasoline and benzoethanol [3.28]. Adaptation carried out by reprogramming the electronic control unit (ECU) and the change of the characteristic maps, in which the engine is running, depending on the mode (increased length of fuel injection in the study mode, and ignition timing is adjusted interactively using appropriate software). In the ECU was entered additional program to ensure effective operation of the engine on benzoethanol. In this paper carried out comparative studies of characteristics of the MeMZ-307.1 transport engine operating on petrol mark A95 and benzoethanol mark E85 on a ETB. The ETB consists of a motor bench and measuring equipment capable of measuring engines indicators of work and test conditions. ETB includes the DC balancing dynamometer type DS 926-4/V with integrated speed sensor and a weight device for measuring the torque, the motor-generator, thyristor excitation unit, control cabinet, control panel.

On the test modes (maximum torque and nominal power) effective efficiency (η_e) of engine adapted to mark E 85 benzoethanol is higher than not adapted engine as well as of petrol version by 6.6 % and by 6.7 % (on maximum torque mode and nominal mode respectively). Indicators of EG emissions of benzoethanol engine is significantly better than indicators of gasoline engine. An exception is the content of nitrogen oxides in EG, which at nominal mode higher for benzoethanol engine than gasoline engine (ETB exhaust system has no car catalytic converter). The values of the air excess factor (α) on the said modes were, respectively, 0.96 and 0.97, and the EG temperature decreased on 54 °C and 93 °C. Excess of benzoethanol E85 consumption compared to gasoline consumption by 35.5 % and 31.5 % for the said modes explained by the difference of the specific heat of combustion, which is 64 %. For the most favorable compromise between power, efficiency and toxicity of an engine running on benzoethanol must be coordinated regulation of the ignition timing depending on excess air ratio. Also promising research direction are improving the efficiency of application of benzoethanol in the PICE by the developing a sensor that is integrated into the car standard fuel system, which evaluates the composition of the mixed fuel, and the allows car ECU to choose autonomously the most effective control program (for petrol and benzethanol).

3.2.5. Emulators of exhaust gas cleaning system of piston internal combustion engines

Ecological parameters of vehicles, which equipped with PICE in general, and in particular of PICE themselves, are legislatively standardized. The technical level of PICE being in operation, corresponded to the level of development of the industry at the time of release, but does not meet modern requirements for ecological characteristics and irrelative to term of operation of PICE and vehicle. Vehicle fleet of Ukraine is characterized by a significant number of units of machinery that has reached a high degree of moral and physical wear, but, nevertheless, can not be put out of operation for various reasons.

In the structure of vehicle fleet of our country has a sufficiently large number of foreign-made vehicle equipped at the time of exit from conveyor systems to reduce exhaust emissions, but in practice many of these vehicle these systems no longer have. This is because rather expensive repairs of these systems subject to the negative effects of exhaust gas generated from the low-quality fuels, as well as prone to thermal destruction. Another two reasons for this phenomenon are the lack of state supervision over compliance of legislatively established latest emissions standards and the lack of qualified personnel in staff of official representative offices of foreign vehicle brands. Typically, after the failure of this system it is completely dismantled from the board of vehicle with the following sensors: exhaust gas pressure, exhaust gas temperature, quantity of oxygen in the exhaust and replace it by the segment of the pipeline and a so-called emulator of operation of exhaust gas cleaning system (with the obligatory reconfiguration of ECU of such system, or of ICE or of vehicle). Emulator generates signals of the sensors of vehicle exhaust system in their physical absence according to the program laid down in it and feeds them to the ECU of engine or vehicle. At the same time the ECU for same vehicle models, which differing only in the presence of exhaust gas cleaning systems or its some parts, have different structure and are not interchangeable. Expenditures on physical and software removal of FPF range from 400 to 700 $ depending on the splitability of DPF housing and the possibility of separation its filter element from it. This procedure is in direct violation as well of the guarantee conditions of use DPF as an ecological legislation in some countries. Therefore, to estimate the number of vehicles equipped with emulators difficult. However, their number significantly and steadily increased. This leads to the need to develop methods to bring environmental performance of vehicles of earlier years of production to the modern standards requirements [3.19].

3.2.6. Diesel particulate matter filter IPMash on engine test bench as a source of technogenic danger

The Laboratory of DPPP of IPMash of NASU equipped by ETB with autotractor diesel engine 2Ch10.5/12 (D21A1). Features of construction of ETB and modular DPF, which was designed in DPPP, described in papers [3.19, 3.30].

It contain a parts, which manufactured of follow non harmful materials: stainless steel rolling sheet, stainless steel woven mesh, bulk natural zeolite of middle size fraction, and do not contain catalytic covering. But it consists of minimal required number of modules and therefore contains compaction elements of asbestos sheet.

At the operation conditions DPF modules filled with PM and therefore in their dismantling process and in other manipulations with them (their parts connected by separable) should prevent sedimentation of PM from them and their place of installation on exposed skin and inhalation because of high toxic effect. Also working DPF filled the exhaust gas flow temperature and therefore in their dismantling process and in other manipulations with them (measuring of its operational parameters) it should be cooled before till range of temperature, which allowing protective gloves. However themselves demolition works must be carried out only by a diesel engine stopped. The above relates to the purpose, tasks and results of development of the ecological safety management system of power plants with a PICE exploitation process [1.11].

3.2.7. Using diesel particulate matter filter as a spark arrestor for fire and rescue vehicles

DPF for diesel ICE of fire and rescue vehicles, which are under operation condition, including the State Service for Emergency Situations of Ukraine, can be used to bring their environmental performance to the level of legislatively established regulations. In world practice known DPF that are in production and operation, the design of which there are no parts of the ceramic honeycomb bodies with channels and/or catalytic coatings and/or equipped with on-board regeneration system (system of recovery of their operating characteristics). DPF, regeneration of 1st kind of which is carried out by thermal or thermal catalytic oxidation of removed from the EG flow and accumulated in their FE PM in order to perform the functions spark arrestor of vehicle exhaust system, they must have housing, equipped with special structural elements of the output buffer of DPF. In the DPPP of IPMash of NASU developed a DPF with new unconventional design and don't contain catalytic coatings. One of the possible ways to implement regeneration process of 1st kind of DPF IPMash assumed the one that is used to oxidize the accumulated PM in its FE by low-temperature plasma induced from the EG by plasmatron. Those devise can be a part of the exhaust system of vehicle or separate device, which used for centralized service of vehicle. In that case, EG temperature required for the regeneration process is reduced to 350 °C (in the other cases, this temperature is 600 – 800 °C) that contributes to the spark supperssion in exhaust and improve the fire safety of operation of vehicle [1.11, 3.31, 3.32].

3.2.8. Basis of classification of methods of regeneration of diesel particulate matter filter

According to UNECE Regulations # 49 and 96 level of EURO III, to the number of normalized pollutants in EG of diesel PICE of vehicles and special machines, which used for ground handling of military and civil aviation equipment in Ukraine, also included a PM. By definition it is all substances in mixture of EG and pure air, which at maximum temperature of 52 °C collected by special filter of fiberglass and aren't a water (an aerosol containing soot cores (amorphous porous carbon) and adsorbed on they surfaces unburned hydrocarbons of motor fuel and oil in general and polycyclic aromatic hydrocarbons in particularly, which has carcinogenic and mutagenic effects on life organisms). PM removed from the exhaust flow, holds and neutralized by using the DPF. The process of purification of DPF themselves from PM, which accumulated during diesel operation called regeneration. PM should be divided into oxidizable and inoxidable. To the oxidizable factions, that are mass majority in EG, can be attributed all components of PM, that can be oxidized by residual oxygen of EG in the DPF body at a temperature, that is lower than 1000 °C, ie, without harm to material of its FE, housing and catalytic coatings. In connection with this, one should distinguish between regeneration DPF of 1st kind (cleaning FE from the oxidizable fractions of PM) and regeneration of 2nd kind (cleaning FE from the inoxidable fractions of PM and coking products of oxidizable fractions) [1.11].

3.2.9. Aspects of technogenic and ecological safety of the diesel particulate matter filter regeneration process

The aspects of technogenic and ecological safety of physical and chemical processes, which are a essence and accompanied process of regeneration of DPF for PICE, they also caused by follow factors.

1) The features of ICE as a source of environmental pollution in general and qualitative and quantitative composition of their EG in particular. In diesel EG up to 90 % of EG average toxicity accounted for on nitrogen oxides NO_X and so-called PM. And 20 – 45 % of that parameter

accounted for PM. This in turn is because PM contained the polycyclic aromatic hydrocarbons, which include carcinogenic and mutagenic effects on humans or animals. Besides, to the appearance in diesel EG these two types of legislative normalized pollutants caused by antagonistic factors.

2) Model of exploitation of the vehicle, which powered by diesel ICE of certain type and purpose with specific ecological and performance indicators. It has a direct impact on absolute value of the mass emissions of PM in its EG flow.

3) The operating efficiency of DPF that is, a part of removed PM from diesel EG flow and neutralized in it FE from the common quantity of their mass emission. Also must be assumed the change of the DPF working characteristics depending of regime, constructive, adjusting and other diesel parameters.

4) The features of organization and flow of DPF regeneration process. Also must be assumed the principal difference between processes of DPF regeneration of 1st and 2nd kind. DPF regeneration of 1st kind is a periodic process of FE purification from the oxidisable fractions of PM, which accumulated due to its exploitation. It is a integral part of life cycle of DPF. DPF regeneration of 2nd kind is a non periodic process of FE purification from the inoxidisable fractions of PM and coking products of oxidisable fractions, which accumulated due to its exploitation. It stands out a much greater period between regenerations (or may be generally nonrecurrent) and may not enter into the life cycle of DPF. Most often the regeneration process of 1st kind is released by appropriated onboard systems of vehicle by the thermal-catalytic method. In this case oxidation of PM takes place in unsteady mode and may be interrupted and produce the toxic products. Most often the regeneration process of 2nd kind carried out by using out-board systems (manual or automated installations stands), with washing of DPF with water in the opposite direction. The resulting suspension of PM in water must be filtered, the received filtrate must be evaporated of drained, obtained dry concentrate of PM must to be burnt at steady state (e.g., in firebox or mini-boiler or plant for burning solid waste) [1.11].

3.2.10. Conclusions

Thus, in present study described results analysis of issues of development of scientific thought and global trends in questions of ensure compliance with legislative established norms of vehicle engine exhaust gas toxity and main pollutantes in diesel exhaust gases, structure of vehicle fleet of Ukraine, using petrol and alcohol mixtures for piston internal combustion engines and emulators of exhaust gas cleaning system, technogenic and ecological safety features of diesel particulate matter filter using and regeneration processes.

3.3. DESCRIPTION OF ENGINE TEST BENCH AS A SOURCE OF DANGER FACTORS IN EXPERIMENTAL RESEARCHES [A.3.10]

Introduction. As well known, the main porpoise of any kind of scientific researches is a creation of newest intellectual product of fundamental of applied nature, which characterized by scientific novelty, originality and practical value. In this connection, that product on its way between initial idea and form of some kind of competitive goods, which implemented in serial production, necessarily passes the stage of experimental researches of its working characteristics. That fact causes the necessary of development of special programs and methods, designing and manufacturing of experimental samples and also creating and improving of laboratory equipment – stands, plants, measuring instruments. But any experimental researches of objects that related with energy plants, except co-called mental experiment, characterized by some kind of danger factors. Therefore scientific research works aimed on identifying, analysis and maximal reducing or elimination of danger factors, sources of which are experimental plants and stands, are relevant because life and health of researchers and laboratory staff are the values of much higher order, than any kind of scientific knowledge.

Analysis of recent publications. In Department of Piston Power Plants (DPPP) of A.N. Podgorny Institute for Mechanical Engineering Problems of NAS of Ukraine (IPMash NASU) was developed modular diesel particulate matter filter (DPF) with new nonconventional construction and bulk natural zeolite in cassettes of stainless steel mash – DPF IPMash. Several variants of DPF construction are embodied in the form of operating layouts of its filter elements (FE). Their working characteristics under real operation conditions was obtainned on engine test bench (ETB) of DPPP [3.33]. The scheme of ETB shown in Fig. 3.1 and its appearance – in Fig. 3.2.

Porpoise of research is description of structure of ETB for following identification and analysis of factors of industrial, ecological, fire and explosive danger of carriage of experimental researches on ETB.

Formulation and solving of problem. ETB as himself is a complicated system of follows interrelated power plants.

1) Bench contains electrical load machine made by firm VSETIN with dynamometer of direct current of type DS 742/4-N in which structure is control cabinet of type VH 136, two-machine unit (motor-generator) of type IDP 942-1 and remote control panel [3.34].

2) On board of bench installed an autotractor diesel engine D21A1 (2Ch10.5/12) [3.35] as the object of study.

3) System of measuring instruments of ETB consists of following devices: sensors, appliances and informational channels, which measure and control the adjustment, regime and other parameters of diesel engine, load devise and other units of the bench [3.36].

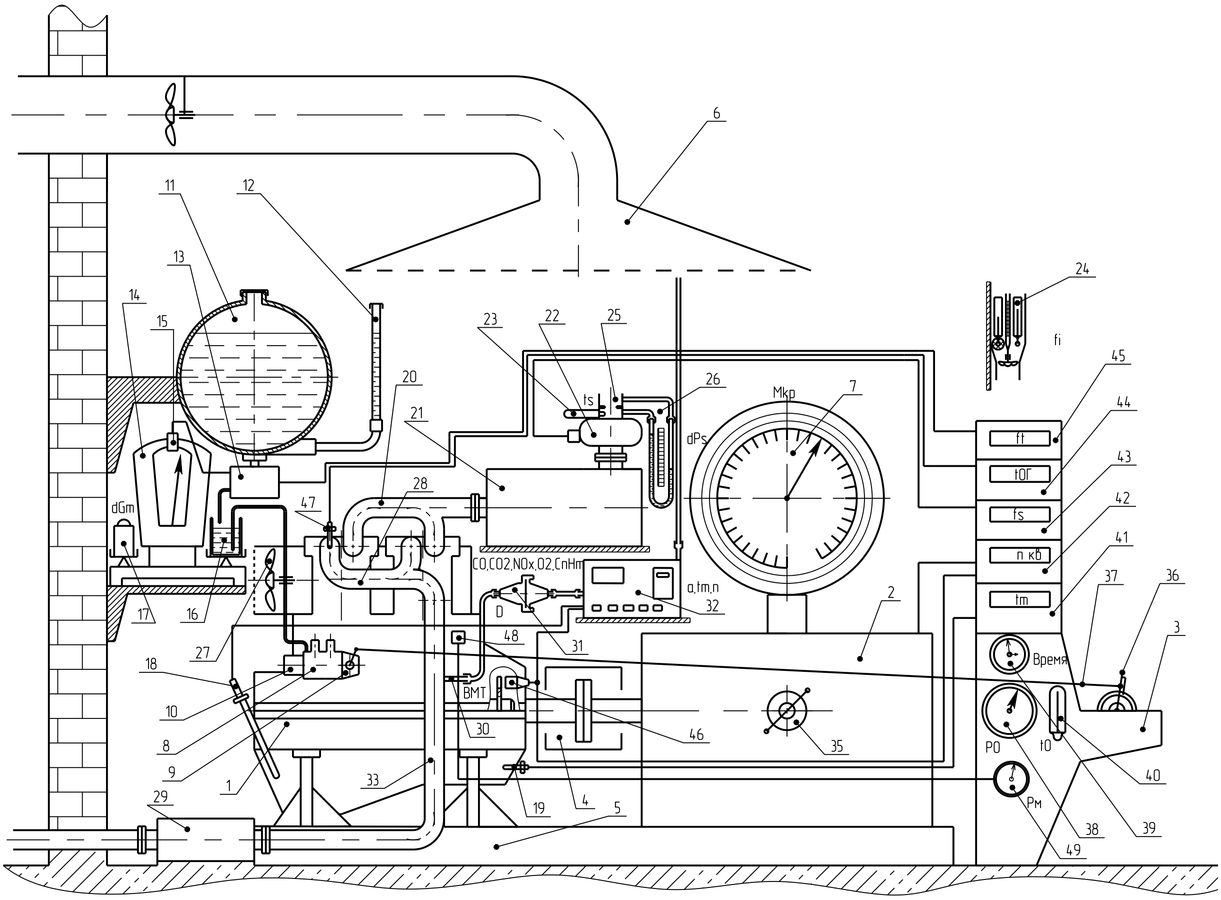
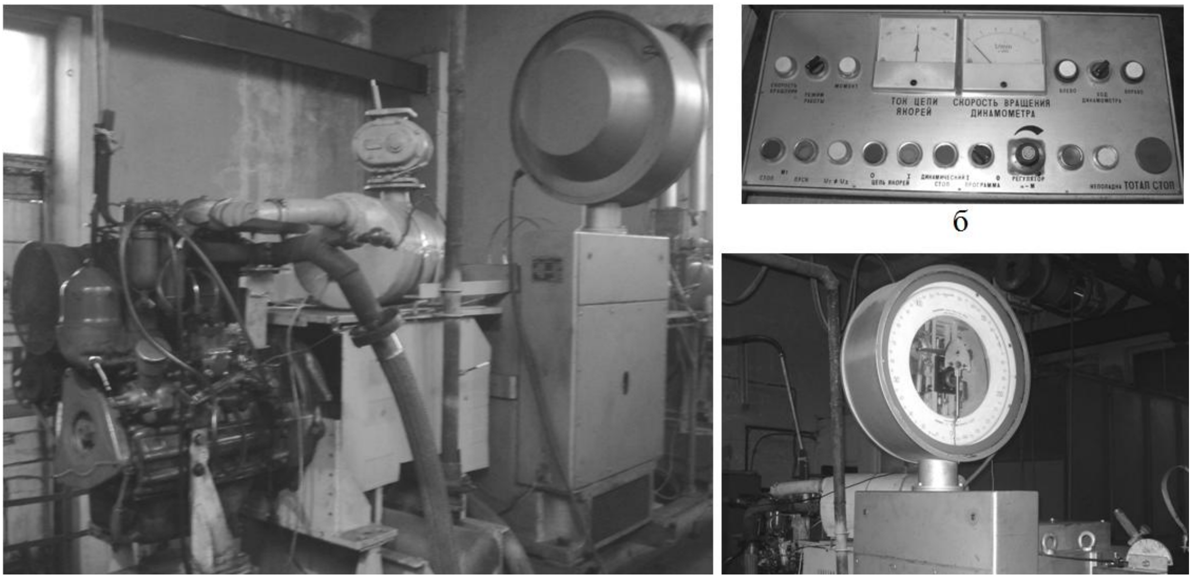


Fig. 3.1 – Scheme of Engine Test Bench:

1 – diesel engine D21A1 (2Ch10.5/12); 2 – load machine (motor-generator IDP 924-4); 3 – remote control panel; 4 – cardan shaft with protecting casing; 5 – welded steel fundament frame; 6 – exhaust ventilation; 7 – dynamometer DS 742-4/N; 8 – high pressure fuel pump; 9 – all regimes regulator of crankshaft; 10 – coupling for variation of angle of advancing of fuel injection; 11 – fuel tank; 12 – sensor of fuel level in tank; 13 – electric-hydraulic automatic valve for fuel topping; 14 – laboratory scales of 2nd class VLR-200; 15 – optical sensor; 16 – consumption tank of fuel consumption measurer; 17 – references weight; 18 – oil dipstick or oil temperature sensor in sump of diesel; 19 – oil temperature sensor in sump of diesel TM100V; 20 – exhaust collector of diesel; 21 – intake receiver of diesel; 22 – rotary gas counter RG-100; 23, 40 – mercury thermometer TL-4 №2 (0 – 50 ºC); 24 – psychrometer; 25 – choke orifice of intake air consumption measurer; 26, 34 – differential U-shape hydraulic manometer; 27 – ventilator of diesel cooling system; 28 – exhaust collector; 29 – EG noise muffler; 30 – EG toxicity sampler; 31 – filter holder for EG smokiness determination; 32 – 5 components gas analyzer Autotest-02.03P; 33 – exhaust tract; 35 – unconnected coupling of loading machine; 36, 37 – control handle and metal cable; 38 – barometer-aneroid BAMM-1M; 39 – timer; 41 – appliance A-565; 42, 43, 45 – frequentcymeter-chronograph F-5040 or F-5041; 44 – appliance A-566; 46 – TDC marker; 47 – resistance thermometer TSM; 48 – oil pressure sensor; 49 – manometer MO

4) Diesel engine and load devise are installed on welded steel fundament frame that rests on a concrete base.

5) Transmission of the bench is mechanically connect flywheel of diesel engine and flange of rotor of loading devise with spline shaft and is covered by protecting casing. These questions are studied in [3.41].



б

a c

Fig. 3.2 – Engine Test Bench:
a – general view of bench; b – remote control; c – loading device with dynamometer

All of these structure units of ETB characterized by definite set of factors of industrial, ecological, fire and explosive danger. The motor experiments provided in accordance with programs and methodics of DPPP and also provisions of GOST 18509-88 and GOST 14846-87 [3.37, 3.38]. The programs of motor research is developed on basis of standardized 13- and 8-regime stationary test cycles that are models of exploitation of automotive and tractor diesel engines, respectively, and are described in UNECE Regulations # 49 and # 96 [3.1, 3.40]. They was adapted to abilities of laboratory of DPPP and features of it process are described in [3.33]. To providing the engine bench researches of DPF IPMash the exhaust system of ETB was modernized by the way of adding to it the place for installing of experimental samples (insert for sample retention (ISR)), the new sampling systems of exhaust gases (EG) for determine its toxicity and opacity and also for measuring of gas dynamic parameters of EG flow. The scheme of modernized ETB exhaust system shows in [3.33, 3.36]. The danger factors of experimental studies on ETB is expedient to consider for each of its single units apart. That will be the porpoise of following studies [3.41].

Conclusions. In present research considered structure, composition and features of engine test bench of DPPP of IPMash of NASU as a source of factors of industrial, ecological, fire and explosive danger.

In following researches will be determined and analyzed that danger factors for each of it single bench units apart. It is the loading device, transmission, diesel engine 2Ch10.5/12, measuring instruments and experimental samples of DPF. Also it will be proposed the list of actions for ensuring industrial, ecological, fire and explosive safety of experimental studies on ETB.

3.4. GENERAL ISSUES OF METROLOGICAL MAINTENANCE AND ENSURING OF TECHNOGENIC AND ECOLOGICAL SAFETY OF EXPERIMENTAL ENGINE TEST BENCH RESEARCHES

[A.3.11 – A.3.15]

These article is based on materials of 5 reports at International science and technical conferences [A.3.11 – A.3.15].

Relevance of the study exhaustive manner characterized by title of the publication. **Purpose of the study** is describing of general issues of metrological maintenance and ensuring of technogenic and ecological safety of experimental engine test bench researches. **Object of the study** is metrological maintenance and ensuring of technogenic and ecological safety of experimental engine test bench researches. **Subject of the study** is general issues of ensuring of object of the study.

Tasks of the study is:

1. analysis of problems of particulate matter mass emission in diesel exhaust gases experimental determination;
2. creation of classification of gravimetric methods for determination of particulate matter mass emission in exhaust gas flow of diesel internal combustion engines;
3. analysis of classification of optical devices for particulate matter content in internal combustion engines exhaust gas determination;
4. analysis of classification of instruments for determination of gaseous pollutants concentrations in internal combustion engine exhaust gases;
5. analysis of aspects of fire safety of engine bench researches.

3.4.1. Problems of particulate matter mass emission in diesel exhaust gases experimental determination

Requirements for the ecological characteristics of diesel piston internal combustion engines (PICE) vehicles obligatory in the territory of Ukraine, the Russian Federation and the European Union [2.2], as fixed legislatively – UNECE Regulation № 49 [3.40] and № 96 [3.1] level of EURO III, IV and V respectively. These documents defines a list of normed pollutants in the exhaust gas (EG) of diesel engines, limits for their mass emissions, bench testing methodology and a list of modes in stationary test cycles (13 and 8 respectively), is a model of the operation of such vehicles. This sets the method for measuring a mass emissions of particulate matter (PM) – gravimetric and means of its realization – full- or partially flow tunnels. The high cost of manufactured tunnels, extreme science intensity of their self-development and the complexity of their certification determine the need to find methods and means for determining the of PM mass emissions, alternative for tunnels and suitable for preliminary and comparative laboratory studies [2.2, 3.1, 3.40, 3.42, 3.43].

In Piston Power Plants Dept. (DPPP) of A.N. Podgorny Institute for

Problems in Machinery of NASU (IPMash NASU) developed particulate matter filter (DPF) with new modular unconventional construction for diesel vehicles in operation. Thus its operating characteristics under real operating conditions determined during the bench experimental studies. They were carried out on the engine test bench (ETB), equipped with an autotractor diesel engine 2Ch10,5/12 (D21A1), but is not equipped with a tunnel [3.42, 3.43, 3.35]. Test programs are based on standardized stationary testing 13 and 8-mode cycles, which are a models of operation of the vehicle and described in [3.40, 3.1].

The main operating characteristics of the developed DPF is the efficiency coefficient K_{CE} of cleaning a diesel EG flow from the PM, which defines by the following formula in % [3.42]:

$$K_{CE}(G_{PM}) = (G_{PM.ICE} - G_{PM.DPF}) \cdot 100 / G_{PM.DPF}, \tag{3.1}$$

where G_{PM} – PM mass emission with diesel EG, kg/h; indexes *ICE* and *DPF* refers to cases of absence and presence of the DPF in the exhaust system of a diesel engine.

This raises the following problems, the solution of which require the use of appropriate approaches.

3.4.1.1. The approach to determining of particulate matter mass emissions

It involves direct measurement of EG samples opacity (by Opacimeter INFRAKAR-D) and the volume concentration of unburnt hydrocarbons in EG (Five-component gas analyzer AUTOTEST-02.03.P) [3.42, 3.43], and the recalculation of these data into units of a of PM mass emissions according to the formula proposed by I.V. Parsadanov (Dr.Sci. (Tech.), Prof., NTU "KhPI") and obtained in certification tests of the autotractor diesel engine SMD-31 of the company Ricardo bench, equipped with a full-flow tunnel [1.14].

$$G_{PM} = \left(2{,}3 \cdot 10^{-3} \cdot N_D + 5 \cdot 10^{-5} \cdot N_D^2 + 0{,}145 \cdot \frac{C_{CH} \cdot 4{,}78 \cdot 10^{-7} \cdot (G_{air} + G_{fuel})}{0{,}7734 \cdot G_{air} + 0{,}7239 \cdot G_{fuel}} + \right.$$
$$\left. + 0{,}33 \cdot \left(\frac{C_{CH} \cdot 4{,}78 \cdot 10^{-7} \cdot (G_{air} + G_{fuel})}{0{,}7734 \cdot G_{air} + 0{,}7239 \cdot G_{fuel}}\right)^2\right) \times \frac{(0{,}7734 \cdot G_{air} + 0{,}7239 \cdot G_{fuel})}{1000}, \tag{3.2}$$

where N_D – light absorption coefficient of EG sample, %: C_{CH} – volume concentration of unburned hydrocarbons of EG sample, ppm; G_{air} и G_{fuel} – mass flow of air and fuel in the diesel engine on steady-state operation, kg/h.

3.4.1.2. The approach to implementation of standardized test cycles

The list of operating modes of diesel engine included in above-mentioned standardized test cycles, there are modes, the implementation of which (transferred on this mode and its characterize parameters automatic maintenance) is difficult for diesel engines and the ETB, not equipped with an electronic control system [3.42, 3.35] – this is the mode with zero and closest to it effective power. The second problem in this case is a hit of measured values in the area of the lower measuring range of measuring instruments of ETB and, as a consequence, the output of errors of their measurement beyond the limits of established by standards [3.37, 3.38]. Therefore, the parameters of the diesel engine and DPF for the modes from the list of toxicity regulations obtained in the study of polynomials derived when describing by the linear regression method of the results of motor tests, in which registered the following characteristics of a diesel engine: the external speed, the loading with the engine speed of maximum torque mode, the loading with the engine speed of nominal power mode and the characteristic of idling [3.42, 3.43].

3.4.1.3. The approach to comparative tests of various designs of diesel particulate matter filters

These tests were carried out as part of the exhaust system of ETB in order to obtain DPF working characteristics by registering one external speed characteristics of diesel engine that has the following features [3.42, 3.43]:

– exhaust gas flow along it (the exhaust gas mass flow rate per unit of the characteristic section of the experimental sample) changes in the most widely for diesel;

– it contains a maximum torque mode, which is usually observed global minimum air excess factor α in the diesel engine operating conditions (the so-called "smoke limit" at α equal to 1.3) and, as a result, the global maximum exhaust smoke. Also on this mode there is a global maximum of EG temperature. It is also important that on this mode at the absence of autotractor diesel engine electronic control systems, the rest of his work parameters agreed to achieve global minimum specific fuel consumption;

– it contains a diesel engine nominal power operating mode, in which there is a global maximum weight hourly fuel consumption;

– on its mode EG temperature is changed in range that sufficient for prediction it depending on operating characteristics of the experimental sample.

3.4.2. Classification of gravimetric methods for determination of particulate matter mass emission in exhaust gas flow of diesel internal combustion engines

Requirements for ecological indicators of the vehicle PICE fixed legislatively [3.40, 3.1, 1.11]. Among the legally normed pollutants in EG of diesel PICE (carbon monoxide (CO), unburned hydrocarbons of motor fuel and oil (C_nH_m), nitrogen oxides (NO_x) and particulate matter (PM)), 2nd place after NO_x according to reduced toxicity occupy PM [3.1, 3.42]. So, existing UNECE Regulation № 49 and № 96 [3.40, 3.1] contain the maximum level of average operating mass emissions of PM with the diesel PICE EG flow, the method and requirements for measuring equipment for its experimental determination, the list and parameters of diesel engine operating conditions at steady test cycle [3.40,3.1]. The levels of these requirements and the dynamics of their alterations from the review [1.11] reflects the Fig. 3.3. PM is dispersed phase of EG aerosol in which in according with definition from the [3.40, 3.1] include all substances which deposited on special Teflon filter, through which passes the EG probe, diluted with clean air in certain ratio, at temperature is not above 52 °C and are not water. Main manners for PM mass emission determination in EG flow as well as some other EG aerosol characteristics and also PM by itself, by used methods is expedient to divide into the followings [2.2, 1.11]:

1) optical;
2) gravimetric;
3) experimentally-estimated;
4) estimated.

Operational principle of such measurement instruments as “Dilution tunnels” is grounded on gravimetric methods [2.2, 1.11]. They operational principle is to search the difference between weight of clean Teflon filters and same specifically prepared filters (stabilized – dried at certain temperature and during certain period of time) through which passed specifically prepared EG sample (cooled and diluted once or twice in a certain ratio by clean atmospheric air to simulate the PM scattering process in the atmosphere), which taking through isokinetic sampler from particular location of EG flow in diesel exhaust system or imitating it dilution tunnel.

From the value of part of the exhaust gas flow into the dilution tunnel such measurement instruments are divided into:

a) full-flow (whole diesel engine EG flow) dilution tunnels;
b) partially-flow (some representative of diesel engine EG flow) dilution tunnels.

Partially-flow tunnels are divided into (overall dimensions of the tunnels differs in three times):

a) mini dilution tunnels;
b) micro dilution tunnels.

Principal schemes of internal structure and samples taking in mini and micro dilution tunnels, developed by domestic scientists, is shown in Fig. 3.5 [3.44]. External view of Teflon filters, which were used in study

[1.14] of PM mass emission with EG flow of autotractor diesel SMD-23, stabilized and weighted is shown in Fig. 3.6.

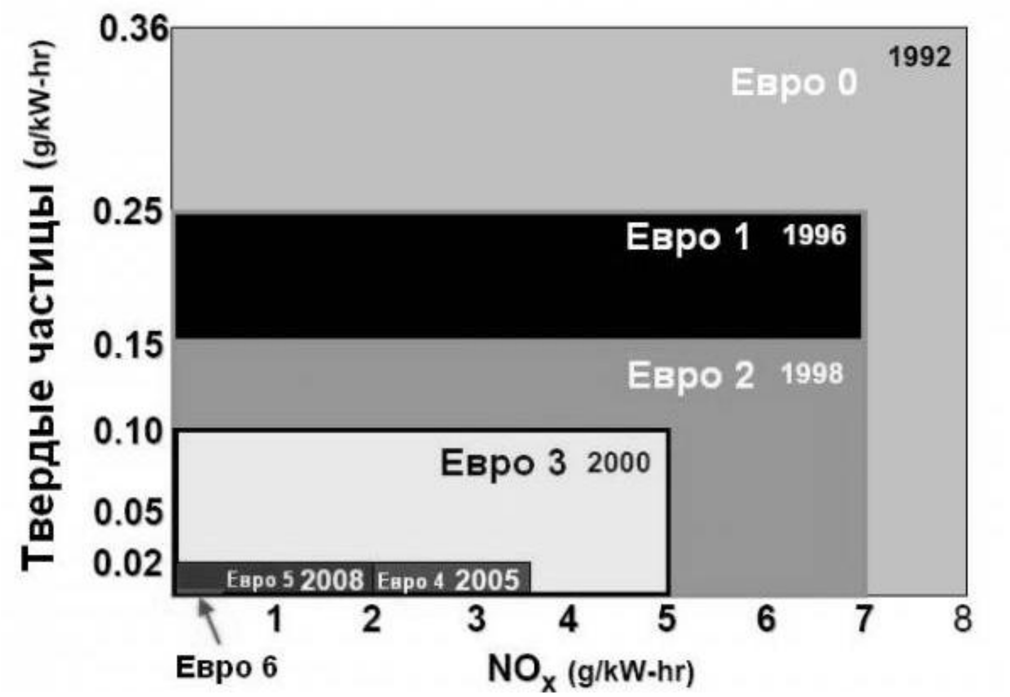
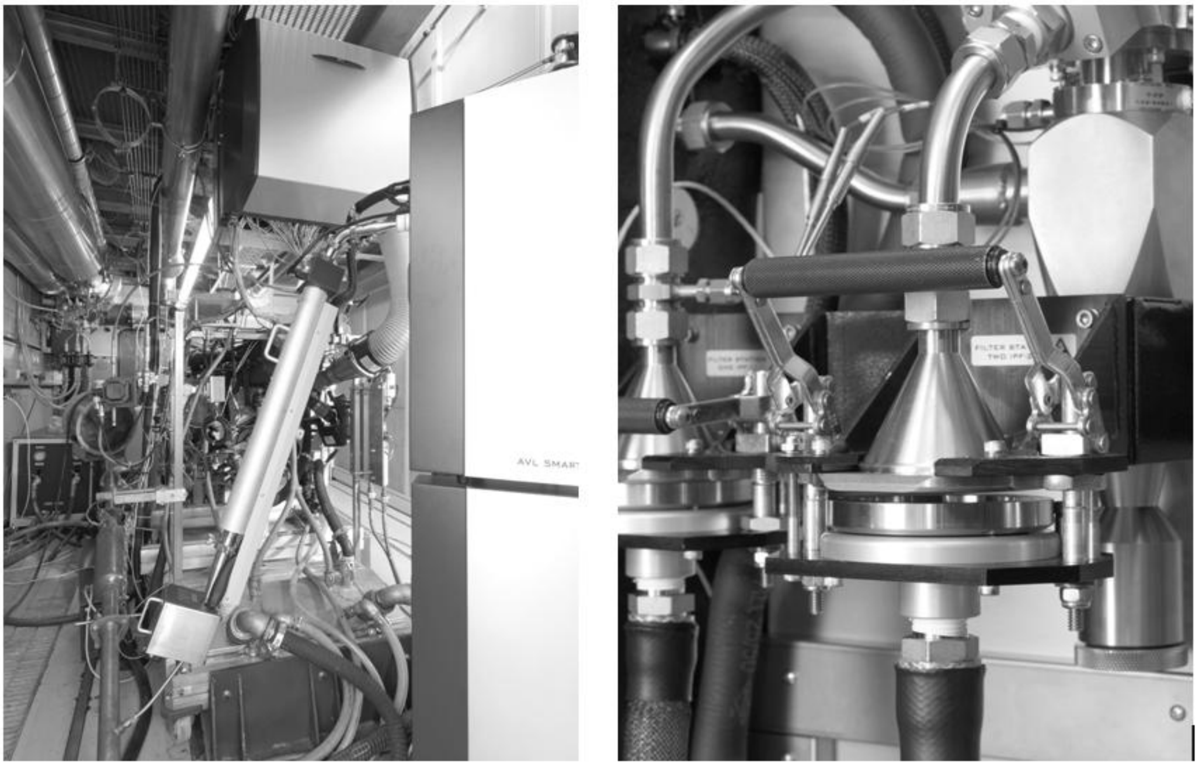


Fig. 3.3 – Legislative established requirements for diesel PICE ecological indicators, in particular average operating mass emissions of PM and NO_x with the its EG flow [1.11] (in the original language)



a b

Fig. 3.4 – External view of partially-flow tunnel which manufactured by AVL company (a) and its filterholder (b) [3.46]

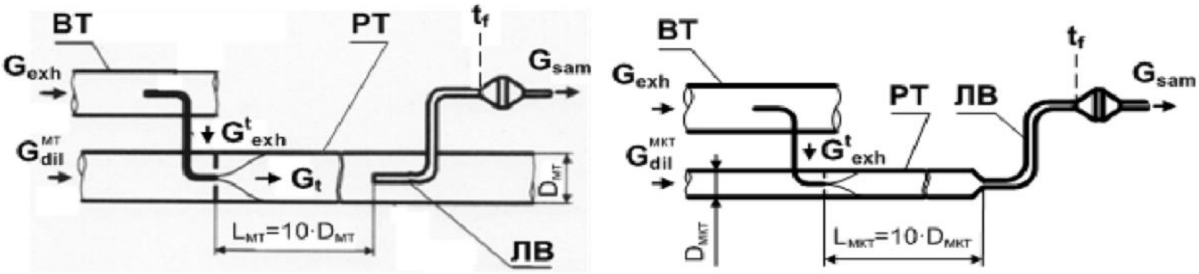


Fig. 3.5 – Schemes of mini- (a) and micro-tunnel (b) [3.44]

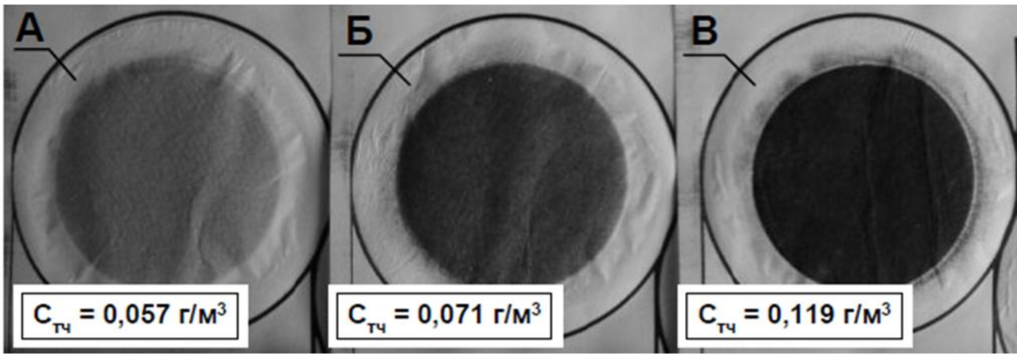


Fig. 3.6 – External view of stabilized and weighted Teflon filters, which used in study of PM mass emission with diesel EG flow [3.45]
(in the original language)

World leader in designing and manufacturing of full- and partially-flow dilution tunnels is Austrian company AVL [3.44, 3.46]. But cost of its products is about hundred thousands US dollars (for partially-flow models) an up to about million US dollars (for full-flow models). External view of partially-flow dilution tunnel, which manufactured by AVL company and its filterholder (allonge) [3.46] is shown in Fig. 3.4.

Thus, in these section of paper vas reviewed such measuring instruments for experimental determination of PM mass emission with diesel PICE EG flow as dilution tunnels, both of foreign and of domestic manufacturing.

3.4.3. Classification of optical devices for particulate matter content in internal combustion engines exhaust gas determination

One of the transport problems are the emissions of PM from the exhaust gases of the piston internal combustion engine of vehicles, both on urban and regional levels.

The main methods for determining the mass emissions of PM from diesel EG flow as well as some other parameters of aerosol "EG – PM" and proper PM according to used methods should be divided into the following [2.2, 3.47]:

1) Optical;

2) Weight;

3) Experimentally-calculated;

4) Settlement.

On use of optical methods relies on such devices [2.2, 3.47]:

1. Instruments for measuring optical density EG (Hartridge type opacimeters). They measure the absorption luminous flux coefficients K (m^{-1}, K = 0...∞) and luminous flux weakening coefficients N_D (in %, N_D = = 1...100) of cooled EG sample column (layer) of light signal (luminous flux) with known parameters, which passed through the EG sample from the calibrated light source, by the photosensitive element that signal recorded by device. With this method, the EG sample selected or from diesel exhaust tract by probe tube (in partially flow devices) or directly from diesel exhaust system outlet cut (in full flow devices).

2. Devices of Laser Digital Holography. They are based on the use of perspective principle which provides EG sample column scanning with a laser beam that hits the high speed photosensitive pixel electronic matrix, if not reflected from the PM (dissipated). Information from the matrix processed by a computer, based on what is built hologram by interference method. In analyzing of this diagram are defined diameter, weight and volume of PM and distribution of these indicators their quantity.

3. Devices of exhaust filtration method (Bosch type opacimeters). Principle of their work based on by passage samples of VG of certain volume through a special Teflon or paper filter and further determine its degree of blackness by an optical method – or visually (compared to the benchmark), or through photometer (shows or register parameters or reflected from the filter surface light flow from calibrated source) or by special graphics software to work with images that are scanned of stabilized filters.

3.4.4. Classification of instruments for determination of gaseous pollutants concentrations in internal combustion engine exhaust gases

EG of PICE consists of within from 200 to 2000 chemical compounds, but only 5 mass % of it are toxic. Among all of harmful substances in EG (pollutants) legislation normalized following four: unburned hydrocarbons of motor fuel and oil C_nH_m, nitrogen oxides NO_x, carbon monoxide CO, particular matter PM. In diesel EG for in total toxicity prevailing PM (they contain also C_nH_m) and NO_x, in EG of petrol PICE – C_nH_m and CO, and for uprated engines – also NO_x[1.11].

Quantitative and qualitative content of gaseous pollutants in PICE EG examined by special devices – multicomponent gas analyzers (MCGA) [3.47, 3.48]. By purpose they may be of the following types:

– automatic – for industrial purpose;

– manual – for laboratory research and controlling the EG composition in the operating conditions.

MCGA by the principle of operation is divided into groups:

1) chemical (volumetric-manometrical);

2) based on physical or physic-chemical methods;

3) physical.

Chemical MCGA measure volume or pressure of the gas mixture by the chemical reaction of its components.

MCGA, based on physical or physic-chemical methods, by the principle of operation is divided into:

– chromatographical;

– thermochemical;

– photocolometrical;

– electrochemical.

Physical MCGA is divided into:

– thermoconductometrical;

– magnetical;

– optical;

– dencimetrical.

Chromatographical MCGA by the measuring methods can be divided into:

– displacerical;

– frontal;

– development.

Thermochemical MCGA measure the temperature effect of exothermic redox catalytic reaction by thermistor.

Photocolometrical MCGA define the gas mixture components with the light absorption from a calibrated source and is divided into:

– fluid type;

– tape type.

Electrochemical MCGA define the gas mixture components with the electrical phenomena caused by the reaction of a chemical agent to a specific mixture component and is divided into:

– galvanical – records the changing in electric conductivity;

– electric-conductometrical – records changing in electric current or voltage;

– potentiometrical – record the change in intensity of electromagnetic field and active ions.

Thermoconductometrical MCGA measure the change in qualitative and quantitative gas mixture composition with change in its thermal conductivity by thermistor and compare them with the pattern.

Magnetical MCGA measure the Ampere force which on measuring device rotor in inhomogeneous magnetic field and is divided into groups:

– thermomagnetical;

– magneticmechanical.

Optical MCGA measure the change in optical properties of gas mixture – optical density, spectral emission or refractive index, and is divided into:

– ultraviolet;
– infrared;
– spectral-photometrical;
– interferometrical.

MCGA by form factor is divided into:

– stationary;
– portative;
– transportable.

Now the most common are optical and electrochemical MCGA, and in the analysis of the content of regulated pollutants in the exhaust gas piston PICE – mainly optical [3.47, 3.48].

3.4.5. Fire safety of engine bench researches

Experimental comparative study of performance of various grades of motor fuels and oils, petroleum and alternative (biodiesel, benzoehtanols, various combustible gases), carried out on engine benches.

In addition, these benches consist of the following components:

– piston internal combustion engine of the appropriate type;
– load device (electrical, hydraulic or mechanical brake);
– transmission of the stand;
– stand control system;
– system of measuring equipment;
– base frame.

Each of these components is characterized by definite indicators of fire safety [1.11]. Special attention should be PICE himself and measurement system of hourly mass fuel consumption.

The system includes the following substances:

– motor fuel (with pressure up to 200 MPa);
– motor oil (with pressure up to 0,5 MPa and temperature up to 150 °C).

Motor fuel is a highly-flammable volatile liquid or gaseous substance, which exothermic redox reactions with oxygen of air and emits heat energy, which of this type of heat engine, like diesel PICE, converts into mechanical work. The engine oil is a flammable volatile liquid which circulates in engine lubrication system and provides a mode of fluid friction in the engine, cooling its details and takeaway products they wear.

Exhaust system of diesel PICE contained follow harmful components: toxic exhaust gasses, engine solid parts and parts (both with temperatures up to 1000 °C), vapor of unburned fuel.

Ignition system (if any) and the launch engine system contain electrical circuits with high voltage and current capable of producing of electrical sparks and arcs.

3.4.6. Conclusions

Thus, in present study described results analysis of issues of problems of particulate matter mass emission in diesel exhaust gases experimental determination, creation of classifycations of gravimetric methods and optical devices for determination of particulate matter mass emission and instruments for determination of gaseous pollutants concentrations in exhaust gas flow of diesel internal combustion engines, aspects of fire, technogenic and ecological safety of engine bench researches.

3.5. METROLOGICAL MAINTENANCE OF EXHAUST GAS SAMPLING SYSTEM OF ENGINE TEST BENCH AS AN OBJECT OF RESEARCHES [A.3.16]

Introduction. As well known, the main porpoise of any kind of scientific researches is a creation of newest intellectual product of fundamental of applied nature, which characterized by scientific novelty, originality and practical value. At the same time in this segment of life cycle it passes the stage of experimental studies of physical processes that form the basis of its functioning and also its operational characteristics as a finished product. Often, the programs of these studies and implement goals and objectives of so-called “pioneer” scientific research works for studying of “white spots” in specific fields of knowledge, that is the essence of scientific research. The implementation of such researches related with developing of appropriate programs and methods, designing and manufacturing of experimental samples and also creating and improvement of appropriate laboratory equipment – benches, plants, measuring instruments and etc. That means, objects of laboratory equipment are unique but designed for implementation of the widest possible range of experiment programs.

It also well known, that no changes can not be executed absolutely precisely and in any case contain some errors. We can only reliably determine its magnitude, which determines the value of obtained data [3.49]. That’s why scientific works aimed at identification and analysis of metrological aspects of creation of new and modernization of existing laboratory equipment are relevant because accuracy of direct and indirect measurements has influence on clarity of the modern world view.

Purpose of the study is description of structure and construction of modernized exhaust gases (EG) toxicity and smokiness sampling system of engine test bench (ETB) of laboratory of Department of Power Piston Plants(DPPP) of A.N. Podgorny Institute for Mechanical Engineering Problems of National Academy of Science of Ukraine (IPMash of NASU) for its following analysis as a metrological system [3.43].

The scheme of modernized exhaust system of ETB shown on Fig. 3.7 and its external view – on Fig. 3.8 [3.43, 3.36]. Options of measurement equipment of ETB summarized in Table 3.1, data in which taken from sources [3.36 – 3.38, 3.51 – 3.63].

Statement of problem of the study and it solving. In DPPP vas developed modular diesel particulate matter filter (DPF) with new non conventional design and bulk natural zeolite in stainless steel mash cassettes – DPF IPMash.

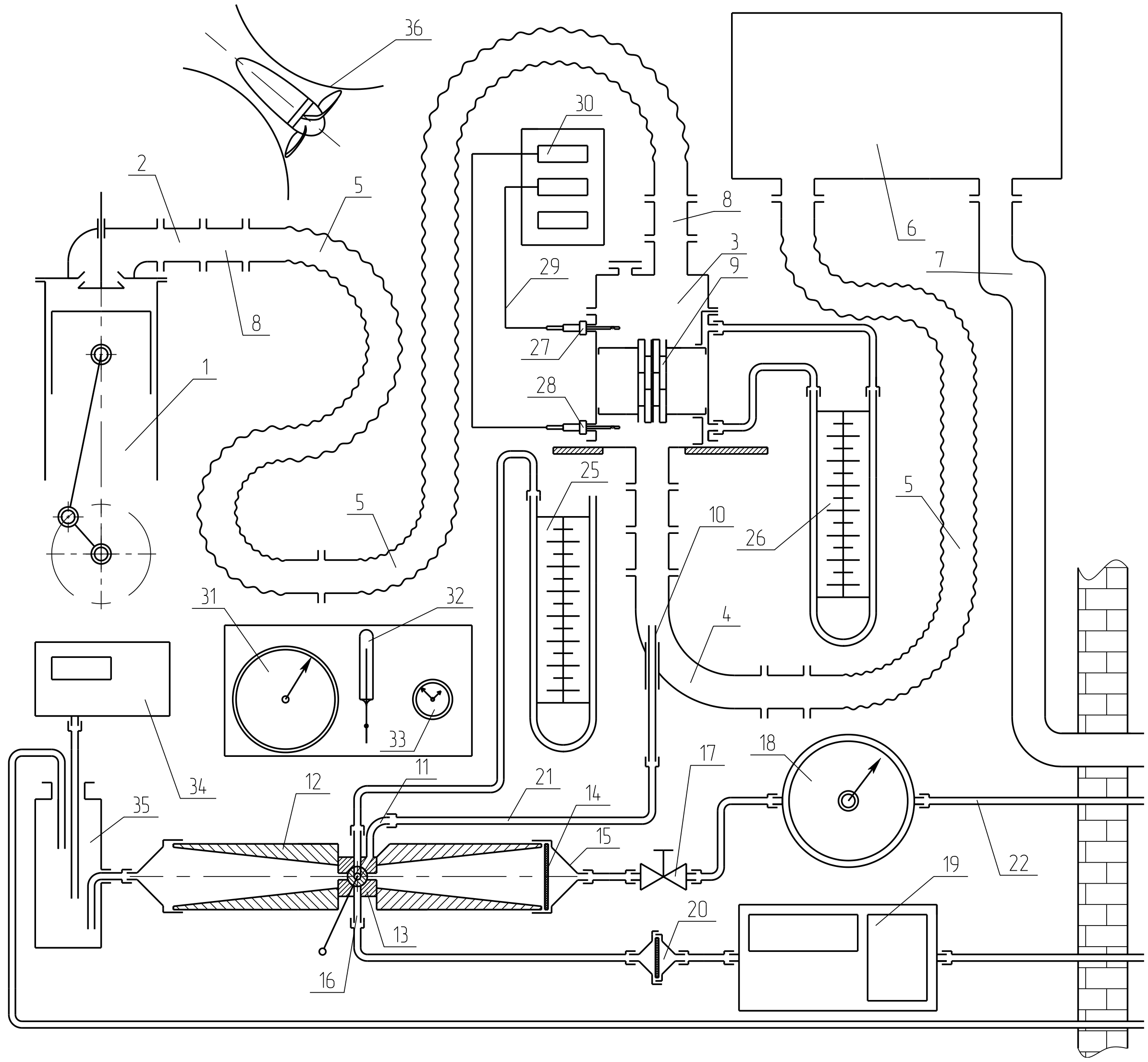
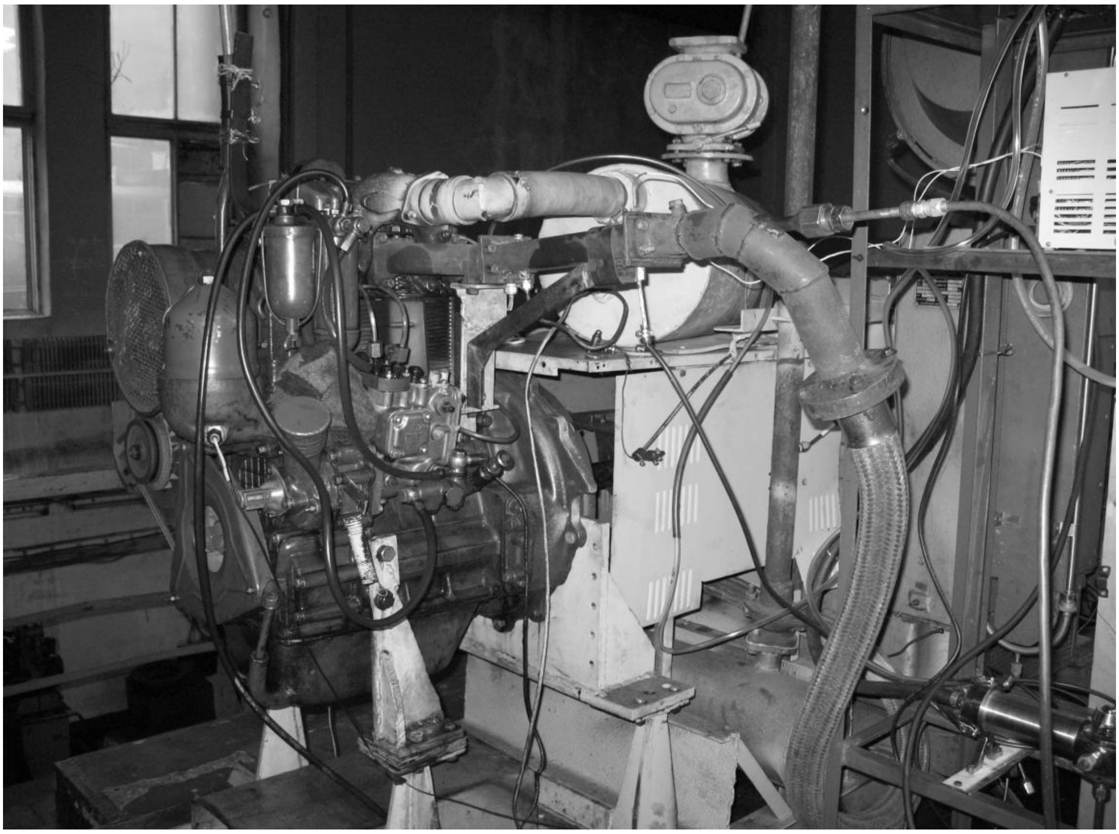
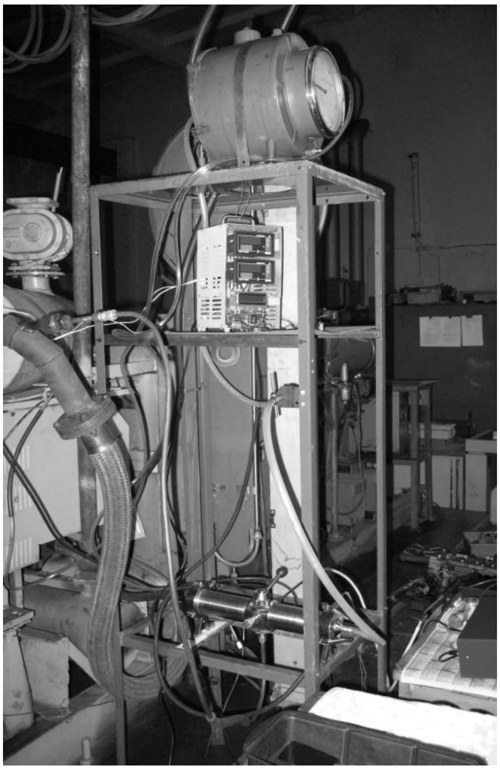


Fig. 3.7 – Scheme of EG sampling system of ETB:

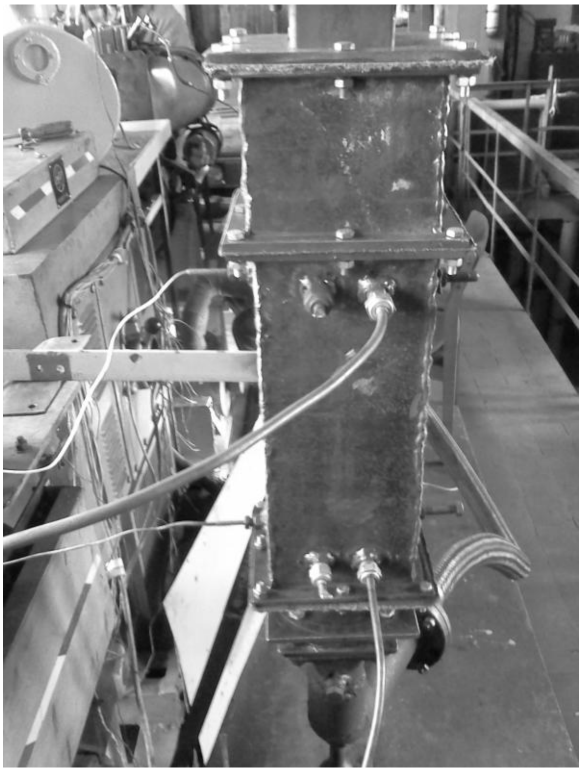
1 – diesel engine 2Ch10.5/12; 2 – diesel exhaust collector; 3 – insertion for experimental DPF samples; 4 – angled EG pipeline; 5 – flexible heat resistant EG pipelines; 6 – EG noise muffler; 7 – exhaust pipeline; 8 – adapters; 9 – operating sample of FE DPF; 10 – sample probe; 11, 12, 13, 15, 16 – intake fitting, cone, four way valve, cap and exhaust fitting of allonge; 14 – exchangeable filter; 17 – adjusting valve; 18 – gas flowmeter; 19 – five-component gas analyzer AUTOTEST-02.03.P; 20 – protective covering with holder; 21 – connection gas pipeline; 22, 23, 24 – outdoor gas pipeline; 25, 26 – differential U-shape hydraulic manometers; 27, 28 – thermometric sensors TKhA; 29 – electrical cord; 30 – appliance OVEN TRM-200; 31 – barometer-aneroid BAMM-1M; 32 – mercury thermometer; 33 – timer; 34 – opacitymeter INFRAKAR-D, 35 – measuring receiver (6,36 l); 36 – air pump



a



b



c

Fig. 3.8 – Modernizing exhaust system of ETB equipped with insertion for DPF operating samples and EG toxicity and smokiness sampling system:
а – general external view, б – stand with measuring instruments,
в – insertion box for DPF operating samples

Table 3.1 – Measuring equipment of ETB and its parameters

Name, designation of the measured parameter and its units	Limits and diapasons of measuring	Measuring instrument
Frequency of rotation of engine crankshaft and motor-generator rotor, n, min^{-1}	0 – 5000 800 – 1800	Measuring complex IDS-742 4/N or mark of TDC and five-ways gas analyzer Avtotest-02.03.P
Torque of engine, M, N·m	0 – 250 0 – 120	Measuring complex IDS-742 4/N with mechanical weight dynamometer
Time of consumption of diesel fuel weighed portion, τ, s	0 – 10000 0 – 600	Scales of 1st accuracy class and weighted portion and electrical hydraulic automatic valve for fuel refilling and optical sensor and frequencymeter-chronometer F-5041
Volume consumption of air, V_{air}, m^3/h	5 – 120 30 – 100	Gas counter RG-100 and frequencymeter-chronometer F-5040
Drop of intake air pressure, ΔP_{int}, mm w.col.	0 – 1200 0 – 300	Throttling washer and differential manometer type DM
Drop of exhaust gases pressure, ΔP_{exh}, mm w. col.	0 – 1500 0 – 300	Differential manometer type DM
Exhaust gas temperature, t_{exh}, °C	-50 – 1400 20 – 700	Device A566 and thermocouple type K
Engine oil temperature, t_{oil}, °C	-50 – 180 40 – 100	Sensor TM-100V and device A565 or sensor and five-ways gas analyzer Avtotest-02.03.P
Engine fuel temperature, t_{fuel}, °C	-50 – 180 10 – 40	Device A566 and sensor type 10011
Intake air temperature, t_{air}, °C	0 – 50 5 – 40	Mercury laboratory thermometer TL-4
Environment air temperature, t_0, °C	0 – 50 0 – 35	– // –
Environment air pressure, B_0, kPa	80 – 106 90 – 104	Aneroid barometer BAMM-1M
Relative air humidity, φ_0, %	0 – 100 0 – 100	Psychrometer
NO_x volume concentration in exhaust gas, C_{NOx}, ppm	0 – 5000 0 – 3000	Five-ways gas analyzer Avtotest-02.03.P
CO volume concentration in exhaust gas, C_{CO}, %	0 – 5 0 – 2	Five-ways gas analyzer Avtotest-02.03.P
O_2 volume concentration in exhaust gas, C_{O_2}, %	0 – 21 0 – 10	Five-ways gas analyzer Avtotest-02.03.P
CO_2 volume concentration in exhaust gas, C_{CO_2}, %	0 – 16 0 – 5	Five-ways gas analyzer Avtotest-02.03.P
C_nH_m volume concentration in exhaust gas, C_{CH}, ppm	0 – 2000 0 – 150	Five-ways gas analyzer Avtotest-02.03.P
Linear dimensions of experimental samples, l, mm	0 – 500 1 – 250	Caliper ShC-1 and locksmith ruler
Samples taking time, τ_{samp}, s	0 – 60 15 – 50	Timer SOSpr-2a
Opacity of exhaust gas: – weakening of light flow coefficient, N_D, %; – absorption of light flow coefficient, K, m^{-1}	0 – 100 10 – 75; 0 – ∞ 0 – 5	Exhaust gas sampling taker and Teflon filter in holder or opacitymeter INFRAKAR-D

Several variations of that DPF construction embodied in form of operating experimental samples of its filter element (FE). Its working characteristics under real exploitation conditions vas studied on ETB [3.43]. ETB is a complex system of interrelated power plants and its structure and features of work described in [3.36].

For executing a bench motor researches of DPF IPMash the exhaust system of ETB vas modernized by adding to it a place for FE operating samples (insertion box for samples (IBS)) and the new EG sampling and EG flow thermodynamic parameters, toxicity and smokiness measuring systems [3.43,3.36].

The tests executing in accordance with programs and methodics of DPPP and also GOST 18509-88 and GOST 14846-87 [3.37, 3.38], in which contains requirements for accuracy of measuring of some physical quantities.

Programs of the study developed on basis of standardized test 13- and 8-mode stationary cycles that are models of exploitation of automotive and tractor diesel engines respectively and are described in UNECE Regulations # 49 and # 96 [3.40, 3.1]. They were adapted to possibilities of equipment of DPPP laboratory by the way that described in [3.43, 3.36].

The methodic of obtaining of errors of direct and indirect measuring of mode parameters diesel engine operation, EG gas dynamic parameters, EG toxicity and smokiness parameters on ETB will be object of following studies.

A variety of measuring instruments on the bench allows us to conclude of rational use of the mathematical apparatus of the beta distribution as described in [8], to evaluate the measurement errors.

Conclusions. In present paper was considered structure, construction and features of EG toxicity and smokiness sampling system of ETB of DPPP IPMash NASU laboratory as a metrological system.

In following studies will be developed and described the method of obtaining of direct and indirect measuring errors of regime parameters of diesel engine, EG gas-dynamic parameters, EG toxicity and smokiness parameters on ETB.

3.6. REFERENCES

3.1. Regulation № 96. Uniform provision concerning the approval of compression ignition (C.I.) engines to be installed in agricultural and forestry tractors with the regard to the emissions of pollutants by the engine. Geneva, 1995. – 109 p.

3.2. D.E.W. Controlling Automobile Emissions / D.E.W. // Platinum Metals Review. – 1991. – № 35 (2). – pp. 94 – 95.

3.3. C.J., R.D.O'S. Advances and Developments in Emissions Control. A review of the 1992 SAE International Congress / C.J., R.D.O'S. //

Platinum Metals Review. – 1992. – № 36 (2). – pp. 86 – 89.
3.4. C. J. Substantial Emissions Control Progress to Meet Future Legislation. Selective report of the 1994 International SAE Congress / C. J. // Platinum Metals Review. – 1994. – № 38 (2). – pp. 57 – 59.
3.5. D.E.W. Progress in Emission Control Technology. A selective report of the SAE Detroit Meeting / D.E.W. // Platinum Metals Review. – 1995. – № 39 (2). – pp. 73 – 74.
3.6. Twigg M.V. Emission Control Technology: Progress Reported at the Spring SAE Conference / M.V. Twigg // Platinum Metals Review. – 1996. – № 40 (3). – pp. 110 – 111.
3.7. Twigg M.V. Emission Control Technology at Detroit. A selective report from the 1997 SAE Annual Congress / M.V. Twigg // Platinum Metals Review. – 1997. – № 41 (2). – pp. 76 – 78.
3.8. Twigg M.V., Emission Control Technology at Detroit: A Selective Report from the 1998 SAE Annual Congress / M.V. Twigg // Platinum Metals Review. – 1998. – № 42 (2). – pp. 56 – 59.
3.9. Twigg M.V. Developments in Emission Control Technology / M.V. Twigg // Platinum Metals Review. – 1999. – № 43 (1). – p. 28.
3.10. Twigg M.V. Aftertreatment for Low Emission Vehicle: A Selective Report from the 1999 SAE Annual Congress / M.V. Twigg // Platinum Metals Review. – 1999. – № 43 (3), – pp. 119 – 121.
3.11. Twigg M.V. Advanced Exhaust Emissions Control. A selective review of the Detroit 2000 SAE World Congress / M.V. Twigg // Platinum Metals Review. – 2000. – № 44 (2). – pp. 67 – 71.
3.12. Twigg M.V., Exhaust Emissions Control Developments: A selective review of the Detroit 2001 SAE World Congress / M.V. Twigg // Platinum Metals Review. – 2001. – № 45 (2). – pp. 71 – 73.
3.13. Twigg M.V. Vehicle Emissions Control Technologies / M.V. Twigg // Platinum Metals Review. – 2003. – № 47 (1). – pp. 15 – 19.
3.14. Twigg M.V. Automotive Exhaust Emissions Control / M.V. Twigg // Platinum Metals Review. – 2003. – № 47 (4). – pp. 157 – 162.
3.15. York A.P.E. 2007 Fuel and Emissions Conference: A selective report on the SAE International Conference / A.P.E. York // Platinum Metals Review. – 2007. – № 51 (3). – pp. 145 – 149.
3.16. Johnson T. SAE 2008 World Congress: Vehicle emissions technology highlights from the SAE Annual International Congress / T. Johnson // Platinum Metals Review. – 2008 – № 53 (1). – pp. 37 – 39.
3.17. Johnson T.V. SAE 2009 World Congress: Key developments in diesel emissions control and catalysis / T.V. Johnson // Platinum Metals Review. – 2009. – № 54 (1). – pp. 37 – 43.
3.18. Johnson T.V. SAE 2010 World Congress: Diesel emissions control highlights of the annual Society of Automotive Engineers (SAE) International Congress / T.V. Johnson // Platinum Metals Review. – 2010. – № 54 (4). – pp. 216 – 222.
3.19. Strokov A.P. and etc. (2010 – 2013), “Scientific and technical

basis for improving the economic and ecological indicators of power plants with ICE by developing a new structural schemes and improving the methods of use of alternative motor fuels. Research report (final)", Kh.: IPMash NASU, 386 p.

3.20. Skljarov N.V. (2011). "Analysis of the problems of improving of autotechnical expertise of road accidents". Automobile transport: collection of scientific papers, no. 29, pp. 250 – 254.

3.21. Dealers Pre-Owned Cars Association (2010), "Pre-Owned Car Market in Ukraine. An independent study of Dealers Pre-Owned Cars Association", [Electronic resource], Access mode: www.sprobegom.ua.

3.22. Information-analytical group AUTO-Consulting (2010), "Ukrainian vehicle fleet began to grow old", [Electronic resource], Mode of access: http:// www.autocon sulting.ua/news.php?catid=16.

3.23. Kim S., Dale B. (2004), "Global potential bioethanol production from wasted crops and crop residues", Biomass and Bioenergy, Vol. 26, pp. 361 – 375.

3.24. Avramenko A.M. (2012), "Doslidjenn'a procesu prygotuvann'a benzoetanolu z vykorystann'am laboratornogo gidrodynamichnogo kavitatora" [Research of bioethanol preparation process using hydrodynamic laboratory cavitator], Modern problems of mechanical engineering: Abstracts of young scientists and specialists conference of AM Podgorny IPMash NASU, November, 5 – 8, pp. 48.

3.25. Bgantcev V.N., Kireeva V.N. (2013), "Issledovanuje korrozionnoj aktivnosti benzoetanolov razlichnogo sostava, poluchennyh s ispol'zovanijem novyh tehnologij" [Research of corrosion activity of different composition benzoethanols obtained by using new technologies], Herald of KhNADU, Vol. 60, pp. 118 – 122.

3.26. Levterov A.M., Levterova L.I., Gladkova N.Ju., Marakhovsky V.P., Avramenko A.M. (2012), "Raschetno-eksperimental'nyje issledovanija harakteristik avtomobil'nogo dvigatel'a na benzoetanol'nyh smes'ah" [Computational and experimental studies of the characteristics of automobile engine on benzoethanol mixtures], Herald of NTU "KhPI", Issue 27, pp. 107 – 113.

3.27. Marakhovsky V.P., Avramenko A.M. (2013), "Pokaznyky roboty avtomobil'nogo dvyguna na benzoetanoli riznogo skladu" [Performance indicators of automotive engine on benzoethanol of various composition], Automotive transport, Issue 32, pp. 29 – 35.

3.28. Bgantcev V.N. (2014), "Osnovnyje napravlenija adaptacyi transportnyh dvigatelej k benzospirtovym toplivam" [The main directions of adaptation of transport engines to the gasoline-alcohol fuels], Automotive transport, Issue 35, pp. 110 – 113.

3.29. Kondratenko A.N., Strokov A.P., Karasichenko N.M. (2013), "Experimental study of the working layout of the filter element of particulate matter filter for diesel engine with bulk natural zeolite. Part 1", Internal Combustion Engines: the All-Ukrainian Scientific and Technical Magazine, Kharkiv, Publ. NTU “KhPI”, no. 1, pp. 88 – 92.

3.30. Kondratenko A.N., Strokov A.P., Khozhainov S.P. (2013), “Experimental study of the working layout of the filter element of particulate matter filter for diesel engine with bulk natural zeolite. Part 2”, Internal Combustion Engines: the All-Ukrainian Scientific and Technical Magazine, Kharkiv, Publ. NTU “KhPI”, no. 2, pp. 92 – 97.

3.31. Kondratenko A.N. (2014), “Using DPF as a spark arrestor for exhaust system of transport vehicle” [Ispol’zovanije FTCh dizelej v kachestve iskrogasitelej vypusknoj sistemy avtotransportnogo sredstva], Chrezvychajnyje situacyi: teorija, praktika, innovacyi: materially Mezhdunar. nauch.-prakt. konf. (May, 22 – 23), Gomel’, Publ. P.O. Sukhoy GGTU, pp. 221 – 222, Print, In Russian.

3.32. Kondratenko A.N., Pluzhnichenko D.A. (2014), “Aspects of fire safety of exploitation of particulate matter filters of diesel” [Aspekty pozharnoj bezopasnosti ekspluatacyi fil’trov tverdyh chastic dizelej], “Pozharnaja bezopasnost’: problemy i perspectivy”: sb. st. po materialam V Mezhdunar. nauch.-prakt.konf.: v 2 chast. Chast’ 1. (September, 18 – 19), Voronezh, Publ. FGBOU VPO Voronezhskij in-t GPS MChS Rossii, pp. 267 – 269, Print, In Russian.

3.33. Vambol’ S.O., Strokov O.P., Kondratenko O.M. (2014), “Stendovi vyprobuvann’a avtotraktornogo dyzelja 2Ch10.5/12 za standartyzovannymy cyklamy dlja vyznachenn’a efektyvnosti roboty FTCh” [Bench researches of autotractor diesel engine 2Ch10.5/12 on standardized cycles for determination of operational efficiency of DPF] [Text], Herald of National Technical University“KhPI”. Collection of scientific works. Series: Automobile- and Tractor Production, Kharkiv: NTU “KhPI”, no 10 (1053), pp. 11 – 18. [in Ukrainian].

3.34. Measuring complex IDS-742-4/N. Users guide PP478,PP932.

3.34. Efros V.V. and etc. (1976), “Dizeli s vozdushnym ohlazhdenijem Vladimirskogo traktornogo zavoda” [Diesel engines with air cooling of Vladimir Tractor Plant] [Text], Moscow: Mashinostrojenije, 277 p. [in Russian].

3.36. Strokov A.P. and etc. (2011), “Razrabotka malozatratnoj tehnologii i avtomatizirovannoj sistemy ochistki otrabotavshyh gazov dizelja ot tverdyh chastic. Otchet o NIR (zakljuchitel’nyj)” [Development of low-cost technology and automatical system for purification of exhaust gases of diesel engine from particulate matters. Scientific research report (final)] [Text], SR no. 0111U001 762, Kharkov: IPMash NASU, 131 p. [in Russian].

3.37. GOST 18509-88, (1988), “Dizeli traktornye i kombajnovyje. Metody stendovyh ispytanij” [GOST 18509-88. Diesel engines of tractors and combines Methods of bench testing] [Text], Moscow: Izd-vo standartov, 78 p. [in Russian]

3.38. GOST 14846-87 (1987), “Dvigateli avtomobil’nyje. Metody stendovyh ispytanij” [GOST 14846-87. Automotive engines. Methods of bench testing] [Text], Moscow: Izd-vo standartov, 42 p. [in Russian].

3.39. Zaporozhec’ I.O., Protojerejs’kyj O.S., Franchuk G.M., Borovyk I.M. (2009), “Osnovy ohorony praci: pidruchnyk” [Basis of occupational safety: textbook] [Text], Kyiv: Tsentr uchbovoi’ literatury, 264 p. [in Ukrainian].

3.40. Regulation № 49. Revision 5. Uniform provision concerning the approval of compression ignition (C.I.) and natural gas (NG) engines as well as positive ignition (P.I.) engines fuelled with liquefied petroleum gas (LPG) and vehicles equipped with C.I. and NG engines and P.I. engines fuelled with LPG, with regard to the emissions of pollutants by the engine. – United Nations Economic and Social Council Economics Commission for Europe Inland Transport Committee Working Party on the Construction of Vehicles. – E/ECE/TRANS/ 505. – 4 May 2011. – 194 p.

3.40. Kondratenko A.N., Vambol’ S.O., Stel’makh A.S. (2015), “Faktory opasnosti eksperimental’nyh issledovanij na motornom ispytatel’nom stende. Chast’ 1” [Danger factors experimental studies on the engine test bench. Part 1], Technologies of Technospheric Safety: Internet Journal, Moscow, Publ. State Fire Academy of Emercom of Russia, issue 2 (60), pp. 1 – 6. [Electronic resource], Access mode: http://ipb.mos.ru/ttb/2015-2. [in Russian].

3.42. Kondratenko O.M., Strokov O.P., Vambol’ S.O., Bgantcev V.M. (2014), “Osoblyvosti vyznachenn’a masovogo vykydu tverdyh chastynok u vidprac’ovanyh gazah dylel’a” [Features of determining particulate matter mass emissions in the diesel exhaust gases], Automotive transport, no. 2 (33), pp. 99 – 102. [in Ukranian].

3.43. Vambol’ S.O., Strokov O.P., Kondratenko O.M. (2014), “Stendovi vyprobuvann’a avtotraktornogo dyzel’a 2Ch10.5/12 za standartyzovanymy cyklamy dl’a vyznachenn’a efektyvnosti roboty FTCh” [Bench testing of autotractor diesel engine 2Ch10.5/12 by standardized cycles to determine the effectiveness of FTCh], Herald of NTU “KhPI”, Series: Automotive and Tractor Building, no. 10 (1053), pp. 11 – 18. [in Ukranian].

3.44. Polyv’janchuk A.P. (2013), “Science and practical foundations for improving the efficiency of determining of particulate matter emission from diesel exhaust gases: thesis… Dr.Sci.(Tech.), 05.05.03 – engines and power plants” [Naukovo-praktychni osnovy pidvyshchennya efektyvnosti vyznachennya vykydiv tverdykh chastynok z vidprats'ovanymy gazamy dyzelya: dys. ... d-ra tekhn. nauk: 05.05.03 – dvyhuny ta enerhetychni ustanovky] [Text], Lugans’k, Dahl’ East-Ukrainian National University, 311 p. [in Russian].

3.45. Kholkina E.A. (2015), “Experimental study of model sample of microtunnel MKT-2 on motor test bench autotractor engine” [Eksperimental'nye isledovanija maketnogo obraztsa mikrotunelja MKT-2 na motornom stende avtotraktornogo dvigatelja] [Text], Herald of Dahl’ East-Ukrainian National University, Severodonetsk, № 3 (220), pp. 155 – 159. [in

Russian].
3.46. AVL Smart Sampler. The Particulate Matter Sampling Solution. Partial flow dilution system for regulatory testing and R&D applications [Electronic resourse]. AVL List GmbH. – Access mode: https://www.avl.com/documents/ 10138/1225114/ AVL+Smart+Sampler.pdf.
3.47. Robert Bosch GmbH (2002), "BOSCH. Avtomobil'nyj spravochnik: perevod s anglijskogo" [BOSCH. Automotive handbook: transl. from English], Moscow, Publ. ZAO KZhI "Za rulem", 896 p. Print. [In Russian].
3.48. Gas Analyzers. Information portal about gas analyzers, gas detectors and gas annunciators [Electronic resource], access mode: http://gas-analy-zer.ru.
3.49. Rabinovich S.G. (1978), "Pogreshnosti izmerenij" [The errors of measuring] [Text], Leningrad, Energija, 262 p. [in Russian].
3.50. Kondratenko O.M. (2013), "Znyzhennja vykydu tverdyh chastynok transportnyh dyzeliv, scho perebuvajut' v ekspluatacii': avtoref. dys. na zdobuttjz nauk. stupenja kand. tehn. nauk: spec 05.05.03 – dvyguny ta energetychni ustanovky" [Reducing of emissions of particulate matter of transport diesel engines that are in operation: abstract of dissertation for obtaining of candidate of technical sciences degree in specialty 05.05.03 "Engines and Power Plants"] [Text], Kharkiv, Publ. NTU "KhPI", 20 p. [in Ukrainian].
3.51. DSTU ISO/IEC 17025:2006, IDT. "Zagal'ni vymogy do komplektnosti vyprobuval'nyh ta kalibruval'nyh laboratirij" [General requirements for the competence of testing and calibration laboratories] (National standard of Ukraine) [Effective as of 01-07-2007], Kyiv, Publ. Derzhspozhyvstandart Ukrainy. – 2007. – 26 p. [in Ukrainian].
3.52. Alexandrovskaja L.N., Kruglov V.I., Sholom A.M. (2002), "Teoreticheskije osnovy ispytanij I eksperimental'naja otrabotka slozhnyh tehnicheskih sistem" [Theoretical basis of the test and experimental development of complex technical systems], Moscow, Logos, 748 p. [in Russian].
3.53. Korobko A.I., Shei'n V.C., Radchenko Ju.A., Plotnikova M.V. (2014), "Validizacija vyprobuval'nogo obladnannja" [Valydation of testing equipment], Materials of International science and practical Internet-conference "Modern technologies and prospects of automotive transport" (08-04-2014), Vinnitca, Publ. VNTU, pp. 4 – 5.
3.54. GOST 18140-84 "Manometry differencyal'nyje GPS. Obschije tehnicheskije uslovija" [Differential manometers. General technical requirements], Moscow, Izd-vo standartov. – 1984. – 49 p.
3.55. TU 25-2021-88. "Termometry rtutnyje stekljannyje laboratornyje" [Mercury glass laboratory termometers], Moscow, Izd-vo standartov. – 1988. – 59 p.
3.56. Barometer-Aneroid BAMM-1M. Pasport L82.832.001PS.
3.57. GOST 166-89 "Shtangencyrkuli. Tehnicheskije uslovija" [Cli-

pers. Technical requirements], Moscow, Izd-vo standartov. –1989. –11 p.

3.58. GOST 427-75 “Linejki izmeritel’nyje metallicheskije. Thenicheskije uslovija” [Metallic measurement rulers. Technical requirements], Moscow, Izd-vo standartov. – 1975. – 7 p.

3.59. TU 25.1894.003-90 “Sekundomery mehanicheskije” [Mechanical timers], Moscow, Izd-vo standartov. – 1990. – 5 p.

3.60. GOST 6616-94 “Preobrazovateli termoelektricheskije. Obschije tehnicheskije uslovija” [Thermoelectric converters. General technical requirements] , Moscow, Standartinform. – 1994. – 11 p.

3.61. Device A565. Operation manual 0273RE.

3.62. Rotational gas counter RG-100. Technical description and manual.

3.63. Electronic and computing frequencymeter F5080. Technical description and operation manual. – 1980. – 40 p.

Chapter 4. PROVISION OF ECOLOGICAL SAFETY OF PRODUCTS OF NANOTECHNOLOGIES DURING THEIR LIFE CYCLE

4.1. GENERAL PROVISIONS

Purpose of studies, presented in the chapter, is creation of science and technical basis of provision of ecological safety of semiconductor products of nanotechnology during their life cycle.

Object of studies, presented in the chapter, is ecological safety of semiconductor products of nanotechnology during their life cycle.

Subject of studies, presented in the chapter, is analysis of ecological safety factors of semiconductor products of nanotechnology during their life cycle and also activities for its increasing.

The chapter *includes* materials of three articles.

The **first of these articles** dedicated to general issues of technology of obtaining of porous semiconductors and ways of controlling the geometry parameters of the pores of semiconductors for manufacturing of combined optoelectronic devices, in which information is processed not only in an electronic but also in an optical form. In the article analised the dependence of the porous InP morphology on the type of reacting anion in photoelectrochemical etching surface texturing method is presented and shown that nanoporous single-crystal InP layers can be obtained through certain conditions of electrochemical etching in terms of the features of the growing process of heavily doped crystals.

The **second article** includes materials about searching of rational technological regimes of achieving of layer of porous silicon as an basic material for manufacturing of photovoltaic converters, namely method of electrochemical etching in a solution of hydrofluoric acid with taking into account dependence of thickness of porous layer on etching duration and also almost linear dependence of porosity on current density.

The **third article** describes the results of analysis of general issues of developing of methodological maintenance of tasks of increasing of ecological safety level of environment by the way of using of innovative technologies for solar energetics with taking into account that increasing of efficiency coefficient of photovoltaic energy converters becomes possible through using of nanostructured semiconductors.

Findings of presented in chapter 4 studies is submitted in general conclusions of the monograph.

Bibliographic description of presented in chapter 4 published scientific articles is submitted in are given in Appendix A.

Розділ 4. ЗАБЕЗПЕЧЕННЯ ЕКОЛОГІЧНОЇ БЕЗПЕКИ ПРОДУКТІВ НАНОТЕХНОЛОГІЙ ПРОТЯГОМ ЇХ ЖИТТЄВОГО ЦИКЛУ

4.1. ЗАГАЛЬНІ МІРКУВАННЯ

Метою досліджень, наведених у розділі, є створення науково-технологічних основ забезпечення екологічної безпеки напівпровідникових продуктів нанотехнології впродовж їх життєвого циклу.

Об'єктом досліджень, представлених у розділі, є екологічна безпека напівпровідникових продуктів нанотехнології впродовж їх життєвого циклу.

Предметом досліджень, описаних у розділі, є аналіз факторів екологічної безпеки напівпровідникових продуктів нанотехнології впродовж їх життєвого циклу та заходи щодо підвищення її рівня.

Розділ *містить* матеріали трьох статей.

Перша з статей присвячена загальним питанням технології отримання пористих напівпровідників і способів контролю параметрів геометрії їх пор для виготовлення комбінованих оптико-електронних приладів, в яких інформація обробляється не тільки в електронній, а й в оптичній формі. У статті проаналізовано залежність пористої морфології InP від типу аніон-взаємодії в текстурирования його поверхні методом фотоелектрохімічного травлення і показано, що нанопористі шари монокристалічного InP можуть бути отримані за допомогою електрохімічного травлення за певних умов згідно до особливостей процесу вирощування сильнолегованих кристалів.

Друга стаття містить матеріали щодо пошуку раціональних технологічних режимів отримання шару поруватого кремнію як основного матеріалу для виготовлення фотоелектричних перетворювачів, а саме методу електрохімічного травлення у розчині плавикової кислоти з урахуванням залежності товщини пористого шару від часу травлення та майже лінійної залежності пористості від щільності струму.

Третя стаття описує результати аналізу загальних проблем розробки методологічного забезпечення задач підвищення екологічної безпеки довкілля шляхом використання інноваційних технологій для сонячної енергетики з урахуванням того, що підвищення ККД фотоелектричних перетворювачів енергії стає можливим за рахунок використання наноструктурованих напівпровідників.

Висновки по результатам досліджень, представлених у розділі 4, винесено у загальні висновки по монографії.

Бібліографічний опис наведених у розділі 4 друкованих наукових праць наведено у Додатку А.

4.2. POROUS INDIUM PHOSPHIDE FOR ENVIRONMENTAL SAFETY [A.4.1]

Introduction

Needs of modern society in processing and transfer of the growing information content led to the formation of the super-high-speed opto-electronic integrated circuits based on silicon and binary semiconductors. Integration of transistor structures into very large-scale integrated circuits is technologically limited by the physical boundaries of the microregion size and the low charge mobility in semiconductors. The solution of this problem is in the increase in the functionality of the elements.

Recently, scientific interest is directed to the formation of nanostructures considered as a promising material for the creation of photon devices. The electrochemical process, which is unique due to its simplicity, low process temperature, and low cost, stands out against different formation techniques of semiconductor nanostructures. The most well-known application of the electrochemical methods is the formation of a porous layer on the surface of semiconductor plate by anode etching. For the first time such structures were obtained on silicon. Lately it was established that porous layers can be also obtained on binary compounds, such as GaAs, GaP, and InP.

Porous semiconductors attract the attention of many researchers due to the relatively simple technology of obtaining them and possibility of controlling the geometry parameters of the pores (from nanometer- to micrometer-scale objects), as well as prospects of manufacturing of combined optoelectronic devices, in which information is processed not only in an electronic but also in an optical form. The recently attained progress in studying the properties of porous silicon stimulated similar studies for the III – V compounds. Particularly, the most promising in this aspect is porous InP, since the energy parameters of its single crystals are very close to the parameters of single-crystal silicon and devices of integrated optoelectronics compatible with silicon, particularly resistive and diode optopairs, can be easily fabricated based on it.

Indium phosphide (InP) has great prospects of wide industrial production. Field-effect transistors and other microwave devices are manufactured based on InP. Monocrystalline InP plates are used as substrates for the growth of different heterostructures, which are the basis of effective radiation sources (injection lasers, light-emitting diodes) and high-speed photodetectors for the systems of fiber-optic communication lines. InP is promising for the development of super-high-speed integrated circuits. Presently InP is the most probable material for the mass production of integrated circuits. It is impossible not to mention about the growing interest in porous InP, which has unusual optical and electrical properties in comparison with the monocrystalline InP.

It is established that different factors, namely, the composition and concentration of electrolyte, current density, and etching time, influence the formation of porous layer. Behavior of the semiconductor under electrochemical treatment also depends on the type and concentration of majority carriers. Here one should keep in mind that electrochemical process is accompanied by a number of coupled chemical reactions, and the final result of the electrochemical treatment of semiconductor depends on the ratio of the reaction rates.

It is possible to use the halogenide, sulfate, phosphate, nitrate aqueous, and anhydrous solutions of alkalis at considerable current densities as electrolyte for obtaining the porous III – V materials (particularly InP), Table 4.1. In most cases, for the electrolytic etching of binary III – V compounds, solutions of HCl in ethanol or water are used.

The interest in investigation of defects in the crystals and their influence on the formation of porous layers of semiconductors increased because of the requirements, each deviation from which leads to the emergence of defects. External conditions are the determining factor, due to which the surface of the crystal during etching varies its shape and morphology, which is expressed on the faces in the form of hatching, figures of etching, etc. Thus, a defect brings information about the events that took place with this crystal and about the factors determining the behavior of the crystal during the anodic etching.

Thus, the questions associated with the methods of obtaining the porous structures of InP, mechanisms of their formation, and dependence of conditions of pore formation on internal defects and imperfections of crystals remain unresolved. In this article, we consider the procedure of obtaining the porous layers on the (111) surface of indium phosphide of n-type of conductivity as well as the influence of defects and dislocations on the configuration and structure of porous layers obtained during this process.

Table 4.1 – Electrolytes and regimes of anodic etching

Electrolyte	Current, voltage	Time	The type of pore
HCl	J = 4–4.2 mA/cm^2	120	Crysto
	J = 4–100 mA/cm^2	10–60	Curro
	U = 0.8–5 V	1–3	Crysto
	U = 4–9 V	1–3	Curro
HCl + HNO_3	U = 4–9 V	1–3	Curro
	U = 1–3 V	–	Crysto
HCl + HF	J = 50 mA/cm^2	1	Crysto
HCl + NH_4Cl	U = 7–10 V	0.3–0.4	Curro
NaCl	U = 5 V	1.5	Curro
KBr + HBr	U = 7–10 V	0.3–0.4	Curro

Technology for Production of Porous Structures

There are several physical and chemical technologies for obtaining porous structures: the colloidal deposition, MOCVD, spark discharge, plasma etching, hydrothermal synthesis, sol-gel methods, vapor deposition, and chemical and electrolytic deposition.

Electrochemical Etching

Electrochemical etching has the following features: low-temperature process, minor surface damage, easy, and low cost. This method does not require high-tech equipment and is fast (2 – 30 min). Electrochemical methods allow for a high density of pores, which is unattainable using other methods.

Electrochemical etching can be divided into two different processes:

• chemical etching (electroless etching);

• anodic etching.

Note that in both cases there is electrochemical etching of charge exchange at the border of the semiconductor and electrolyte.

Chemical etching is usually a process of electrochemical oxidation without external potential. The performance of this type of etching requires strong enough reagents that can form/rip holes and electrons to/from the valence band of the semiconductor. Thus, the redox coupled with high positive standard electrode potential is required for efficient etching. Electronic energy distribution function oxidants exceed the energy level of the valence band in solid.

The mechanism of electrochemical oxidation is usually divided into two partial reactions:

• injection of holes in the valence band (release of electrons);

• broken bonds will be occupied by molecules such as OH, which leads to the dissolution of the material.

These two steps of chemical etching split apart in time. Because of this, you can stop the progress of the first phase and the second stage (dissolution) will also be stopped. When applying an electrical displacement that causes electrons to move from the solution to the electrode, the process is called anodic etching (holes move to the buffer zone).

On the other hand, if they are moved from the electrode into the solution, the process is called cathode etching (holes are removed from the buffer zone). Anode etching, like chemical etching, requires hole for the process. A large number of holes on the surface will induce a bond failure. Similar to the chemical etching, broken bonds will react with nucleophilic molecules (such as OH^-) in the electrolyte. If all the bonds of atoms of the solid will be replaced by bonds with nucleophilic molecules, this will form new compounds that consist of atoms of the solid and nucleophilic molecules. New compound will have only a small portion of the solid bonds or will not have them at all. If this compound is dissolved in the electrolyte, it can dissolve chemically pure, and thus, the surface of the sample will be free and ready for the next interaction with nucleophilic molecules of the etchant.

Otherwise, i.e., if the newly created compound is dissolved in the electrolyte, a thin oxide layer on the surface of the electrode will form which will prevent electrochemical attack. For this reason, suitable for electrochemical etching, electrolytes contain two main components:

• nucleophilic (i.e., decelerating) components;

• components that dissolve oxides.

In general, for n-type semiconductors required for etching, holes can be generated by the avalanche breakdown mechanism that can be achieved by a high positive potential on the electrode or whether this effect can be achieved with a semiconductor light photons with energies greater than the energy gap of the semiconductor.

Getting the Initial Pore Growth

Getting the initial pore growth can be realized in two main areas:

• providing certain places of origin of pores, i.e., lithographs – "seeding pore formation";

• pore formation is going its own way – "random pore formation".

Seeding origin has a practical significance only for macropores because micropores or mesopores, by definition, require very small structures. The easiest way to ensure this process is the use of standard lithography to transmit the desired pattern on the photoresist. The template can be referred to as the "mask".

After macropore growth is finished and if stable pore growth conditions prevail, the mask is no longer needed. Thus, it does not matter if the mask dissolves during a long process of etching.

Applying a template can be realized by other methods:

• electron beam lithography: expensive and slow way, but still used and necessary for small sizes;

• imprinting the appropriate template;

• laser interferometry: standing waves, which are formed from the impact of several lasers, can produce periodic structures in photoresist. The method is a bit limited, but relatively easily repeated;

• overlaying masks with template. For example, here can be used a two-dimensional crystals from latex or have any mask.

There are several aspects that must be considered for the process of seed pore formation:

• pores may arise in the given nodes, but not for everyone. They can also arise out of nodes elsewhere – in particular, if the mask is not too stable and homogeneous;

• even if the pore formation was properly, receiving pores may move at further etching and not grow steadily, so the target structure is disrupted with increasing of depth. This is an inevitable process, if the external length scale imposed on the porous structure is too different from the scale of the internal process;

• However, the pores can emerge and grow steadily, but their form is far from ideal.

Emergence of random pores takes place on unstructured but nevertheless uniform and clean surface. The concept of “clean surface” is obviously relative. But, as it is obvious, “dirty” heterogeneous surfaces (e.g., polished surface with a locally damaged area) will somehow influence the pore formation. Random pore growth can be quite different on the polished or “rough” surface. The characteristic feature of most semiconductors is the stable structure of their pores by random pore formation. In other words, the average pore diameter and the distance between them have their own values with relatively small standard deviation.

The Structure of Porous Layers

According to the recommendations of the International Union of Pure and Applied Chemistry (IUPAC), pore sizes are divided into:

• macropores (pore width greater than 50 nm);

• mesopores (pore width of 2 – 50 nm);

• micropores (pore width less than 2 nm).

Pores in A3B5 compounds exhibit a variety of forms. Therefore, it is convenient to classify them in the direction of growth:

• pores are oriented along the crystallographic directions (crysto);

• pores are oriented on current (curro);

• pores have no definite direction.

This shows the anisotropy of etching crystals.

Anisotropic etching is important for the structuring of semiconductors and is mainly related to the differences in the rate of etching low-indexed surfaces of crystals. The reasons for this behavior are not yet fully understood. Typically, we investigate low-indexed crystal surface – orientations (111) (100) (110). Each set of planes has its own different behavior in solution. One of the reasons may be the density of atoms in the crystallographic planes (high density = low dissolution rate). However, this is not the only factor that determines the anisotropy. In III – V compounds, there are several additional factors that contribute to the anisotropy; this is due to different chemical properties of atoms in the third and fifth groups of the periodic table of elements. For example, along the surface with the orientation <111>, atomic planes are occupied by atoms of the third and fifth groups, forming double layers, i.e., there are small and large gaps between the planes {111}, which alternate. Each atom has three bonds within a double layer and one bond outside the double layer. Surfaces limited by atoms of In are called {111} A, while surfaces limited by atoms of P {111} B. It is important to note that almost all surface oxidation processes such as {111} have a slower dissolution rate. This can be explained by the assumption that three bonds (within the same double layer) are much harder to break from A than from B, due to the fact that the electronic cloud of a bond is polarized in the direction of B atom (more electronegative).

If we assume that in order to break the bond by atom B, we need the average time t1, whereas for A, it takes time $t_2 >> t_1$. So to eliminate the double layer of B, we must spend time ($3t_1 + t_2$), whereas for A, it is equal to the total time ($3t_2 + t_1$). It is easy to see that ($3t_2 + t_1$) >> ($3t_1 + t_2$). As a result, the etching of B (along the <111> B) is much faster than A (along the direction (<111> A). Besides, along the directions of atomic planes <100>, space is also alternately occupied by atoms of the third and fifth groups. However the atomic planes are equidistant and symmetrically related to each atom with atoms of neighboring layers. Thus, the time required for etching of two layers from A side is ($2t_2 + 2t_1$) and from B ($2t_2 + 2t_1$). As a result, in this case there is no difference on what surface is etched, because the average time is the same.

Obtaining Low-Dimensional Structures on the Surface of Indium Phosphide

Indium phosphide monocrystals were produced in the research laboratory of Molecular Technology GmbH company (Berlin). Thickness of the samples was 1 mkm. Plates were cut out perpendicular to the growth axis and polished on both sides.

InP samples with different surface orientations of the n- and p-types and with different charge carrier concentrations were chosen for the experiment. Electrochemical etching was performed using the standard plant in the electrolytic cell with the platinum cathode. The plant scheme is presented in Fig. 4.1.

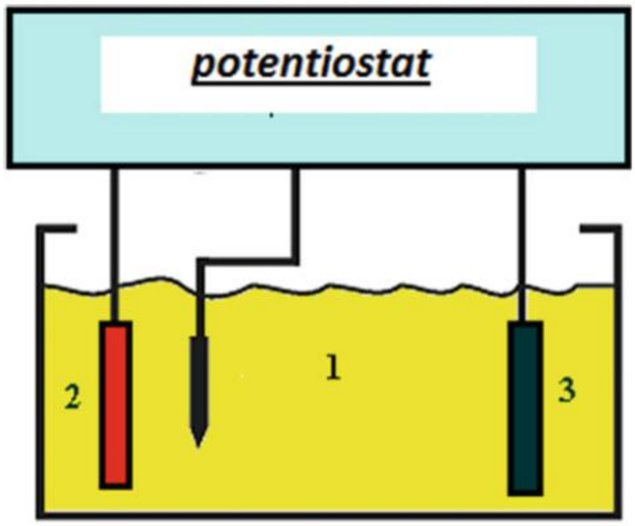


Fig. 4.1 – Plant for the semiconductor etching

Solutions of hydrofluoric and hydrochloric acids with different concentraitons were taken as the electrolytes. Etchants based on HF and HCl with added iodides (KOH), ethanol, and nitric acid were also used. The experiment was carried out at room temperature.

Samples were thoroughly purified before the experiment. The following are the purification steps:

1. degreasing in hot (75 – 80 °C) peroxide-ammonia solution;

2. treatment in hot (90 – 100 °C) concentrated nitric acid (metal ion removal);

3. washing in distilled water;

4. drying of the plates using centrifuge in the purified dry air.

After experiment the samples were purified in acetone and isopropanol, washed in distilled water, and dried in extra pure hydrogen, whereupon they were undergoing natural aging during 3 days.

Morphology of the obtained porous structures was investigated using the scanning electron microscope JSM-6490. Chemical composition was studied with the EDAX method, and the diffractometric investigations were carried out using the diffractometer DRON-3 M.

Physicochemical Regularities of the Porous Layer of Indium Phosphide

Effect of the Type of Electrolyte Anion on the Porous InP Morphology Obtained by the Electrochemical Etching

The processes that form at the junction of the semiconductor and electrolyte should lead to the establishment of thermodynamic equilibrium between the electronic subsystem of the semiconductor and hydrogen redox system solution, as well as the establishment of local chemical equilibrium at the interface which minimizes its free energy. Setting electrochemical equilibrium between aqueous electrolyte and semiconductor *n*-type is provided by the transition of electrons from the conduction band to the hydronium cations. As a result, semiconductor is positively charged, and the electric double layer arises in solution with excess anionic concentration at the border of the crystal.

Let us consider the surface of InP as a free crystal surface. Depending on the crystallographic orientation of this surface, the atoms that go into it may have one or two broken bonds. In the volumesurface equilibrium, one orbital of the broken bonds of the indium atom should be vacant, and phosphorus atoms occupied by the unshared pair of electrons. Then during the adsorption of at least one atom in the anion of the indium, full heat of adsorption should be the same with the heat on the electrophilic center. At the same time for P atoms, conversion of the filled orbitals of broken bond into the electrophilic center requires energy, which, in general, exceeds the energy released in the act of adsorption. Therefore, in the absence of an electric shift, only a small part of the surface atoms of phosphorus may be associated with halogen adatoms. On the surface of indium phosphide *n*-type, a thin dense layer of particles is formed, in which the negative charge of the semiconductor is concentrated – Helmholtz layer. As the anodic shift increases, gradual convergence of the energy of levels takes place, filled states in the Helmholtz layer and vacant states in the crystal. As a result of the convergence, channels of tunneling electron transfer in the crystal from components of this layer arise. As the deviation from the initial equilibrium conditions, the growth of several processes may take place, the complete oxidation of the material, electrode oxidation of solvated anions, and the emergence and growth of pores; pore formation in this sense is the nature of an avalanche breakdown.

Table 4.2 – Conditions for obtaining of various classes of nanostructures on the surface of indium phosphide

Low-dimension structures	Electrolyte	Current density, мА/см^2	Etching time, min	Additional conditions
Porous layers *n*-type *p*-type	HF HCl	50–250	3–30	For etching of *p*-type tungsten lighting lamps of 200 W
Surface textured	HBr	130–170	6–10	Tungsten lighting lamps of 200 W
Superlattices	HF	80–150	25–35	Pulsating voltage: etching at a voltage of 5 V (1 min), etching without voltage (simple chemical etching) – 2 min
Nanoclusters	HF+ C_2H_5OH	70–130	10–15	After digestion – aging for 3 days in the open air
Zero-dimensional structures	HF+ HNO_3	180	4–6	Influence of pulse magnetic field by a series of symmetrical triangular impulses amplitude B = 0.5 T with a frequency f = 50 Hz

Table 4.3 –Types of nanostructures on the surface InP

Low-dimensional structures	Structure type	Unit size	Structure features
Porous layers	Pore	Pore diameter 7–300 nm	The form depends on the orientation of the surface: for the (111) oriented crystal pores have a triangular shape for the (100) – close to square
Textured surfaces	Pyramidal clusters	The height of the pyramid from 0.7 to 1.1 μm	The angle of inclination of faces 64°–85°
Superlattices	Periodic layers of porous and single-crystal indium phosphide	Width of porous and single-crystal bands 20–25 nm and 30–35 nm, respectively	Superlattice is formed across the sample thickness. Monocrystalline layer also has pores, but they are few; they are located mainly at the interface of two layers and have ordered nature
Nanoclusters	Crystalline indium oxide	Cluster size of 10–200 μm	Flower-crystal structures
Zero-dimensional structures	Clusters of the indium quantum dots type	From 3 to 40 nm	The clusters are distributed uniformly over the surface of the crystal; some clusters are combined in a massive accumulation

Morphology analysis of the tested samples obtained using the scanning electron microscopy (SEM) showed that almost in all cases the active pore formation was observed (Table 4.2 and 4.3). In the conditions when pore formation is the dominant electrochemical process, which takes place at the given value of the polarizing voltage on the monocrystal semiconductor anode, the steady-state configuration of the porous layer surface is formed by the time of the maximum current density attainment.

Under equal conditions (identical crystals, equal charge and anion concentration in the solution), the electrolytic reaction rate depends on the type of reacting anion. Depending on the degree of dissociation into ions, electrolytes can be classified as strong and weak ones. Their behavior on dissolving is different. Some molecules of weak electrolytes dissociate into ions under solventation. Their dissociation is the reversible process since ions are easily associated in collisions; therefore, in solutions of weak electrolytes, the dynamic equilibrium between ions and undissociated molecules is attained. When strong electrolytes dissolve, the dissociation occurs almost completely, and ionic crystals or molecules dissociate with the formation of aquated (solvated) ions.

Some of the most important acids, namely, HNO_3, H_2SO_4, $HClO_4$, HCl, and HBr, belong to strong electrolytes. Most of weak electrolytes are inorganic compounds, such as H_2CO_3, H_2S, HCN, and HF.

HF-Based Etchants

Small size of F atom substantially influences the fluoride properties. F atom in chemical compounds practically always is negatively charged. F is the most active oxidant among the elementary substances; it reacts with almost all substances. The feature of fluorine chemistry is the presence of stable hydrogen bonds HF. The average degree of association of HF molecules in a liquid state is closed to 6. Etching acid is considered to be the half-strength acid (the dissociation constant is $6.8 \cdot 10^{-4}$). Electronegativity of F–atoms in the series F^-, Cl^-, and Br^- is the largest and is equal to 4 on the Pauling scale.

In the halogenide-ion series, the minimum voltage value of the formation initiation always corresponds to fluorine anion. Morphology of the porous samples obtained using etching acid demonstrates the net of meso- & macropores.

Formation of such pores is often connected with the displacement of defects and dislocations on the crystal surface. In this case the substantial overetching of the surface is observed (Fig. 4.2).

In Fig. 4.2 it is possible to see clearly the etched regions that imply about very “harsh” etching conditions. Porous surface demonstrates the developed morphology with the formed large etching pits. Such surface has a huge effective area in comparison with the monocrystal one, but it is imperfect enough for use as the substrate for heterostructure production. In this case, in order to decrease the electrolyte effect on the porous structure formation, it is reasonable to change the etching regimes (time, current density) for more soft ones or use more dilute etchant solution.

When adding ethanol to this solution, the value of threshold voltage of the pore-formation initiation substantially increases, and here porous layer has more qualitative structure that has appeared in the decrease in pore size (Fig. 4.3).

In general, ethyl alcohol is an organic diluent of electrolyte. When adding it to the aqueous solution of etching acid (the component ratio is HF : H2O : C_2H_5OH = 1 : 1 : 2), the electrolytic reaction rate slows down, and therefore, more time is needed to obtain the porous structures.

Ethyl alcohol is used for the improvement of HF penetration into pores. In our case this leads to the formation of the densest of anisotropically propagating pores along the directions <111> A and <111> B (Fig. 4.4). The degree of porosity is about 30% of the total area of the sample.

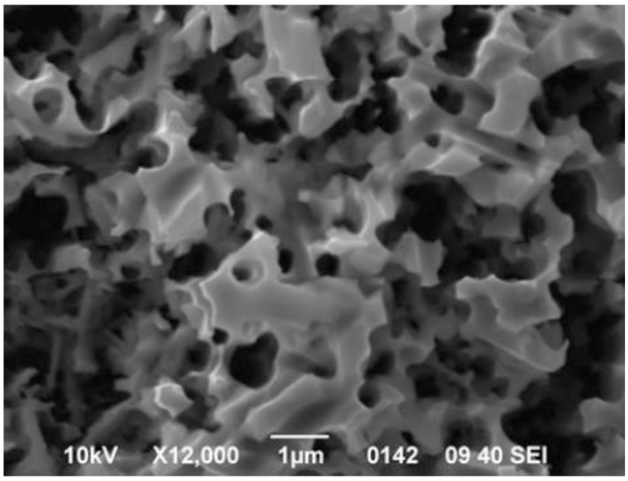


Fig. 4.2 – Morphology of porous *n*-InP (111);
electrolyte HF : H_2O = 1 : 1, j = 80 mA/cm^2, t = 10 min

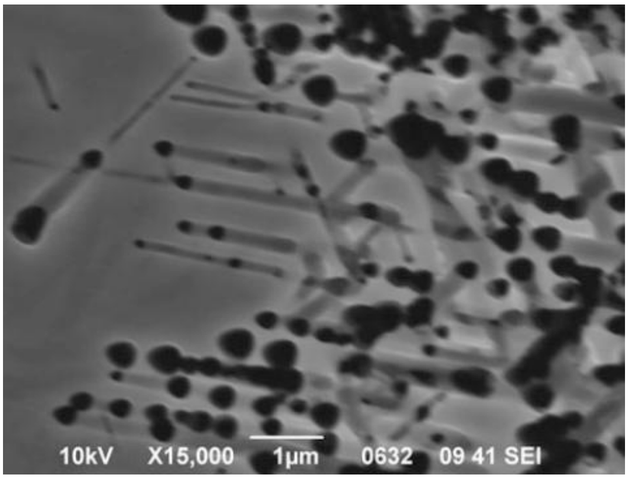


Fig. 4.3 – Morphology of porous *n*-InP (111);
electrolyte HF : H_2O : C_2H_5OH = 1 : 1 : 2, j = 40 mA/cm^2, t = 15 min

In Fig. 4.5 we present the cleavage of porous *n*-InP (111) obtained in the HF-based etchant. Irritated area, the appearance of which can be caused by the dislocation displacement, is clearly observed under the crystal surface.

The following fact is found to be interesting: the crystal surface is not so irritated as an area under it. This implies about the pore formation inside the crystal as well, where pores can be combined due to the thinning of the walls and their accumulation around defects.

HCl-Based Etchants

Hydrochloric acid is the aqueous solution of hydrogen chloride; it is strong monatomic acid. The maximum concentration of such solution at 200 °C is 38 % and the density is 1.19 g/cm^3. HCl is most often used during the electrochemical etching of the crystals that is explained by the possibility of this acid to easily dissociate into ions.

HCl-based etchants allow to obtain the layer composed of the nanopores mainly. Figure 4.6 demonstrates the ordered assembly of pores formed on the monocrystal InP substrate during the etching in 5 % hydrochloric acid solution. Pores appeared all over the sample surface. The average pore size is 40 nm that implies about the nanodimensionality of the given structure. The wall size between pores is in the range (5 – 10) nm. Such a result is important technologically, since the quality of porous films is determined by the nanostructure sizes, degree of porosity, and uniformity of the pore distribution over the sample surface. The smaller the pore size and the larger porosity percent, the more quailtative porous structure is. The degree of porosity is about 60 % of the total area of the sample.

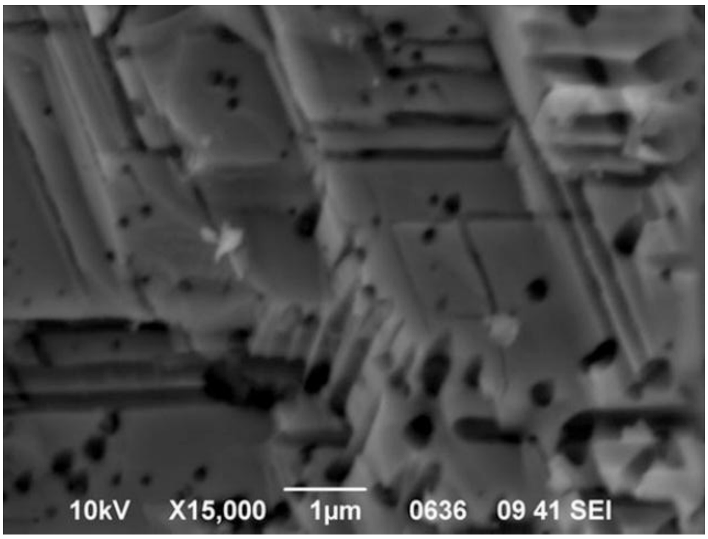


Fig. 4.4 – Anisotropic pore propagation along the directions <111> A and <111> B

In Fig. 4.7 we present the cleavage of the porous sample obtained in 5 % hydrochloric acid solution. This figure demonstrates the long parallel pore channels placed strictly perpendicular to the crystal surface. Such pores are directed along the lines of flow and reach the depth of 60 mkm inside the sample.

Salts and Acids Addition to the Electrolyte Solution

Iodide addition to the fluoride solution essentially influences the pore-formation process. When adding KI (potassium iodide) to 50 % etching acid solution, the pore-formation process slows down somewhat what the current-voltage characteristics taken during anodization imply about. Morphology of the samples obtained in such solution demonstrates the decrease of the pore inlets (the degree of porosity is about 15 %). However, the branching of the pore channels under the crystal surface increases. Here the irregular layer preceding the long mutually parallel pores widens up to 2 mkm (in comparison with the irregular pore layer formed in the aqueous fluoride solution, which in this case is 0.5 – 1 mkm).

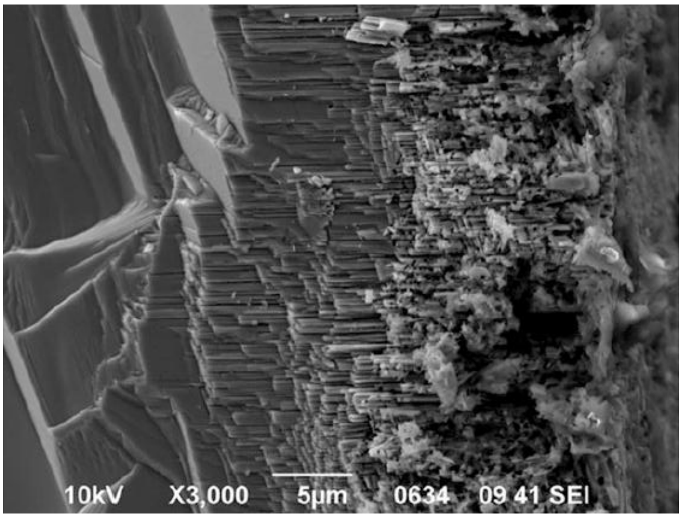


Fig. 4.5 – Cleavage of porous *n*-InP (111),
electrolyte HF : H_2O : C_2H_5OH = 1 : 1 : 2, J = 50 mA/cm^2, t = 10 min

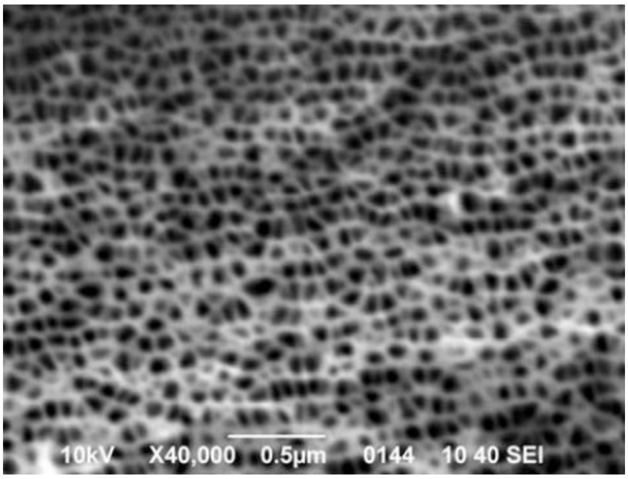


Fig. 4.6 – Morphology of porous *n*-InP (100) obtained
by the electrochemical etching in 5 % HCl solution, t = 5 min

Nitric acid in addition to the chloride solutions accelerates the electrolytic reaction rate and allows to obtain the porous surfaces with the more densely packed pores (the degree of porosity is 60 – 70 %). However, as in the case of iodides, nitric acid influences the thickness of irregular porous layer. In this case the given value is about 1.8 mkm (in the absence of nitric acid, it is 0.4 – 0.7 mkm).

Influence of the Carrier Concentration of Indium Phosphide on the Porous Layer Formation

Additional doping of the monocrystalline InP surface is a sufficiently interesting, to our opinion, way to obtain pores of the specified shape and provide the necessary quality of the por-InP – monocrystalline InP boundary. This circumstance allows, firstly, to form pores of the required shape, which makes further cleaving of the basic plate easier, and, secondly, to provide the necessary quality of the cleavage surface.

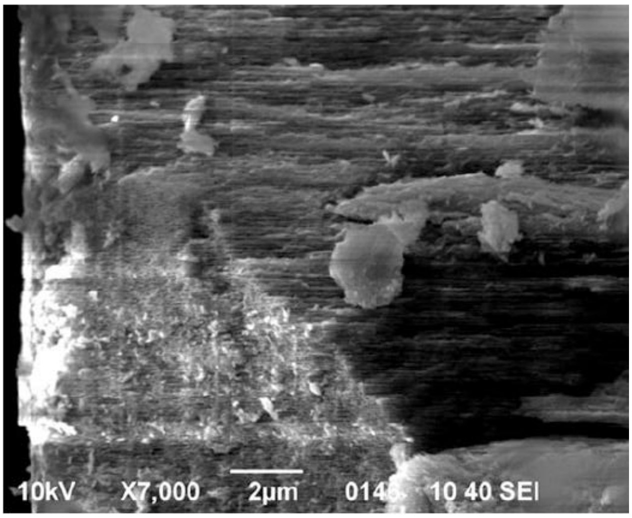


Fig. 4.7 – Cleavage of porous *n*-InP (100) obtained by the electrochemical etching in 5 % HCl solution, t = 5 min

Rate of a chemical reaction essentially depends on the doping level of the semiconductor. Threshold voltage of the pore formation decreases with the increase in the volume concentration of free electrons. Moreover, increase in the doping level leads to the reduction of the dislocation density but simultaneously is accompanied by the generation of microdefects (stacking faults, small prism dislocation loops, dispersed second-phase release). As known, the pore growth occurs along preferential directions, which the given defects of the crystal surface are. Figure 4.8 illustrates the morphology of the InP porous surface with different charge carrier concentration.

A porous layer with low pore density is formed during the etching of the semiconductor with the concentration of impurity charge carriers of the order of $1.8 \cdot 10^{16}$ cm^{-3}. However, in this case the obtained pores are sufficiently small (20 – 50 nm) and demonstrate a certain order and uniform distribution over the ingot surface. Moreover, the coarse etched areas, which appear due to the dislocation outcrop, can be observed on the sample surface. With the increase in the number of charge carriers, one can observe a completely different scenario for the pore distribution over the sample surface. Pores with different diameters (from 100 nm to 3 m) appear under electrochemical treatment of the samples, which are doped with sulfur up to the concentration $2{\cdot}10^{17}$ cm^{-3}. Appearance of crystallites, which can indicate the formation of oxide islands on the upper porous semiconductor layer, is possible in this case. Another situation takes place during electrochemical treatment of the heavily doped InP crystals (about $2.3{\cdot}\ {\cdot}10^{18}$ cm^{-3}). Such concentration of impurity charge carriers is the most favorable for the formation of a qualitative porous layer on the surface of monocrystalline InP that is expressed in a high pore density and their uniform distribution over the plate surface. Pores, which are formed in this case, have a size of the order of tens of nanometers; the degree of porosity is 60 %. Varying other etching conditions (current density, etching time), it is possible to obtain porous structures with different parameters (pore diameter, porosity, depth of the porous layer). However, while using materials for crystal etching with higher impurity concentration ($3{\cdot}10^{19}$ cm^{-3}), the surface etching without pore formation is observed, that is, the upper crystal layers just break off along certain planes. Such structures cannot be used as effectively as porous ones due to the fact that the surface layer is strongly disturbed. Thus, the given experiment demonstrates the role of the charge carrier concentration for the pore formation on the semiconductor surface.

However, one should take into account that additional doping leads to the impurity segregation, which appears during the crystal growth. Elastic long-range stresses can impede the formation of continuous splicing surface. The regions of compositional and structural inhomogeneities, namely, the bands of impurity segregation and crystalline defect clusters, are the sources of these stresses. Microfluctuations of the growth rate on the boundary of the solid and liquid phases lead to the formation of the sulfur segregation bands (growth bands). Denser pore clusters in the central segregation lines with respect to the peripheral ones indicate the increase in the sulfur concentration along the direction from the center to the InP crystal periphery. Moreover, sulfur distribution in InP crystals can be nonuniform not only along but also across the growth axis. In this case, change in the lattice parameter of the solid solution excites elastic stresses.

Moreover, significant etching of the crystal surface is observed in the areas of dense pore clusters. This can be connected with the outcrop of the secondary pores, as well as with the coalescence of small pores into bulk holes.

Generation of the bulk etching holes can be explained from the point of view of the impurity influence on the defect formation in the crystal. Doping with donor impurities up to the high concentrations is accompanied by the appearance of microdefects but leads to the decrease in the dislocation density.

Intrinsic point defects play the main role in the microdefect formation. At high doping levels, decomposition of supersaturated solid solution of the doping impurity influences the formation of microdefects. The main production problems during InP crystal growth are the following: tendency to twinning, formation of dislocation clusters, and segregation phenomena conditioned by high impurity content in semi-insulating crystals. Impurity concentration, which is the function of the crystal growth rate, has periodicity and excites the so-called doping streakiness. This is partly explained by the fact that the crystal growth rate on the microscopic level is not the same, but cyclic.

Appearance of nanoregions with different element concentrations can lead to the qualitative change in the InP properties. Imperfection of the crystals connected with the striate growth structure influences the semiconductor properties of the crystals. The presence of the domain (the twin) structure is an undesirable factor from the point of view of using the given materials in optical devices and sensors.

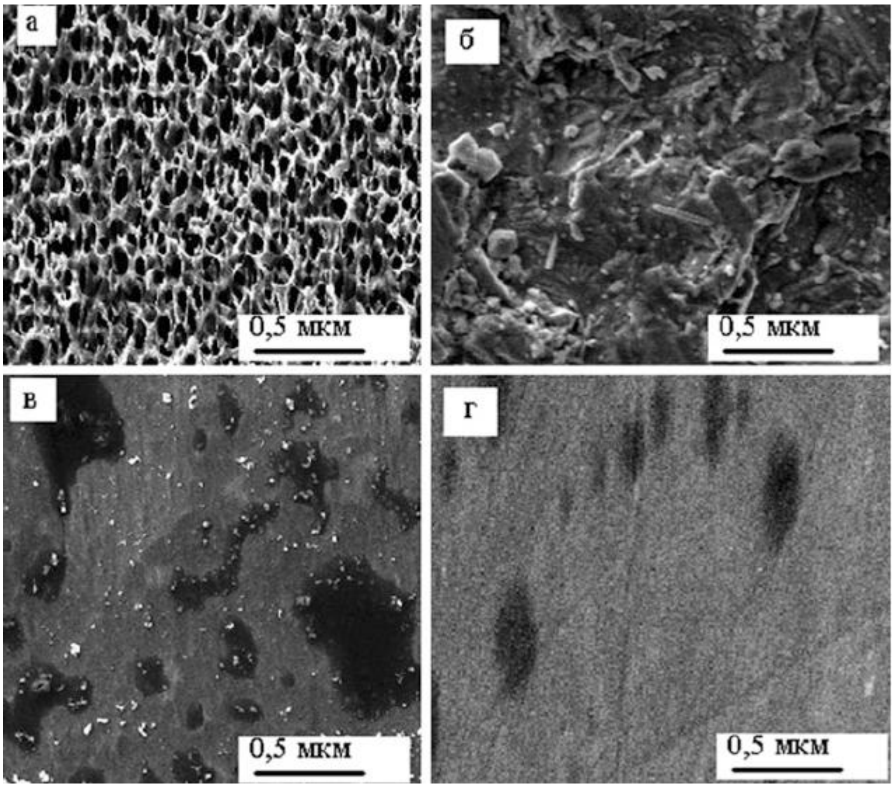


Fig. 4.8 – SEM image of the (001) InP porous surface, j = 100 mA/cm^2, t = 10 min. Concentration of impurity charge carriers: $2.3 \cdot 10^{18}$ cm^{-3} (a), $3 \cdot 10^{19}$ cm^{-3} (b), $2 \cdot 10^{17}$ cm^{-3} (c), $1.8 \cdot 10^{16}$ cm^{-3} (d)

Therefore, investigation of the mentioned phenomenon is of a great importance from the point of view of both the crystal production technique and research of the properties connected with nonuniformity of element distribution, which enter into the composition of the grown crystals.

Influence of Dislocations on the Process of Pore Formation in *n*-InP (111) Single Crystals

The chemical composition was analyzed with the use of the procedure of energy dispersive X-ray analysis (EDAX). The component composition was analyzed for four arbitrarily selected points at the surface.

It is evident that the results of analysis of oxygen and fluorine on the sample surface are associated with random processes correlating with the etching process. The excess of indium atoms indicates that they are situated not only in the associated state (in the form of the In-P clusters) but also in the free state (due to their accumulation along the crystallographic axis [111] of *n*-InP), which is promoted by the production process of single-crystal growth.

In a microphotograph of the surface (Fig. 4.9), the nonuniformity of the distribution of the pores over the crystal surface is observed. After the electrolytic etching, dark and light bands emerge on the surface of the samples; these bands are detected visually. Using scanning electron microscopy, we managed to establish that the dark bands are places of more dense accumulation of the pores, i.e., etch pits. Etching locally took place precisely in the region of the defects of the crystal structure.

The width of each band was ~100 mm. Dark bands have clear external boundaries, while the boundaries directed inside the crystal are more spread. The striation nonuniformity in the distribution of the components is a very widespread phenomenon during growing the single crystals by the Czochralski method. We can also observe an increase in the concentration of input orifices of the pores along the direction from the center to the periphery of the crystals. The formation of the continuous overgrowth boundary can be prevented by the elastic long-range stresses. The sources of these stresses are the regions of the compositional and structural nonuniformity or the bands of segregation of the impurity and accumulation of the defects of the crystal structure.

In this case, each fragment is a region of increased impurity concentration. Such a region can be considered as the inclusion possessing the intrinsic deformation caused by the lattice mismatch and discrepancy in coefficients of thermal expansion of segregation bands and the surrounding material. As the ingot cools, the elastic stresses of such inclusion decrease and the shift components of residual elastic stresses can cause plastic deformation.

Figures 4.3 and 4.4 represent the image of the fragment of the surface of the *n*-InP sample, on which the location of formation of pore cores is clearly seen. The edges of pores are somewhat extended along the (111) plane. Comparison with the known published data indicates that the anions (the F^{-} ions) play the decisive role in the formation of the pores (their shape, diameter, and location). The diameter of the most of pores is in the range from 100 to 600 nm. We can also notice that, both in the plane of the (111) surface and to the depth of the sample, the pores practically have no specific growth direction, which largely manifests itself during etching of the (111) V surface, the formation of pores in the plane of which is energetically more favorable.

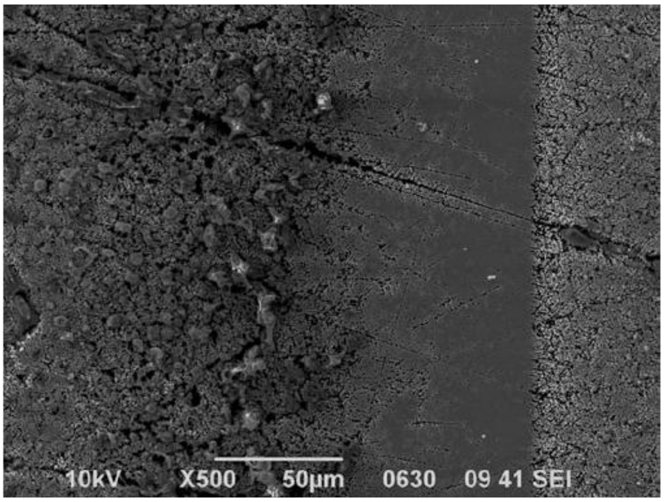


Fig. 4.9 – Surface morphology of the porous *n*-InP

The pore depth depends on the imperfection of the material in the places of their formation. The seeds of the pores are the dislocations, which are the sources of elastic stresses and generate elastic deformations around them. Elastic interactions of starting dislocations with point defects of the crystal structure lead to an increase in the concentration of residual defects near the dislocation axis and to the formation of the Cottrell cloud. During etching of the *n*-InP single crystals, the tendency is observed to grouping the pores into symmetrical agglomerations near the seed pores, which emerged previously and are associated with the outcrop of dislocations and microcracks on the (111) surface.

In some cases, the impurity atoms of the crystal act electrochemically on the dissolution processes in the region of the dislocation outcrop on the surface since the preferential localization of impurity is often performed in the region of dislocation lines. The symmetry and periodicity of the ensemble of pores repeat the symmetry and periodicity of the defect structure of InP, which emerges in the surface layer of semiconductor.

The number of etch pits in this case is considered as the measure of dislocation density. The calculation of the average dislocation density ND is performed by the formula

$$N_D = n_{av} / S; \quad (4.1)$$

where n_{av} is the average number of etch pits and S is the area of the field of view.

The calculation of the dislocation density in the places of the increased impurity concentration (dark bands) yields the value $2 \cdot 10^6$ cm^{-2}. In the regions less filled with pores, the dislocation density is ~10^4 cm^{-2}. This result agrees well with the manufacturer's data of the samples obtained from the producing company – namely, the dislocation density is 10^6 – 10^7 and 10^4 in the places of accumulation of the impurity and in the regions where the impurity concentration is lower, respectively.

It should be also noted that, in InP, the pores in the (111) plane emerge over the entire range of electric potentials of formation of the pores corresponding to the conditions of pore formation in all fluoride electrolytes.

Texturing of the Indium Phosphide Surface While submerging the semiconductor InP plate in the etchant solution, its molecules are adsorbed on the plate surface. With direct current passing through the electrolyte, adsorbed molecules detach from the surface of the plate. In this case the phosphorus atoms adsorb easier with the hydrogen ions that provide faster etching of the phosphorus sublattice. Stoichiometry of the sample is violated toward the increase in the concentration of indium atoms. As a result the set of pyramidal clusters is formed on the plate surface. Slope of the cluster edges provides the obtaining of a rather low reflection coefficient and the tenfold increase in the active area of the plate in comparison with the monocrystalline sample.

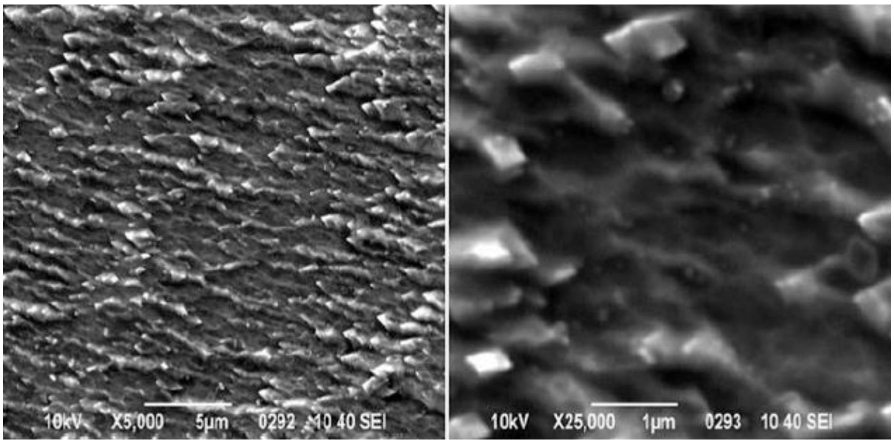


Fig. 4.10 – *p*-InP textured structure

The optimal concentration of the electrolyte, current density, and etching time were established experimentally in order to obtain the most uniform in height and shape texture. Thus, the optimal conditions for the obtaining of quailtative texturing p-InP surface are given below: the etchant composition is HBr : H_2O 1 : 1; the current density is 150 mA/cm^2; the etching time is 8 min; the power of the tungsten lamp is 200 W.

Figure 4.10 demonstrates the morphology of the textured InP plate. As seen from this figure, the dense system of pyramidal growths with the slope connected with the crystal anisotropy and current direction is formed on the monocrystal surface. The pyramid height varies from 0.7 to 1.1 mkm. Under the assumption that the abovementioned conditions are not executed, the semiconductor behavior during the anodization has some peculiarities. Thus, with the increase in the etching time up to 15 min, the pore grooves start to grow deep into the substrate that is accompanied by the plate surface failure. While etching takes less than 8 min, the incomplete surface texturing is observed, i.e., some surface regions stay with the conserved monocrystallinity and surface orientation.

If the current density is more than 150 – 170 mA/cm^2, the etching of InP layer of the thickness of about 8 – 10 mkm is observed. At current densities less than the mentioned values, the pyramids have insufficiently pronounced shape and height (less than 0.5 mkm). At higher acid concentrations in the electrolyte solution, the insoluble films composed of the adsorbed by the semiconductor surface bromine atoms are formed. At low acid concentrations the figure formation on the InP surface does not take place at all. Illumination of the plates is the necessary condition as well. This provides high density of the pyramid distribution over the surface of the sample (density is about five pyramids per 1 mkm).

We have to note that solutions of other acids also do not provide sufficient level of the surface texturing. Moreover, *n*-InP monocrystals demonstrate an inability to texture. The fact is that while anodizing in the acid solutions, the plates with electron conductivity are easily etched forming the porous layers.

Conclusion

The large and well-developed porous semiconductor surface puts on the agenda the study of the fundamental characteristics of matter that lies in the relationship and mutual influence of the surface and volumetric properties. The research can lead to answer the question: What determines the properties of porous indium phosphide – extensive surface or decrease in the volume? In any case, the modification of the morphology of space essentially creates a new interesting object, in which different classes of phenomena both physical and chemical nature are closely intertwined; besides the surface and volumetric properties in this sense are difficulty separated. In this connection, it opens the prospect of further study of the presence of fractal properties of the phenomena associated with the formation of porous space. The possibility of forming porous spaces with regular distribution of pores and diverse correct form of the intersection allows quite easily to create photonic crystals.

Etching indium phosphide in fluorinated and chlorinated etchants, along with epitaxy and lithography techniques, is included in the arsenal of modern microelectronics that allows us to create objects with reduced dimensionality. Types of porous indium phosphide (*por*-InP), which constitute a new class of substances, have different physicochemical properties: photo- and electroluminescence, adsorption sensitivity, properties of photonic crystals, etc. The presence of photo-and electroluminescence properties is directly associated with decreasing of the output dimension of the semiconductor crystal. Adsorption sensitivity is caused by the fact that substances from the environment are well adsorbed by the porous bodies.

Approaching the limits of miniaturization of classical microelectronic devices enhances the interest in devices capable of providing of the further progress of electronics. One possible way of such progress is the development and creation of devices, in which moving of certain number of electrons is controlled.

A more complete understanding of the relationship of process parameters with the characteristics of porous indium phosphide will determine the conditions for the formation of the material with strictly specified, reproducible properties that enhance its applied potential and will develop the theoretical understanding of the mechanism of pore formation in semiconductors. In addition, por-InP is a good model to study the subject of quantum size effects, fractal phenomena of self-organization, and the fundamental problems of nanoelectronics.

This subsection of the monograph is based on research materials reflected in publications [4.1 – 4.29].

4.3. DEVELOPMENT OF EFFICIENCY IMPROVEMENT METHOD OF PHOTOVOLTAIC CONVERTERS BY NANOSTRUCTURIZATION OF SILICON WAFERS [A.4.2]

4.3.1. Introduction

Modern social, environmental and economic trends of society development determine the key role of energetics in transition the strategy of society transition to sustainable development. Energy issues serve as key global issues of the day, the nature of which decision directly determines not only overcoming the ecological crisis, but construction of the global economy and development strategies. Hence, the urgency to find alternative ways to provide human by energy is followed.

The growth of the industrial capacity of mankind is based mainly on the progress in the field of energy technologies. Energetics plays a central role, as in the emergence of ecological crisis and to overcome it. Most important mechanism for harmonization of "society-energy-biosphere" system is a gradual transition to large-scale implementation of alternative energy sources in the energetics.

The most promising method of alternative energy is photovoltaic solar energy conversion method through existing advantages:

1) direct energy conversion of light photons into electricity;
2) diversity of basic framework for the production of solar cells;
3) ability to create modular systems of different capacities;
4) use of concentrated solar radiation;

5) quietness;
6) ease of use;
7) environmental friendliness and so on.

Disadvantages of using solar energy often are the following:
1) high cost of solar panels;
2) electricity generation only during daylight hours;
3) depending on the climatic conditions;
4) need for large areas to photovoltaic stations;
5) problems of energy storage;
6) imperfect technology, low efficiency and so on.

Imperfect creation technology of photovoltaic converters (PVC) and their low efficiency is a major deterrent of global replacement of traditional energy to renewable. So, there is a need to develop innovative technologies that can increase efficiency and other electrical characteristics of solar panels.

In this regard, relevant studies are devoted to finding ways to improve the processes of manufacturing photovoltaic converters. In the development of appropriate technological solutions it should be taking into account characteristics of the materials used as raw material for PVC.

4.3.2. The object of research and its technological audit

The object of this research is the process of preparing silicon wafers for further use as the main component of solar panels.

One of the problems in this process is the degradation of silicon in service and high rates of reflection coefficient, which greatly affects the PVC performance. Technological audit was conducted to identify the basic laws of state impact of silicon wafers on PVCs technology performance. Its aim is to determine the feasibility of nanostructurization of single-crystal ingots and passivation of their surface.

The basis of the most common commercial photovoltaic devices is solid single-crystal silicon solar cells with p-n-junctions [4.35]. Well established technology for producing and processing of single-crystal silicon allows maintain key positions for solar cells based on it in the near future [4.36]. The high cost of technologies for single-crystal silicon films and multicomponent technology of multilayer semiconductor structures are prevented to widespread PVCs use. Mono-Si-based solar cells have efficiency is about 15 – 20 %.

Because of a high refractive index of silicon (n = 3,5), much of the solar radiation is reflected from the surface of the photovoltaic converter (value can be ~ 35 %) and therefore do not contribute to the process of generation of electron-hole pairs. This leads to a decrease in the efficiency of converters [4.37]. Typically, this problem is solved by application of antireflection coatings on the surface of solar cells. The use of such coatings leads to the increase of the conversion efficiency, extend the life and improve electrophysical and operational performances of photovoltaic converters.

The technical and economic alternative to existing devices in the near future can make the items, which operation is based on photoelectrochemical methods of surface conversion.

4.3.3. The aim and objectives of research

The aim of this research is to develop technological solutions for treatment of the front surface of the silicon solar cells and to establish feasibility of porous layer formation on their surface.

To achieve this aim it is necessary:

1. Identify technological modes of obtaining porous silicon layer.
2. Investigate the correlation between the parameters of porous layer and conditions of crystal etching.
3. Set the feasibility of using porous silicon as the main material for PVCs.

4.3.4. Literature review

Among areas to overcome the problem of PVC imperfection it can be allocated the next:

– Search of new materials for solar panels [4.37, 4.38].

– Preparation improvement of elementary base [4.30, 4.40 – 4.42].

– Use of antireflection coatings for PVC [4.43, 4.44].

In particular, [4.38] proposes the photoelectric converter having a two-way sensitivity and made on based crystals as p- and n-type. Reduction of the rate of surface recombination in these PVCs is ensured in the implementation of techniques that specific to PVCs with PERL-structure. Efficient absorption of solar radiation is provided by using chaotic textures of direct pyramids type without further photolithography. The reflection coefficient from the front PVC surface with DSBC-structure is 5,8 %. Such PVCs in exposure mode AM1,5 have the following output parameters: U_{hh} – 704-706 mV, J_{sc} – 42,2 mA/cm^2, FF – 0,82 – 0,83. Also their technological aspects allowed to achieve the following values of output parameters: U_{hh} – 663-665 mV, J_{sc} – 32,6-36,6 mA/cm^2, FF – 0,76 –0,78, η – 16,8 – 18,6 %.

The authors of [4.38] proposed resource-saving industrial technology of radiation-stable PVCs of n + -p-p + type with area of 7 cm^2 on the basis of low-cost single-crystal silicon KDB-10 grown by the Czochralski method, with thick $t_к$ = 350 ± 50 microns, orientation (111) and (100), which in exposure mode AM0 have efficiency of 12 – 15 %. Development of such PVCs provided an opportunity to use them to build solar cell of spacecraft KS5MF2 «Micron» – the first in Ukraine from spacecraft series «Microsatellite».

The technology of porous layers of semiconductors by electrochemical etching is represented in [4.30, 4.40, 4.41]. The use of porous silicon for solar panels was investigated by the authors of [4.43]. It was proved that the increase in conversion efficiency (25 – 30 %) is achieved for the por-Si solar cells compared to cells without porous layer.

The authors of [4.43, 4.44] believe that the most promising antireflection coating for photoelectrochemical cells is zinc oxide (ZnO). This material is cheap, accessible and non-toxic. But consensus on the morphology of these coatings is still not there.

Thus, the results suggest that the consensus on the possibility of improving the efficiency of photovoltaic energy conversion does not exist. Obviously, the choice of the most appropriate technical solution should be based on experimental and theoretical studies of the structure and properties of porous silicon layers.

4.3.5. Materials and methods of research

Samples of single-crystal n-type silicon of solar grade (silicon with silicon content of more than 99,99 % by weight, with an average lifetime of non-equilibrium carriers of 25 microseconds and electrical resistivity of 10 Ohm*cm) were selected for experiment. Surface orientation: (111) (100) (001). Silicon single crystals were grown by the Czochralski method and doped with phosphorus. Then the ingots were cut into 1 mm thick wafers by the method of wire cutting by the diamond-impregnated wire. Samples were purified in acetone and isopropanol before thee experiment.

The layers of porous silicon were formed by electrochemical etching in a solution of hydrofluoric acid at room temperature. This method is the most common for making porous semiconductors, due to the simplicity and low cost [4.30]. In addition, this method is different from other by rate and accountability of the process. Multivariate implementation of the method is technically possible, combining it with other additional (external) physical and technological influences, factors, fields and so on.

Another factor that makes electrochemical crystal processing as attractive method for forming porous spaces is the possibility to adjust the pore size from a few nanometers to tens of micrometers [4.40]. This is achieved by adjusting the doping level and orientation of the surface wafers and etching conditions. In addition, a wide range of porous characteristics such as thickness, porosity, effective area surface and morphology may control, changing etching conditions.

The conditions of the experiment were chosen in the following range of characteristics:

a) current density – from 10 mA/cm^2 to 2,2 A/cm^2;

b) etching time – from 5 to 30 minutes;

c) electrolyte – HF : H_2O = 1 : 1;

d) electrolyte temperature – 20 ^oC.

The scheme of the simplest galvanic cell is shown in Fig. 4.11. The silicon wafer serves as the anode, the cathode is platinum.

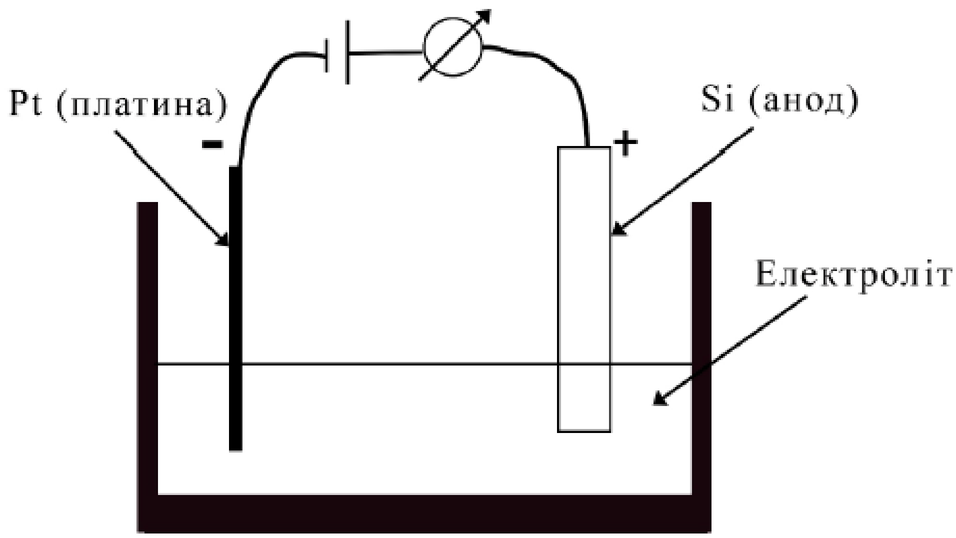


Fig. 4.11 – The scheme of device for electrochemical silicon etching
In the figure the following symbols are applied:
Электролит – Electrolyte; Анод – Anode; Платина – Platinum

Samples after experiment had several stages of cleaning: washing in ethanol, deionized air drying and annealing in a stream of nitrogen. Annealing is carried out to stabilize the properties of porous wafers. Oxide layer is removed from semiconductor surface using this passivation method. Thin crystalline film of chemically inert material is formed instead of this layer. Such film can do the properties of ultrathin buffer layer and protect the semiconductor surface from contact with aggressive components of the environment.

4.3.6. Research results

The thickness of the porous silicon layer on the Si substrate adjusts with etching time. The porosity, i. e. the proportion of voids in the porous layer, is depended on the current density of the electrolyte, resistance and Si substrate doping density.

Anodic reaction during the formation of porous layer can be written as:

$$Si + 6HF \rightarrow H_2SiF_6 + H_2 + 2H^+ + 2e^-. \qquad (4.2)$$

Atoms of silicon creates adatoms SiF_6^{2}-, requiring the presence of ions F^- (from HF solution) [4.38]. Adatoms escape from the wafer surface and create rudimentary positively charged holes. The concentration of holes in positively charged silicon is enough (about 10^{14} – 10^{18} cm^{-3}) for the formation of nanometer-sized pores.

When using a fairly low current density (from 10 to 200 mA/cm^2), there is a local solution of single-crystal silicon surface. Rudimentary pores are formed in places with surface defects, further the pores are growth into the depth of the silicon substrate. This process occurs by diffusion of the holes to the interface Si-electrolyte.

In the case of high current density (0,3 – 1 A/cm^2), when the number of holes moving to the border Si-electrolyte is very high, is the most appropriate is etching of upper regions of the silicon substrate. It provides uniform etching of silicon surface and formation of a smooth substrate surface (called electrolytic polishing process).

Increase of current density above the critical point at the end of anodizing process leads to disconnection of the porous silicon film from Si substrate. Such behavior at high current density is useful for separating porous layers from substrate.

Fig. 4.12 shows the morphology of porous silicon grown on the surface of n-type mono-Si. The porous layer has a developed structure, pore size ranging from 0,2 to 3 microns, porosity is about 70 %. The thickness of the porous layer is 35 microns. Pores have a columnar structure.

In this case, there is heterogeneity of porosity and thickness of the porous layers. Most likely, this is due to the presence of bubbles that formed in the electrolyte and bonded to the silicon surface. To avoid this heterogeneity, concentration of HF should be locally constant on surface of the silicon substrate.

Removal of the bubbles from the surface of a silicon wafer, and, thus, obtaining of homogeneous porous silicon layers is done by means of electrolyte mixing. The distance between the silicon wafer and the platinum cathode also affects the uniformity, while form of the platinum cathode virtually no affects homogeneity.

The thickness of the porous layer depends primarily on etching time. Fig. 4.13 shows the experimental dependence of the thickness of the porous silicon area (100) under the following etching conditions: current density j = 150 mA/cm^2, etching time t = 20 min, electrolyte HF : H_2O = 1 : 1. It is shown that the average growth kinetics of porous silicon layer is about 2,2 m/min. It is noted that this parameter is determined for each etching case separately.

It should be noted that porous silicon is a special form of crystalline silicon. The crystal structure of porous silicon is a network of silicon in nanoscale areas surrounded by empty space with a very high ratio of surface area to volume (up to 10^3 m^2/cm^3) – so-called effective area of the crystal. Quantum effects in this case play a fundamental role. In particular, the photoluminescence of porous silicon shows shear in short-wave spectrum in relation to the crystal.

The porosity shows a nearly linear dependence on the current density in the range of 30 to 200 mA/cm^2 (Fig. 4.14) at constant other parameters.

Materials used as raw materials for the manufacture of solar cells have a number of requirements, including:

1) direct band gap structure;

2) band gap width from 1,1 to 1,7 eV;

3) must be composed of readily available and non-toxic materials;

4) good photovoltaic conversion efficiency;

5) long-term stability.

Silicon is the second most abundant element in the earth's crust (35 %) after oxygen. This is the basic material for photovoltaic conversion of solar spectrum radiation ranging from ultraviolet to near-infrared region of the spectrum, but it can absorb a small portion of solar radiation that can convert photons with energy of band gap of silicon. The theoretical curve for the conversion efficiency of solar cell material compared to the band gap shows that silicon (1,1 eV) is not at maximum of the curve (about 1,4 – 1,5 eV), but relatively close to it. Efficiency for ideal silicon solar cells can reach about 30 % (at 300 K) [4.38].

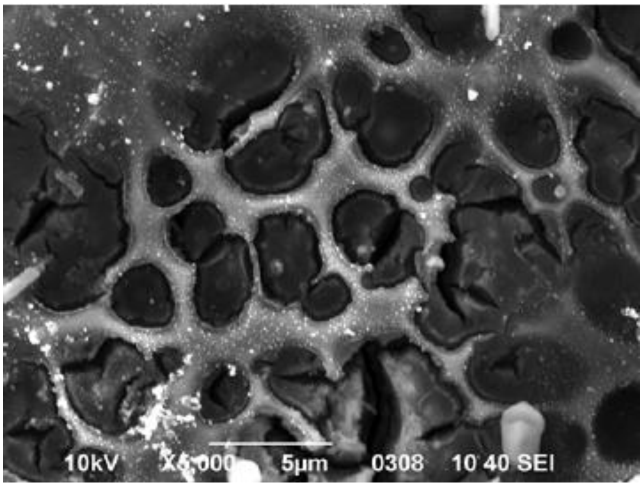


Fig. 4.12 – Morphology of por-Si (100): current density j = 150 mA/cm^2, etching time t = 20 min, electrolyte $HF:H_2O$ = 1:1

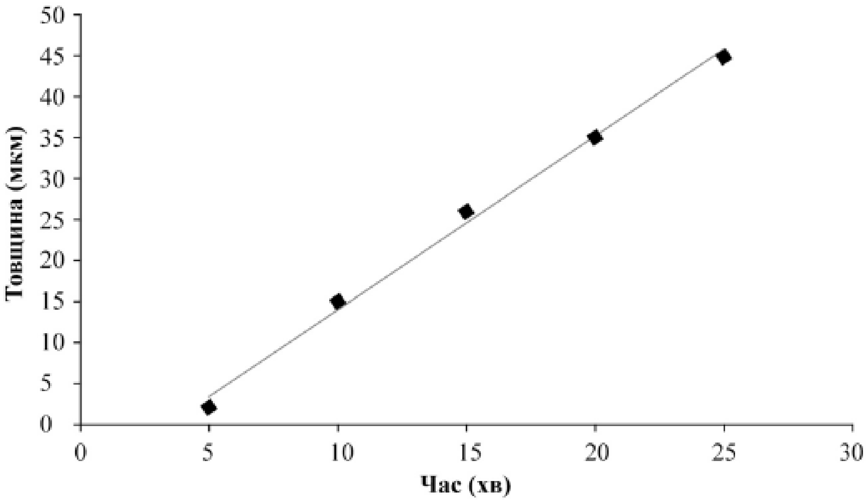


Fig. 4.13 – Increase of the porous silicon layer thickness (100) during electrolytic processing in 50 % solution of hydrofluoric acid for 20 minutes at a constant current density j = 150 mA/cm^2

In the figure the following symbols are applied:

Час (хв) – Time (min); Товщина (мкм) – Thickness (micrometer)

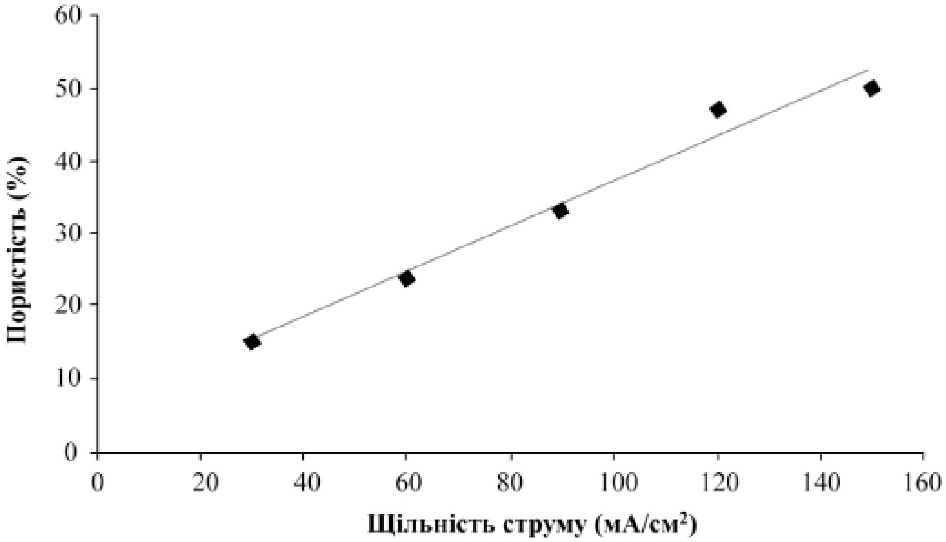


Fig. 4.14 – Porosity dependence on the current density (for por-Si (100), current density j = 150 mA/cm^2, etching time t = 20 min, electrolyte HF : H_2O = 1 : 1) In the figure the following symbols are applied:
Пористість (%) – Porosity (%);
Щільність струму (мА/см^2) – Current density (mA/cm^2)

Photoelectron properties associated with non-direct band gap structure and high reflectivity of crystalline silicon (about 30 –35 %) still do it as contender for making solar cells with high conversion efficiency. The high refractive index of crystalline silicon (about 3,5) in the solar spectrum (300 – 1100 nm) creates large optical losses that can be reduced by using antireflection coatings (ARC). Although availability of highly-effective double and triple antireflection coatings, most industrial crystalline silicon solar cells use simple and inexpensive single-layer ARC with relatively poor antireflection properties.

Opportunities for reflectivity minimization (by catching the light in the pores), an increase band gap width of porous layer of silicon (through quantum maintenance of the charges in microcrystallites por-Si) by changing the porosity allow to use the layers of porous silicon as antireflection coating, and as broadband photosensitive layer.

The high degree of surface roughness of the porous silicon allows for its use as ARC, because the textured surface reduces light reflection. In addition, scattering in por-Si may be due to the roughness relative to the thickness of the porous layer.

4.3.7. SWOT analysis of research results

Strengths. Among the strengths of this research it should be noted results in optimal conditions of silicon etching to formation of porous layers on its surface, as well as determining por-Si parameters from anodizing modes. In favor of this assertion are evidenced the above analysis results of contemporary world literature, where no such correlation. This is holding back the beginning of the use of porous silicon as the main base of the solar panels. Use of the proposed dependencies will optimize the electrochemical crystal etching process and produce the layers of porous silicon with strictly controlled properties.

Weaknesses. Weaknesses of this research are related to the fact that the proposed solution will be effective when using ultrapure dislocation-free silicon. Using polycrystalline wafer, electrochemical treatment will not lead to the formation of the porous layer. Wafers of monocrystalline silicon are known to be much more expensive than other versions of this semiconductor. This can lead to an increase in the cost of silicon solar panels. However, the expected significant increase in the efficiency of photovoltaic converters will minimize this factor.

Opportunities. Additional features that achieve the aim of research appear likely in these external factors. Considered technological object is widely studied by foreign scientists. Green energy program is introduced in the world. In Japan, there are programs «Sunshine» and «Moonlight». Germany has a government program that provides tax incentives to manufacturers of solar panels, which are mounted on rooftops. At the same time for several years there is a program «One hundred thousand solar roofs». A similar program «Million Solar Roofs» is in the US. Solar energy market is growing rapidly. Thus, the demand for solar cells of new generation will grow. This is a motivating factor for further research in this area.

Threats. Difficulties in the implementation of research results are related to the following factors. The first of these is knowledge-base of proposed technologies that require, on the one hand, the training of qualified personnel and, on the other hand, considerable resources. Another factor is the market of modern solar cells. Leaders of industrial solar cells today are Chinese companies that offer solar panels are much cheaper than other manufacturers. However, such PVCs are much inferior to their performance. It is necessary shift in the direction of product quality from the price.

Thus, SWOT-analysis of research results allows to determine the main directions for the successful achievement of the objectives of research, including: further improvement of obtaining porous layers of semiconductors, integration of porous layers in elementary base of photoelectrochemical converters, investigation of surface passivation modes for the purpose of refusal of ARCs.

4.3.8. Conclusions

1. The technological modes of obtaining porous silicon layer are determined. The porous silicon is expedient form by electrochemical etching in a solution of hydrofluoric acid. It is established that nitrogen annealing of the samples after etching leads to stabilization of the properties of porous silicon layer.

2. The dependence between the parameters of porous layer and

conditions of crystal etching is investigated. It is established that the thickness of the porous layer is correlated with the etching time. The porosity shows a nearly linear dependence on the current density in the range of 30 to 200 mA/cm^2 at constant other parameters.

3. The feasibility of using porous silicon as the main material for making PVCs is established. The high degree of surface roughness of the porous silicon allows for its use as ARC, because the textured surface reduces light reflection.

4.4. PROVISION OF ENVIRONMENTAL SAFETY THROUGH THE USE OF POROUS SEMICONDUCTORS FOR SOLAR ENERGY SECTOR

[A.4.3]

4.4.1. Introduction

An analysis of the present state of ecological situation in Ukraine displays a trend to deterioration. The rapid pace of modern technological development has caused a significant increase in the consumption of energy resources. Energy sector is the basis for the development of all the sectors of industry. At the same time, energy sector is one of the main sources of adverse impact on the environment, such as hydro, atmo-, and lithosphere. About half amount of anthropogenic greenhouse gas emissions and harmful substances are produced by sector of traditional energy.

On the other hand, Ukraine meets its needs in energy sector only by 70 %, that is, it is an energy dependent state. In terms of resource provision, sufficiency and reliability of electricity and heating supplies that meet the growing needs of economy and population are of paramount importance, in terms of quality of life, a crucial problem is ecologically friendly energy production. Aspects of the energy sector are a key global challenge, the nature of which directly influences not only the construction of the global economy and strategies for the development of the state, but also overcoming the environmental crisis. Hence is the relevance of finding alternative ways of supplying the humankind with energy.

The most promising method of alternative energy sector is photoelectric method of converting solar energy due to its evident advantages:

– direct conversion of energy of light photons into electrical energy;
– variety of elementary base for creating solar elements;
– opportunity for creating modular systems of various capacities;
– ability to use concentrated solar radiation;
– absence of noise;
– operation simplicity;
– environmental friendliness, etc.

Shortcomings of using solar energy most often include the following: high cost of solar panels, generation of electricity only during daylight hours, dependence on climatic conditions, need for large areas for the installation of photoelectric power plants, problems with energy accumulation; imperfection of technology and low efficiency, etc.

The imperfection of technology of creation of photoelectric modifiers (FEM) and their low performance efficiency (PE) are major restraining factors to global replacement of traditional energy with renewable energy. Thus, there is a need for the development of innovative technologies that can improve performance efficiency and other electro-physical characteristics of solar panels.

At the modern level of production, manufacturing silicon solar elements with a total capacity of 100 GW requires not less than 1 million tons of silicon of high purity degree [4.45]. To achieve the expected capacity of the solar photoenergy sector by 2030 [4.46], it is necessary to produce pure silicon in the amount not less than 20 thousand tones annually, which is not only complicated technological and financial, but also ecological problem, because obtaining pure silicon is an environmentally harmful production. Another shortcoming of traditional silicon solar elements is relatively low energy efficiency – on average, about 11 % [4.45]. The use of nanostructures would allow a significant improvement of characteristics of photoelectric modifiers.

The relevance of the research is predetermined by the necessity of solving environmental and resource problems and lies in developing the methods of providing for environmental safety by using nanostructures for solar energy.

4.4.2. Literature review and problem statement

Paper [4.47] proposes the way of texturing silicon to increase effectiveness of converting solar energy. The authors of the work propose to use silicon of multi-porous structure as the front surface of the solar element. The method of "hybrid" technology based on the developed crater- and column-like morphology of silicon surface makes it possible to change the type and dimensions of the multi-porous texture in a wide range. Both chemical and electrochemical technologies do not require thermostabilization, since porous silicon is formed at room temperature.

Article [4.48] considers the possibility of applying two- and three-layer anti-reflecting coatings (ARC) based on porous silicon for silicon photovoltaic modifiers by means of approximation of the optical matrix. Based on this method, the spectra of displaying anti-reflecting coatings of MgF_2/ZnS, SiO_2/TiO_2 and MgF_2/CeO_2 were calculated, which are usually used in the photovoltaic modifiers, and the results of calculations were compared with the corresponding experimental data. It was shown that the spectra of displaying, calculated using the method of approximation of optical matrices, and the experimental data coincide. The aforementioned multilayer anti-reflectors of coating result in the improvement of characteristics of silicon solar elements, but have the following shortcomings: magnesium fluoride and zinc sulfide are relatively soft materials and have little resistance to aggressive environment, which over time leads to the degradation of parameters of solar elements. Unlike standard ARC with SiO_2/TiO_2 and other materials used in silicon photovoltaic converters, using porous silicon, it is possible not only to save a small image in the visible and infrared spectrum areas, but also to expand it into the short-wave (UV) area (up to 400 nm).

In paper [4.49], textured pyramidal silicon layers were formed using the method of electrochemical etching. The authors demonstrated that the larger the height of pyramid clusters, the lower reflecting ability, observed in the range of short wavelengths. The feasibility of using porous silicon as material for solar elements was substantiated by researchers in article [4.50]. An increase in porosity of crystals causes the blue shift and an increase in photoluminescence peaks [4.51].

Porous silicon is widely used for optoelectronic devices due to antiglare properties. This material has the following advantages: the expansion of the restricted zone, a wide range of absorption and a high range of optical transmission from 700 – 1000 nm. Paper [4.52] presents experimental research into electrochemically prepared porous silicon structures. It was found that with an increase in the time of etching, the thickness of por-Si also increases, and the index of refraction is reduced accordingly. A high degree of roughness of porous silicon surface implies its application as antirefracting coating, the textured surface reduces light reflection. In addition, scattering in por-Si is possible due to roughness in relation to thickness of the porous layer.

Authors of article [4.53] obtained solar elements based on por-Si at the efficiency of 15.5 %. Porosity of the samples reached the value of 91 %, which causes blue shift of PL. Prepared samples of por-S layers with different porosity were used for manufacturing solar elements, using the following procedure. The samples were coated with photo resister. Then the mask was placed directly above the layers of porous silicon. The samples were subjected to the action of UV radiation for 40 seconds to form a patterned coating. N- and P-type of alloying were achieved by using the method of coating by placing the phosphorus and boron solution in the middle of the layers of por-Si, and then applying coating by centrifuging at the rate of 1000 rpm for 10 seconds at room temperature. Then the por-S layers were placed in a furnace at the temperature of 100 °C for 15 minutes to remove the moisture.

As we can see, world scientists actively explore the methods of creating photoelectric modifiers based on nanostructured silicon. In addition, the nanostructures based on the semiconductor group A3V5 [4.30, 4.33] and A2V6 [4.54] are increasingly considered as the material for solar elements. But still there is no unified mechanism to obtain nanostructured semiconductor layers with the assigned properties. The aspects of correlation between parameters of porous layers and conditions of their obtaining are not explored enough. In addition, the problems of provision of the environmental safety (ES) by introducing nanotechnology into the alternative energy sector is not sufficiently explored either.

4.4.3. The aim and tasks of the study

The purpose of this study is to search for the methods of providing for the environmental safety by using nanostructured semiconductors as an elementary basic framework for photoelectric modifiers of energy.

To achieve this aim, the following tasks were to be solved:

– to develop a scheme of the problems for providing environmental safety for solar energy sector;

– to establish the types of negative influence of traditional energy sector on the ecological state of the environment, to compare factors of influence on the environment of traditional and non-traditional sectors of energy industry;

– to explore basic regularities of the formation of a porous layer on the surface of semiconductor of the A3V5 group and of silicon;

– to select essential technological stages of production of solar panels based on nanostructured semiconductors;

– to establish and propose methods for increasing the efficiency of photoelectric modifiers of energy based on nanostructured materials.

4.4.4. Materials and methods of research into provision of environmental safety by using nanomaterials for solar energy sector

To solve complex technological, technical, environmental, economic and other problems, a systems analysis is widely used. This scientific approach can rationally formulate and solve complex problems, which are characterized by the capacity of structuring and selecting specific tasks, taking into account available resources. Therefore, we will accept the systems approach as methodological foundations for achieving set purpose of providing environmental safety.

Environmental safety should be seen as a dynamic process, evolving and improving in interconnection with scientific research, design-technological and organizational-technical preparations for controlling this process. To formalize the solution of the set problems, we used the principle of multilevel decomposition. This principle is characterized by dividing the process into hierarchical levels of functionally completed stages of solving a complex of local problems at this level.

Development of technological stages of production of solar panels was based on the principle "from the particular to the general". In this case, attention is paid not only to the technical aspects of this process, but also to the scientific principles of obtaining and implementation of innovative technologies, in particular, obtaining materials for photoelectric modifiers of energy.

To obtain and study the possibility of using nanomaterials for FEM, the sets of plates of semiconductors of silicon (Si), gallium arsenide

(GaAs), indium phosphide (InP), gallium phosphide (GaP) were used. The plates were previously cleaned and polished. The method of photo-electrochemical etching in acid solutions was used as a method for obtaining nanostuctures at the surface of semiconductors. In order to stabilize properties of the derived structures, passivation by ammonia was used. The morphology was examined with the help of a raster electronic microscope.

4.4.5. Results of studying ways of providing environmental safety based on using nanostructured semiconductors for the fabrication of solar elements

4.4.5.1. Systems approach to the problems of providing environmental safety based on nanostructures for the fabrication of solar elements

With regard to the model of providing environmental safety, a hierarchical construction of its structure and the establishment of structural links between the components mean the following subordination of its technological components: it is impossible to develop and produce technological equipment or install a range of the necessary equipment without preliminary development of technological processes of controlling the ecological safety [1.12].

Hierarchical levels of stages for solving a set of problems to control environmental safety, which uses innovative technologies for solar energy sector, are presented in Fig. 4.15. In order to construct a multilevel decomposition scheme, we used the study into the functions of components of the system of environmental safety control as an integral part of the creation of methodological base for constructing such a system [1.8].

In the process of building a hierarchical structure for the system of controlling the environmental safety, we adhered to the basic principles of multilevel decomposition:

– existence of vertical and horizontal links between the levels and stages;

– priority of action of the levels and stages from top to bottom;

– interrelation of the levels, variability of the selection and solution of tasks at each level.

Thus, a generalized scheme of providing environmental safety consists of four stages, each of which contains two levels. The first stage involves the identification of sources and classification of factors of environmental danger. At this level, it is necessary to study the influence of energy sector on the environment.

The task of the second stage is development of technologies and technological processes that can improve the state of environmental safety.

In this case, by preliminary technologies we should imply the methods of treatment of semiconductor plates, which will be applied to PEP.

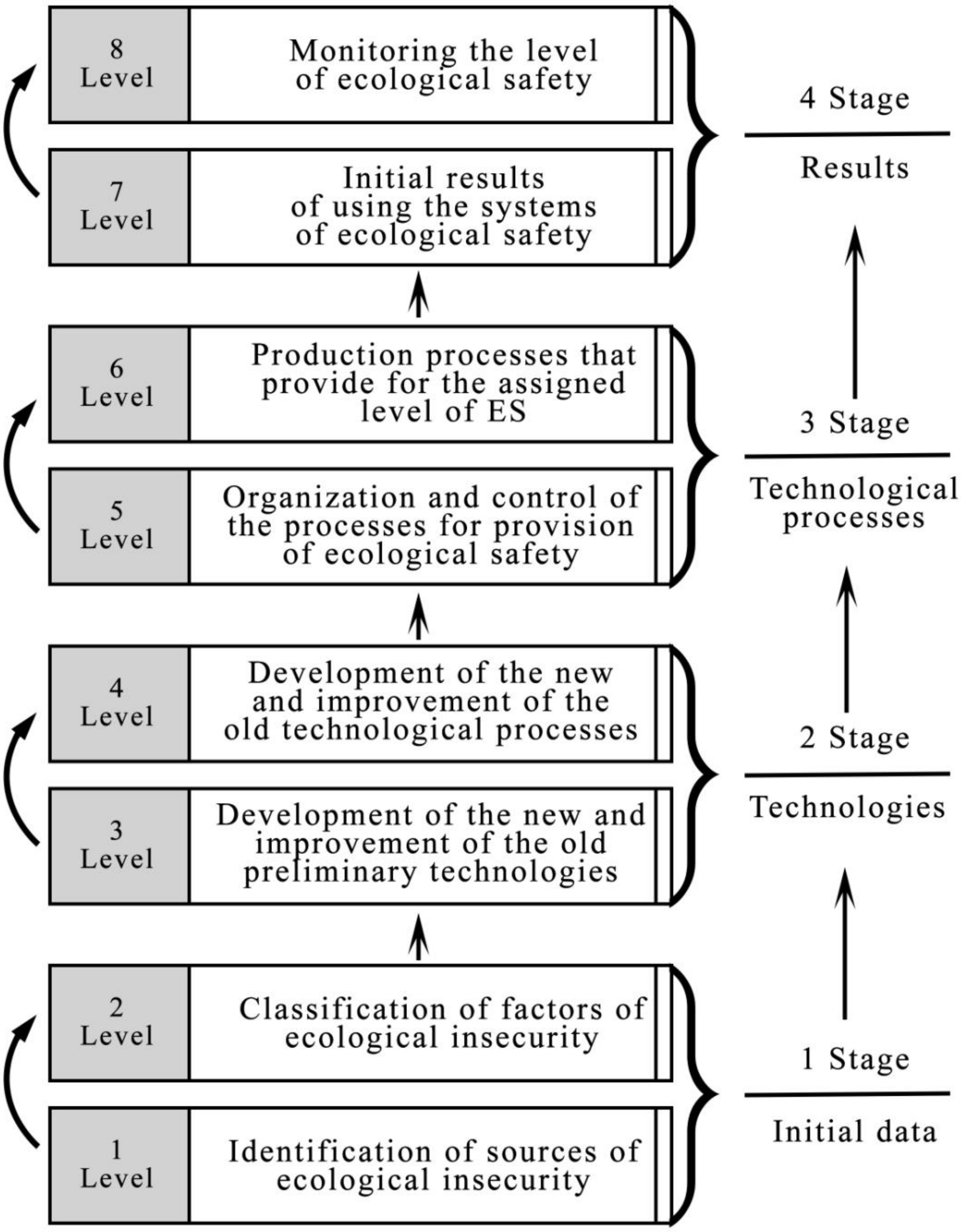


Fig. 4.15 – Scheme of multilevel decomposition of the problems for providing environmental safety through the use of innovative technologies for solar energy sector

The third stage involves organization and implementation of technological processes that provide a specified level of environmental safety. Technological processes include the stages of production of solar panels based on semiconductor nanostructures.

At the fourth stage, it is necessary to evaluate effectiveness of the proposed technologies through examining basic physical parameters of the received structures and to explore the ways to increase efficiency of photoelectric modifiers of energy.

4.4.5.2. Identification of environmental sources and classification of factors of ecological danger in traditional and non-traditional energy sectors

Renewable energy sources are believed to be the real ways of protecting against climate changes without creating new threats for the population and future generations.

Comparison of basic forms of influence of traditional and alternative energy sectors on the environment is presented in Table 4.4.

Table 4.4 – Influence of different types of energy sector on the environment

1	Influence	Traditional energy sector	Solar energy sector
2	Resources	use of non-renewable resources	the energy source is completely renewable
3	Hydrosphere	thermal pollution of water bodies, exhausts of polluting substances	does not influence the state of hydrosphere
4	Atmosphere	thermal effect, gases and dust emission into the atmosphere	ecologically friendly kind of energy
5	Lithosphere	pollution during energy carriers transportation and burying wastes and during energy production	does not pollute lithosphere, however requires considerable areas for locating PES
6	Radioactivity	contamination with radioactive and toxic wastes	radioactive elements are not used
7	Temperature of atmosphere	temperature rise	there is an opinion that the use of solar energy is able to increase considerably temperature near the surface of Earth, but this theory has not been proved
8	Hydrological mode of rivers	change in the mode under the influence of hydroelectric power plants as, as a result, pollution on the territory of a water body	does not influence
9	Electromagnetic fields	creation of electromagnetic fields around the electric power lines	are not created
10	Technogenic catastrophes	there is a risk (supported by many examples) of emergencies at power plants	this kind of risk is reduced to minimum. When one panel fails, the others continue operation without any changes

To align a constant growth in energy consumption and increasing negative effects of energy sector, taking into consideration that the humanity will feel the shortage of energy resources, may by possible using two methods: energy saving or development of environmentally friendly types of energy production, which include energy of the Sun.

4.4.5.3. Nanostructured semiconductors as the base for creating photoelectric power modifiers

Solar cells have traditionally been produced based on monocrystalline silicon. Their efficiency, as a rule, does not exceed 15 – 20 %. In addition, such elements are fragile and require existence of anti-reflecting coating, improvement in technologies, etc.

Overcoming a number of problems becomes possible under condition of nanostructuring of semiconductors, namely the formation of a porous layer on the surface of the plates [4.31]. Such technology can largely improve the electrical and physical properties of solar elements due to the multifold increase in the working area of the plate (due to the existence of a huge number of pores at the surface). In addition, a significant increase in the efficiency of solar elements is expected, as well as the intensity of their absorption of light, the possibility of accumulation of large amount of energy, a longer operation term (increasing life cycle of the device), etc. As it was mentioned above, porous surfaces are formed by the method of photoelectrochemical etching. Using various modes of processing, one can control parameters of the obtained structures (Table 4.5, Fig. 4.16). The plates of semiconductors of Si, InP, GaAs, GaP with the n-type of conductivity with the orientation of the surface were selected (111). The period of etching for all samples was the same – 10 min, density of current was 150 mA/ cm^2.

The received structures are characterized by stability of chemical and electrical properties. Porosity of samples is in a wide range from 20 to 80 %, the most common is the value of 40 –60 %. According to results of the study, we can conclude that the smaller the size of pores, the more orderly the pores are arranged and the larger the value of porosity is.

Analyzing data in Table 4.5, it can be argued that the addition of electrolyte ethanol to the solution leads to increased permeability of the solvent into the pores. This creates a better germination of pores into the crystal thickness and creation of massive pores.

The non-uniformity of porosity and thickness of porous layers can be explained by the existence of bubbles that are formed in the electrolyte and stick to the surface of the crystal. To avoid this non-uniformity, the concentration of HF must be locally constant at the surface of the treated sample. Removal of bubbles from the surface of the plate, and therefore obtaining homogeneous layers of porous layer is achieved by mixing the electrolyte. Distance between the plate and the platinum cathode also affects the uniformity, while the shape of the platinum cathode virtually has no impact on uniformity.

It is necessary to note that the most common regularities in the formation of porous layers at the surface of semiconductors were presented above. The processes of pores formation differ for different crystals. At present, there is no single model for the formation of nanostructures. However, in all cases, it is possible to conduct certain generalizations:

Table 4.5 – Modes of obtaining nanostructures at the surface of semiconductors and dimensions of the formed pores

Semiconductor	Electrolyte	Dimensions of pores, µm	Specific features of pores formation
Si (Fig. 2, a)	HF: H_2O=1:1	0,2 – 0,4	Cylindrical pores, surface is covered with passivating layer
	HF:H_2O:C_2H_5OH=2:1:1	0,4 – 0,8	Cylindrical pores, the length of a pore is 100 µm
InP (Fig. 2, b)	HF: H_2O=1:1	0,05 – 0,1	Densely packed cylindrical pores
	HF:H_2O:C_2H_5OH=2:1:1	0,1 – 0,4	Densely packed cylindrical pores first grow in crystallographic directions, then are leveled along the lines of current, the length of a pore is up to 100 µm
GaAs (Fig. 2, c)	HF: H_2O=1:1	0,4 – 0,8	Uneven pored layer with low porosity (up to 20 %), the surface is covered with an oxide layer
	HF:H_2O:C_2H_5OH=2:1:1	0,6 – 0,9	Porosity amounts to 50 %, the length of a pore may amount up to 20 µm
GaP (Fig. 2, d)	HF: H_2O=1:1	0,4 – 0,7	Pores have a "crater" construction, are located on the surface unevenly, the length of a pore is up to 3 µm
	HF:H_2O:C_2H_5OH=2:1:1	0,5 – 0,8	Pores have a "crater" construction, are located on the surface unevenly, the length of a pore is 10 – 20 µm

– thickness of a porous layer correlates with the duration of crystal etching. In this case, there is critical duration of time, within which the pores formation is terminated and alternative processes take place (removal of porous layer from the surface, polishing etc.). For each semiconductor, this period is an individual indicator;

– density of current, at which processes of the pores formation are observed, is in the range from 20 to 200 mA/cm^2. At lower density of current, only a local etching of the deformed areas of plate takes place, whereas at an excessively large index of this parameter, the plate polishing is observed;

– hydrofluoric acid is not only a single available etcher for semiconductors of the group A3V5 and silicon. Pores may be formed using bromide, nitric and hydrochloric acids. In this case, the morphology of porous plates will be significantly different depending on the chosen type of etcher and its concentration in electrolyte;

– the shape of the pores and density of porous layer are also strongly influenced by parameters of the crystal itself – the type of conductivity, surface orientation, degree of alloying of plates, the number of point defects and dislocations, etc.

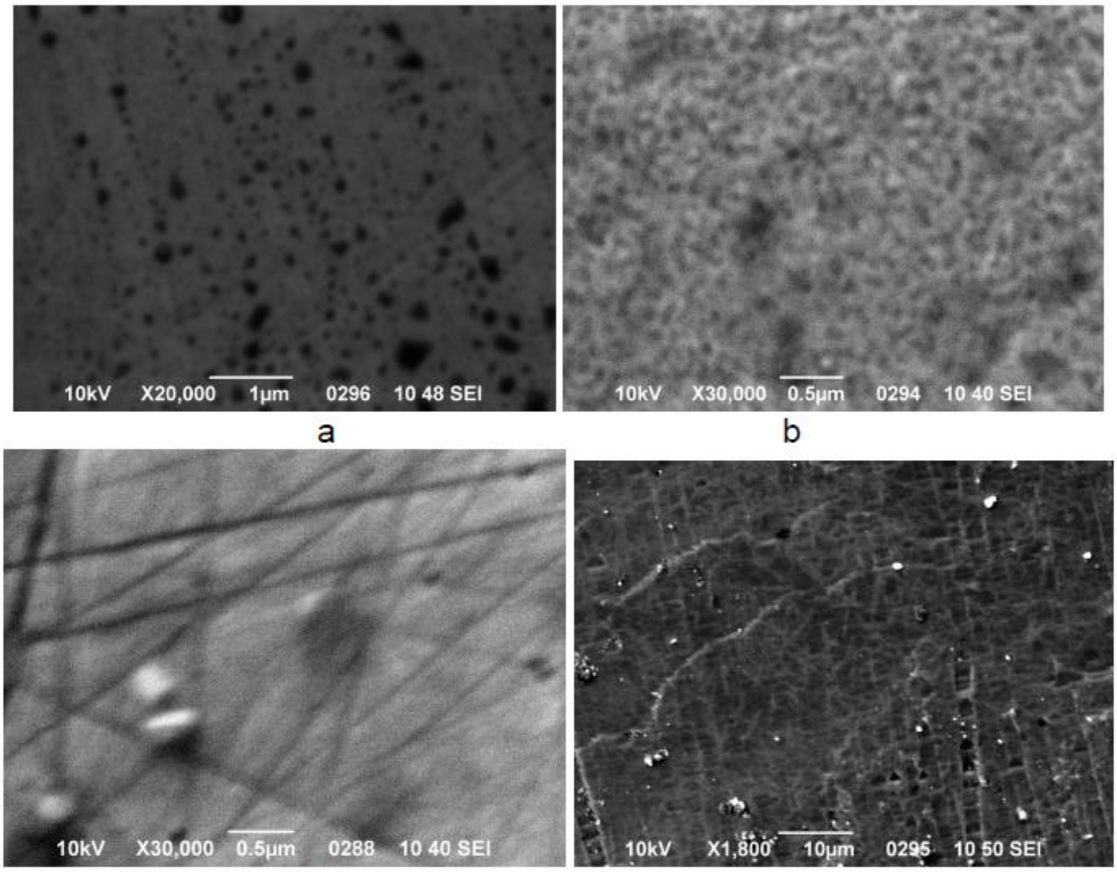


Fig. 4.16 – Morphology of porous structures at the surface of semiconductors obtained by the method of electrochemical etching at current density of 150 mA/cm^2 for 10 minutes in the solution of electrolyte HF : H_2O = 1 : 1: a – por-Si; b – por-InP; c – por-GaAs, d – por-GaP

By varying the conditions of etching for different crystals, it is possible to obtain a significant diversity of morphology of porous layers. The main task is the possibility to control the processes of self-organization of nanostructures with the view to forming porous layers with the assigned properties. In more detail the processes of pores formation at the surface of semiconductors are considered in papers [4.34, 4.32]. Studies [4.58 – 4.60] present mechanisms for the formation of nanostructures on other semiconductors. Summarizing the obtained experimental data, we concluded that during the formation of low-dimensional structures, the processes of self-organization appear, however, it becomes possible to predict morphological and, as a consequence, electro-physical properties of the obtained structures changing conditions of the experiment.

4.4.5.4. Development of technological stages of the fabrication of solar panels

Technological route determines the sequence of operations and composition of technological equipment. Quality of the device and effectiveness of its production largely depend on the way the technological route is built. Development of the route includes:

1) selection of technological bases and the sequence of producing the elements;

2) determination of the workpiece modules and technological transitions;

3) development of the sequence of workpiece treatment;

4) formation of operations. The basic most important stages are presented in Fig. 4.17.

It should be noted that, in reality, different variants of the sequence of production of the same construction are possible. This multi-variability is the resulting effect of a large number of factors: size of the series, availability of production equipment, a variety of tools, the ease of installation, organizational factors, etc.

4.4.5.5. Assessment of feasibility of using nanostructures for photoelectric modifiers

The formation of porous layers at the surface of semiconductors results, first of all, in an increase in the effective area by thousands and tens of thousands times (depending on the degree of porosity). Obviously, this fact leads to the increased efficiency (20 % and higher) of solar modules under condition of using nanostructures. Photoluminiscence of porous structures demonstrates a shift in the visible portion of light. Due to this, the target range of electromagnetic radiation extends throughout the entire visible region, including its long-wave part. The high degree of roughness of the porous layer surface implies the possibility of its use as antirefraction coating, since the textured surface reduces the light reflection. In addition, scattering is possible due to roughness in relation to thickness of the porous layer.

The possibilities to minimize the reflection capacity (due to catching light in pores), an increase in the width of the restricted area of the porous layer (due to quantum retaining of charges in microcrystals) by means of changing porosity, make it possible to use the layers of a porous semiconductor as anti-reflecting coating, and as a broadband photosensing layer.

Under condition of using nanostructured semiconductors, the sensitivity of solar panels to the contamination of the surface decreases greatly. This happens due to a thin passivating layer, formed during etching of semiconductor and further treatment of the samples with ammonia.

The economic benefits of using porous silicon in solar power sector include low cost of an area unit of a solar battery, which is provided for by the cost parameters of the basic technology of porous material production.

The represented above advantages of using nanostructured semiconductors over the monocrystalline ones make them unquestioned candidates as the basic material for PEP.

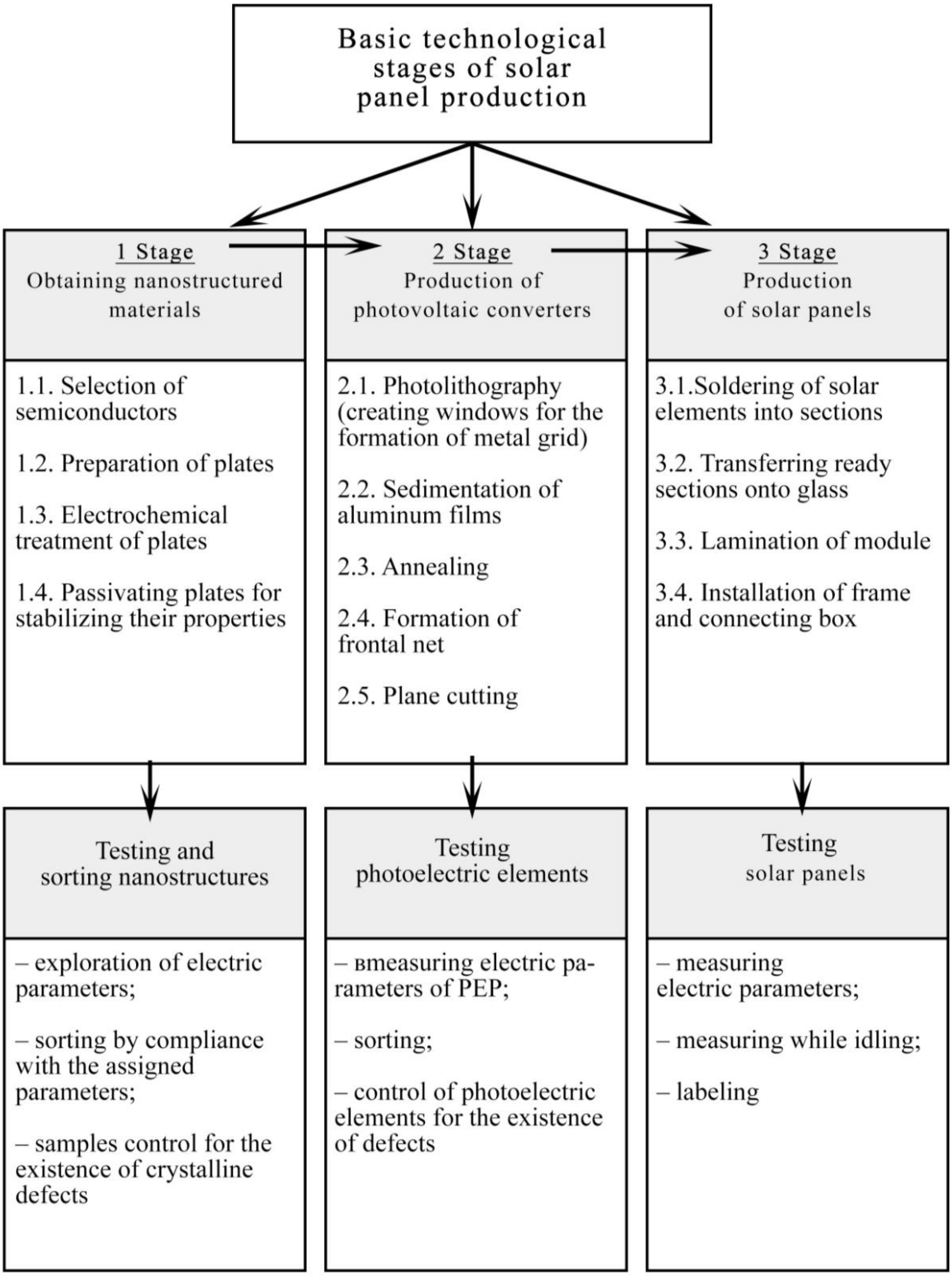


Fig. 4.17 – Technological stages of the fabrication of solar panels based on nanostructured semiconductors

4.4.6. Discussion of results of research into provision of environmental safety by using nanostructures for solar energy sector

As a result of the study, we completed all four stages of the multilevel decomposition of the problems for providing environmental safety through the use of innovative technologies for solar energy sector (Fig. 4.15). Thus, at the first two levels, the main sources of threats arising from the use of traditional energy sources were analyzed and comparative analysis of the impact of traditional and alternative energy sectors was conducted. The third and the fourth levels were completed through development of the technology for obtaining nanostructures and identification of the basic regularities of the formation of porous layers at the surface of semiconductors. In the course of completing the fifth and the sixth levels, technological stages of the production of solar panels based on nanostructures were developed. The latter two levels involved studying the feasibility of using nanostructures for solar cells as an effective tool to provide environmental safety.

However, in this case it would be incorrect to talk about the possibility of using obtained generalizing results for the formation of a unified system to control the environmental safety. To design the system to control the environmental safety, which uses innovative technologies for solar energy sector, it is necessary to conduct a series of comprehensive studies, namely [4.58]:

– development of database of initial data for creating SCES;

– further improvement of technologies for obtaining materials for photoelectric modifiers and development of technological regulations for PEP;

– research into the processes that provide control of the environmental safety, etc.

A system for control of the environmental safety through the use of innovative technologies for solar energy sector requires a detailed step-by-step analysis of all components of the process of manufacturing solar elements based on the nanostructured porous materials, which becomes the basis for further research.

A special feature of the presented study is the systems approach to the solution of problems of environmental safety. This approach is based on the identification of local problems and their stage-by-stage solution. Such studies are of interdisciplinary and multidisciplinary nature and allow a comprehensive approach to the issues of provision of environmental safety.

4.4.7. Conclusions

1. A scheme of provision of the environmental safety through the use of innovative technologies for solar energy sector was developed. This scheme is a multilevel decomposition of the problems that includes the following levels: initial data for creating SCES, improved technologies

for the provision of ES, organization and implementation of technological processes that ensure the assigned level of ES and results of using innovative technologies. A split into levels allows comprehensive and efficient solution to the problem of providing the assigned level of environmental safety and obtaining functional products.

2. It was found that traditional energy sector causes significantly more damage to the environment than alternative energy sources. In particular, it leads to the thermal effect, dust and gases emission, creates electromagnetic fields, etc. Reducing this effect is possible through gradual replacement of traditional energy with the alternative one.

3. Basic regularities of the formation of porous layer at the surface of semiconductor of the A3V5 group and silicon were explored. To obtain nanostructures, it is expedient to use the method of electrochemical etching in the solution of hydrofluoric acid. Technological conditions are selected individually for each semiconductor.

4. A generalized scheme for the technological process of producing solar elements based on nanostructured semiconductors was presented. The scheme contains a three-stage technology, which includes obtaining nanostructures, manufacturing photoelectric modifiers and direct production of solar elements.

5. It was demonstrated that the use of nanostructures for solar elements might increase their efficiency (20 % and higher) due to the increase in effective area of the receiving surface. The passivating layer that is formed during etching of semiconductor provides for the stabilization of properties and reduces sensitivity to the surface contamination.

4.5. REFERENCES

4.1. Suchikova Y. (2010) Influence of the carrier concentration of indium phosphide on the porous layer formation. J Nano Electron Phys 4 : 142–147.

4.2. Suchikova Y., Kidalov V., Balan O. (2010) Texturing of the indium phosphide surface. J Nano Electron Phys 2 : 52–53.

4.3. Suchikova Y., Kidalov V., Sukach G. (2009) Effect of the type of electrolyte ànion on the porous InP morphology obtained by the electrochemical etching. J Nano Electron Phys 4 : 111–118.

4.4. Suchikova Y. (2010) Influence of dislocations on the process of pore formation in n-InP (111) single crystals. Semiconductors 45 (1) : 121–124.

4.5. Suchikova Y., Sukach G. (2010) Morphology of porous n-InP (100) obtained by electrochemical etching in HCl solution. Funct Mater 17 (1) : 1–4.

4.6. Langa S., Carstensen J., Christophersen M., Föll H., Tiginyanu I. (2001) Observation of crossing pores in anodically etched n-GaAs. Appl Phys Lett 78 (8) : 1074–1076.

4.7. Langa S., Carstensen J., Christophersen M., Föll H. (2002) Formation of tetrahedron-like pores during anodic etching of (100) oriented n-GaAs. Electrochem Solid-State Lett 5 (1) : 1–4.

4.8. Langa S., Carstensen J., Christophersen M., Steen K., Frey S., Tiginyanu I., Föll H. (2005) Uniform and nonuniform nucleation of pores during the anodization of Si, Ge, and III-V semiconductors. J Electrochem Soc 152 (8) : 525–531.

4.9. Schmuki P., Lockwood D., Labbe H., Fraser J. (1996) Visible photoluminescence from porous GaAs.ApplPhysLett 69(11): 1620–1622.

4.10. Zeng A., Zheng M., Ma L., Shen W. (2006) Etching temperature dependence of optical properties of the electrochemically etched n-GaAs. Appl Phys A 84 : 317–321.

4.11. Schmuki P., Erickson L., Lockwood D., Fraser J., Champion G., Labbe H. (1998) Formation of visible light emitting porous GaAs micropatterns. Appl Phys Lett 72 (9) : 1039–1041.

4.12. Finnie C., Bohn P. (1999) Near-field photoluminescence of microcrystalline arsenic oxides produced in anodically processed gallium arsenide. Appl Phys Lett 74 (8) : 1096–1098.

4.13. Tondare V.N., Naddaf M., Bhise A.B., Bhoraskar S.V., Joag D.S., Mandale A.B., Sainkar S.R. (2002) Stability of field emission current from porous n-GaAs (110). Appl Phys Lett 80 (6) : 1085–1087.

4.14. Dmitruk N., Kutovyi S., Dmitruk I., Simkiene I., Sabataityte J. (2005) Atomic force microscopy, Raman scattering and optical reflectance of porous GaAs films. In: Proceedings of the first international workshop on semiconductor nanocrystals, SEMINANO : 399–403.

4.15. Ben Jomaa T.R., Beji L., Ltaeif A., Bouazizi A. (2006) The current–voltage characteristics of heterostructures formed by MEH-PPV spin-coated on n-type GaAs and n-type porous GaAs. Mater Sci Eng 26 (2–3) : 530–533.

4.16. Rėza A., Šimkienė I., Babonas G.J., Sabataitytė J. (2003) Spectroscopic ellipsometry of porous n-GaAs. Mater Sci 9 (4) : 441–446.

4.17. Zangooie S., Woollam J.A. (2000) Ellipsometric characterization of thin porous GaAs layers formed in HF solutions. J Mater Sci Lett 19: 2171–2173.

4.18. Dmitruk N., Kutovyi S., Dmitruk I., Simkiene I., Sabataityte J., Berezovska N. (2007) Morphology, Raman scattering and photoluminescence of porous GaAs layers. Sens Actuators B 126 (1): 294–300.

4.19. Simkiene I., Sabataityte J., Kindurys A., Treideris M. (2008) Formation of porous n-A3B5 compounds. Acta Phys Polon A 113 (3) : 1085–1090.

4.20. Tiginyanu I.M., Irmer G., Monecke J., Vogt A., Hartnagel H.L. (1997) Porosity-induced modification of the phonon spectrum of n-GaAs. Semicond Sci Technol 12: 491–493.

4.21. Meijerink A., Bol A.A., Kelly J.J. (1996) The origin of blue and ultraviolet emission from porous GaP.Appl Phys Lett 69(19): 2801–2803.

4.22. Kuriyama K., Ushiyama K., Ohbora K., Miyamoto Y., Kakeda S. (1998) Characterization of porous GaP by photoacoustic spectroscopy: the relation between band-gap widening and visible photoluminescence. Phys Rev B 58 (3) : 1103–1105.

4.23. Tomioka K., Adachi S. (2005) Structural and photoluminescence properties of porous GaP formed by electrochemicaletching. J Appl Phys 98(7): 073511–073611–7.

4.24. Sarua A., Tiginyanu I.M., Ursaki V.V., Irmer G., Monecke J., Hartnagel H.L. (1999) Charge carrier distribution in freestanding porous GaP membranes studied by Raman spectroscopy. Solid State Commun 112 : 581–585.

4.25. Ichizli V., Hatnagel H.L., Mimura H., Shimawaki H., Yokoo K. (2001) Field emission from porous (100) GaP with modified morphology. Appl Phys Lett 79 (24) : 4016–4018.

4.26. Stevens-Kalceff M.A., Langa S., Tiginyanu I.M., Carstensen J., Christophersen M., Föll H. (2000) Comparative SEM and cathodoluminescence microanalysis of porous GaP structures. In: MRS conference proceedings, vol 638, p F5.31.

4.27. Schuurmans F.J.P., Vanmaekelbergh D., Lagemaat J., Lagendijk A. (1999) Strongly photonic macroporous gallium phosphide networks. Science 284 (5411) : 141–143.

4.28. Karavanski V.A., Lomov A.A., Sutyrin A.G., Imamov R.M., Dravin V.I., Mel'nik N.N., Zavaritskaya T.N. (2003) Influence of defects on the formation of thin porous GaP(001) films. Crystallogr Rep 48 (5) : 851–859.

4.29. Melnikov V.A., Golovan L.A., Konorov S.O., Muzychenko D.A., Fedotov A.B., Zheltikov A.M., Timoshenko V.Y., Kashkarov P.K. (2004) Second-harmonic generation in strongly scattering porous gallium phosphide. Appl Phys B 79 (2) : 225–228.

4.30. Suchikova, Y.A. Kidalov, V.V., Sukach, G.A. (2011). Influence of dislocations on the process of pore formation in n-InP (111) single crystals. Semiconductors, 45(1), 121–124.

4.31. Suchikova, Y.A. Kidalov, V.V., Sukach, G.A. (2010). Preparation of nanoporous n-InP (100) layers by electrochemical etching in HCI solution. Functional Materials, 17(1), 131–134.

4.32. Sychikova, Y.A., Kidalov, V.V., Sukach, G.A. (2013). Dependence of the threshold voltage in indium-phosphide pore formation on the electrolyte composition. Poverkhnost'. Rentgenovskie, Sinkhrotronnye i Neitronnye Issledovaniya, 7, 25–30.

4.33. Sychikova, Y.A., Kidalov, V.V., Sukach, G.A. (2010). Influence of the carrier concentration of indium phosphide on the porous layer formation. Journal of Nano- and Electronic Physics, 2(4), 75–81.

4.34. Suchikova, Y.A. (2015). Synthesis of indium nitride epitaxial layers on a substrate of porous indium phosphide. Journal of Nano- and Electronic Physics, 7 (3), 03017-1 – 03017-3.

4.35. Ostafiychuk, B. K., Muronyuk, I. F., Kotsyubynsky, V. O., Glukhanyuk, V. D., Chelyadyn, V. L., Nagirna, N. N. (2008). Dye-Sensitized Solar Cells (Review). Physics and Chemistry of Solid State, 9 (1), 11–18.

4.36. Alekseenko, S. V. (2006). Alternative Energy and Energy and Resource Saving Innovations. Technology. Solutions, 3, 38–41.

4.37. Aroutiounian, V. M., Martirosyan, Kh. S., Hovhannisyan, A. S., Soukiassian, P. G. (2008). Use of Porous Silicon for Double- and Trilpe-Layer Antireflection Coatings in Silicon Photovoltaic Converters. Proceedings of National Academy of Sciences of Armenia. Physics, 43 (2), 111–119.

4.38. Listratenko, A. M. (2001). Research and development of low-cost production technology of high-performance silicon solar cells for space application. Radioengineering, 121, 121–125.

4.39. Zhao, J., Wang, A., Green, M. A. (1999, November). 24·5% Efficiency silicon PERT cells on MCZ substrates and 24·7% efficiency PERL cells on FZ substrates. Progress in Photovoltaics: Research and Applications, 7 (6), 471–474. doi:10.1002/(sici)1099-159x(199911/12)7:6 <471::aid-pip298> 3.0.co; 2-7

4.40. Suchikova Y. A., Kidalov V. V., Sukach G. A. (2010). Influence of the Carrier Concentration of Indium Phosphide on the Porous Layer Formation. Journal of Nano- and Electronic Physics, 2(4), 142–147.

4.41. Suchikova, Y. A., Kidalov, V. V., Sukach, G. A. (2010). Preparation of nanoporous n-InP(100) layers by electrochemical etching in HCI solution. Functional Materials, 17 (1), 131–134.

4.42. Dzhafarov, T.; In: Morales-Acevedo, A. (2013). Silicon Solar Cells with Nanoporous Silicon Layer. Solar Cells – Research and Application Perspectives. InTech, 386. doi:10.5772/51593

4.43. Shin, B.-K., Lee, T.-I., Xiong, J., Hwang, C., Noh, G., Cho, J.-H., Myoung, J.-M. (2011, September). Bottom-up grown ZnO nanorods for an antireflective moth-eye structure on CuInGaSe2 solar cells. Solar Energy Materials and Solar Cells, 95(9), 2650–2654. doi:10.1016/ j.sol mat.2011.05.033

4.44. Boden, S. A., Bagnall, D. M. (2010, May). Optimization of moth-eye antireflection schemes for silicon solar cells. Progress in Photovoltaics: Research and Applications, 18 (3), 195–203. doi:10.1002/pip.951

4.45. Freik, D. M. Photovoltaic Converters of Solar Radiation. Achievements, Current Status and Trends (Review) [Text] / D. M. Freik, V. M. Chobanyuk, M. O. Galuschak, O. S. Krunutcky, G. D. Mateik // Physics And Chemistry Of Solid State. – 2012. – Vol. 13, Issue 1. – P. 7–20.

4.46. World map of the PV Industry [Text] // Sun & Wind Energy. – 2008. – Vol. 4. – P. 120–126.

4.47. Erohov, V. Yu. Silicon multiporitoy texture for photovoltaic solar energy [Text] / V. Yu. Erohov, A. A. Druzhinin // Tehnologiya i konstruirovanie v ellektronnoy apparature. – 2009. – Vol. 3. – P. 21–23.

4.48. Arutyunyan, V. M. The use of porous silicon for two- and three-layer antireflection coatings for silicon photovoltaic inverters / V. M. Arutyunyan, H. S. Martirosyan, A. S. Ogannisyan, P. G. Sukiasyan // Izvestiya NAN Armenii, Fizika. – 2008. – Vol. 43, Issue 2. – P. 111–119.

4.49. Ou, W. Optical and electrical properties of porous silicon layer formed on the textured surface by electrochemical etching [Text] / W. Ou, L. Zhao, H. Diao, J. Zhang, W. Wang // Journal of Semiconductors. – 2011. – Vol. 32, Issue 5. – P. 056002. doi: 10.1088/1674-4926/32/5/056002

4.50. Huang, Y. M. Porous silicon based solar cells [Text] / Y. M. Huang, Q.-L. Ma, M. Meng, B. G. Zhai // Materials Science Forum. – 2011. – Vol. 663-665. – P. 836–839. doi: 10.4028/www.scientific.net/msf.663-665.836

4.51. Salman, K. A. The effect of etching time of porous silicon on solar cell performance [Text] / K. A. Salman, K. Omar, Z. Hassan // Superlattices and Microstructures. – 2011 – Vol. 50, Issue 6. – P. 647–658. doi: 10.1016/j.spmi. 2011.09.006

4.52. Dubey, R. S. Electrochemical Fabrication of Porous Silicon Structures for Solar Cells [Text] / R. S. Dubey // Nanoscience and Nanoengineering. – 2013. – Vol. 1, Issue 1. – P. 36–40.

4.53. Salman, K. A. Effect of Silicon Porosity on Solar Cell Efficiency [Text] / K. A. Salman, K. Omar, Z. Hassan // Int. J. Electrochem. Sci. – 2012. – Vol. 7. – P. 376–386.

4.54. Kosyachenko, L. A. Quantitative assessment of optical losses in thin-film CdS/CdTe solar cells [Text] / L. A. Kosyachenko, E. V. Grushko, X. Mathew // Solar Energy Materials and Solar Cells. – 2012. – Vol. 96. – P. 231–237. doi: 10.1016/j.solmat.2011.09.063

4.55. Voropayeva, S. L. Predicting reliability of structures gap-sno2 on the based of 3d model of their surface [Text] / S. L. Voropayeva // Eastern-European Journal of Enterprise Technologies. – 2013. – Vol. 6, Issue 13 (66). – P. 96–98. – Available at: http:// journals.uran.ua/eejet/article/view/19683/17579

4.56. Obedzynskyy, Yu. K. Epitaxial structures on the base of cd1-xznxsb and laser optimization of their properties [Text] / Yu. K. Obedzynskyy, A. Y. Savchuk, V. N. Strebezhev, Y. N. Yuryychuk // Eastern-European Journal of Enterprise Technologies. – 2013. – Vol. 6, Issue 12 (66). – P. 103–106. Available at: http://journals.uran.ua/eejet/article/view/19696/17581

4.57. Orlov, A. Peculiarity of Seed-Layer Synthesis and Morphometric Characteristics of ZnO Nanorods [Text] / A. Orlov, V. Ulianova, G. Pashkevich, O. Bogdan // Eastern-European Journal of Enterprise Technologies. – 2013. – Vol. 6, Issue 12 (66). – P. 72–75. – Available at: http://journals.uran.ua/eejet/ article/view/19737/17573.

4.58. Elkina, L. G. Environmentally sound management: principles, methods and forms of organization of the enterprise / L. G. Elkina, R. R. Nabiullina // Vestnik UGATU. – 2009. – Vol. 12, Issue 3 (32). – P. 48–56.

Chapter 5. CRITERIAL AND ECONOMIC ASSESSMENT OF ECOLOGICAL SAFETY MANAGEMENT SYSTEMS FUNCTIONING PROCESS EFFICIENCY

5.1. GENERAL PROVISIONS

Purpose of studies, presented in the chapter, is creation of science and technical basis of criterial assessment of functioning efficiency of ecological safety management systems of technics during their life cycle and technologies formed the basis of its work.

Object of studies, presented in the chapter, is functioning efficiency of ecological safety management systems of technics during their life cycle and technologies formed the basis of its work.

Subject of studies, presented in the chapter, is criterial assessment of functioning efficiency of ecological safety management systems of technics during their life cycle and technologies formed the basis of its work.

The chapter *includes* materials of three articles.

The **first of these articles** dedicated to issues of energetic and economic assessment of effectiveness of technological process of improved plasma technology of utilization of domestic solid waste in compliance with its basic variant and other thermal utilization methods.

The **second article** includes materials about results of calculated foundation of choice of US dollar as the unit of expression of monetary equivalents of components of complex fuel and ecological criteria as freely convertible global reserve currency, history of circulation of which completely covers the history of existence of piston internal combustion engines, on example of autotractor diesel engine 2Ch10.5/12.

The **third article** describes the results of calculated assessment of ecological safety level of exploitation process of emergency and rescue technics, equipped with piston internal combustion engine, with using of improved mathematical apparatus of complex fuel and ecological criteria on example of autotractor diesel engine 2Ch10.5/12, which operates on regimes of 13-mode standardized steady testing cycle.

Findings of presented in chapter 5 studies is submitted in general conclusions of the monograph.

Bibliographic description of presented in chapter 5 published scientific articles is submitted in are given in in Appendix A.

Розділ 5. КРИТЕРІАЛЬНЕ ТА ЕКОНОМІЧНЕ ОЦІНЮВАННЯ ЕФЕКТИВНОСТІ ПРОЦЕСУ ФУНКЦІОНУВАННЯ СИСТЕМ УПРАВЛІННЯ ЕКОЛОГІЧНОЮ БЕЗПЕКОЮ

5.1. ЗАГАЛЬНІ МІРКУВАННЯ

Метою досліджень, наведених у розділі, є створення наукових основ методологічного забезпечення критеріального оцінювання ефективності функціонування систем управління екологічною безпекою техніки впродовж її життєвого циклу та технологій, покладених в основу її роботи.

Об'єктом досліджень, представлених у розділі, є ефективність функціонування систем управління екологічною безпекою техніки впродовж її життєвого циклу та технологій, покладених в основу її роботи.

Предметом досліджень, описаних у розділі, є методологічне забезпечення критеріального оцінювання ефективності функціонування систем управління екологічною безпекою техніки впродовж її життєвого циклу та технологій, покладених в основу її роботи.

Розділ *містить* матеріали трьох статей.

Перша з статей присвячена питанням енергетичного та економічного оцінювання ефективності технологічного процесу вдосконаленої плазмової технології утилізації твердих побутових відходів у порівнянні з її базовим варіантом й іншими термічними методами утилізації.

Друга стаття містить матеріали щодо результатів розрахункового обґрунтування вибору долара США як одиниць вираження вартісних еквівалентів складових комплексного паливно-екологічного критерію як вільноконвертованої світової резервної валюти, історія обігу якої повністю охоплює історію існування поршневих двигунів внутрішнього згоряння як таких, на прикладі автотракторного дизеля 2Ч10,5/12.

Третя стаття описує аналіз результатів розрахункового оцінювання рівня екологічної безпеки процесу експлуатації аварійно-рятувальних енергетичних установок, оснащених поршневим двигуном внутрішнього згоряння, за допомогою вдосконаленого математичного апарату комплексного паливно-екологічного критерію на прикладі автотракторного дизельного двигуна 2Ч10,5/12, що працює за режимами 13-режимного стаціонарного стандартизованого випробувального циклу.

Висновки по результатам досліджень, представлених у розділі 5, винесено у загальні висновки по монографії.

Бібліографічний опис наведених у розділі 5 друкованих наукових праць наведено у Додатку А.

5.2. ECONOMIC AND ECOLOGYCAL ANALYSIS OF IMPROVED WASTE UTILIZATION PLASMA TECHNOLOGY [A.5.1]

5.2.1. Introduction

Wastes are the of environmental hazards formation sources, and therefore must be utilized. Their quantity is large and the choice of technology utilization is a responsible stage. Firstly, it is connected by that the implementation of some of the utilization technologies can reduce the level of ecological safety, which is unacceptable. Second, the selected utilization technology may be energy or economically effective. Countries that intend to avoid the landfilling of waste unsuitable for recycling, give preference to thermal methods for decontamination and disposal, such as incineration, pyrolysis and gasification.

Their use allows to obtain synthesis gas, in which structure except for the carbon monoxide (CO) and hydrogen (H_2), there are components such as carbon dioxide (CO_2), nitrogen oxides (NO_x), a small amount of methane (CH_4), ethylene (C_2H_4) and etc. The obtained low-calorie gas is used for direct combustion to produce heat for domestic needs and generate electricity. Thus, the use of thermal processes waste utilization reduces their quantity and allows to obtain useful products in the form of electricity and heat. At the same time, the plants implementing these methods of waste utilization and recycling has not ensure ecological safety, leading to the need for additional processing exhaust gases and solid residues (dross).

An alternative to the above manner, is a plasma technology, which is based in the decomposition of high-toxic substances (dioxins and furans) into simpler molecules at extremely high temperatures and in the absence of free oxygen. At the plasma jet temperature completely destroyed any organic and biological materials, assured destroyed most toxic materials are melted and vaporized most refractory inorganic compounds. Plasma gasification process provides an ecologically pure waste utilization without the formation of tar and dioxins. The products of plasma gasification are a high-calorie combustible gas and a neutral solid residue as a glassy slag that does not require additional treatment.

5.2.2. Analysis of published data and problem statement

Experience in the use of plasma technology for the processing and decontamination of solid municipal, industrial and medical waste is described by many authors, including those in S.V. Petrov, S.G. Bondarenko, E.G. Didyk, G.S. Marinsky, A.V. Chernets, V.N. Korzhik, M.N. Bernadiner, A.L. Mosse, V.V. Savchin, A.V. Lozhechnik, Pragnesh N Dave, Asim Joshi, Hua Zhang, LimingShao. Waste utilization plasma technology involves large amounts of electricity, in contrast to the high temperature pyrolysis or gasification processes, that are used as fuel obtained gas. From the authors A.V. Artemov, A.V. Pereslavtsev, Y. Krutikov, V.V.

Vambol, V.N. Kobrin, N.V. Nechiporuk, Nickolas J. Themelis, Marco J. Castaldi denoted that the main factors that hinder the widespread industrial use of plasma technology for the processing of waste are not large enough resource of low-temperature plasma generators, as well as the fact that the plasma arc discharge is a relatively local source of heating.

On the other hand it proved experimentally that the synthesis gas produced during the plasma technology for utilization more calories than in conventional gasification. In the article V.M. Batenin, V.I. Kovbasyuk, L.G. Kretova, Y.V. Medvedev compared the energy efficiency of processes of plasma and autothermal gasification at 1400 K for waste utilization. It is shown that an additional energy output from the synthesis gas, is achieved through the use of plasma generators, with existing methods of energy conversion can't cover the real costs of consumed electricity.

In [5.1, 5.2], the authors proposed an advanced technology of plasma waste disposal, which includes the following processes: thermochemical gasification, plasma post-combustion of the resulting gases, their sharp cooling, preliminary cleaning, methanation, final purification of gases and cryogenic separation of synthesis gas for fuel products.

5.2.3. Object, purpose and problem of the research

Object of research – energy and economic indicators of improved plasma waste utilization technology.

Purpose of research is energy and economic evaluation of plasma waste utilization technologic process and also grounding of application expediency of improved plasma technology by the way of comparison of its energy and economic indicators with other thermal waste utilization methods.

For achieving of setting research purpose solved the following problems:

– evaluation of plasma waste utilization application energy efficiency from point of view of its energy costs minimization in comparison with other thermal methods;

– evaluation of plasma waste utilization application economic expediency from point of view of its recoupment period in comparison with other technologies;

– evaluation of usability of fuel products obtained during utilization process for energy and monetary costs reducing.

5.2.4. Material and results of energy and economic indicators of improved plasma waste utilization technology researching.

5.2.4.1. Evaluation of energy indicators.

It is proposed to carry out a comparative assessment of waste utilization energy costs for the conventional gasification technology ("Technology 1"), and improved plasma utilization technology ("Technology 2"). In the improved plasma waste utilization technology [5.1] the reactor made up of two chambers, one of which is the gasification reactor, and the other – the plasma reactor (Fig.5.1). In the gasificator carried out the process of high temperature waste gasification and then the its resulting products – steam-gas mixture (synthesis gas) and slag – are processed in the plasma jet. Such stepwise waste treatment reduces energy consumption, due to the fact that in a plasma reactor not processed all raw materials, and only a portion (about 20 %).

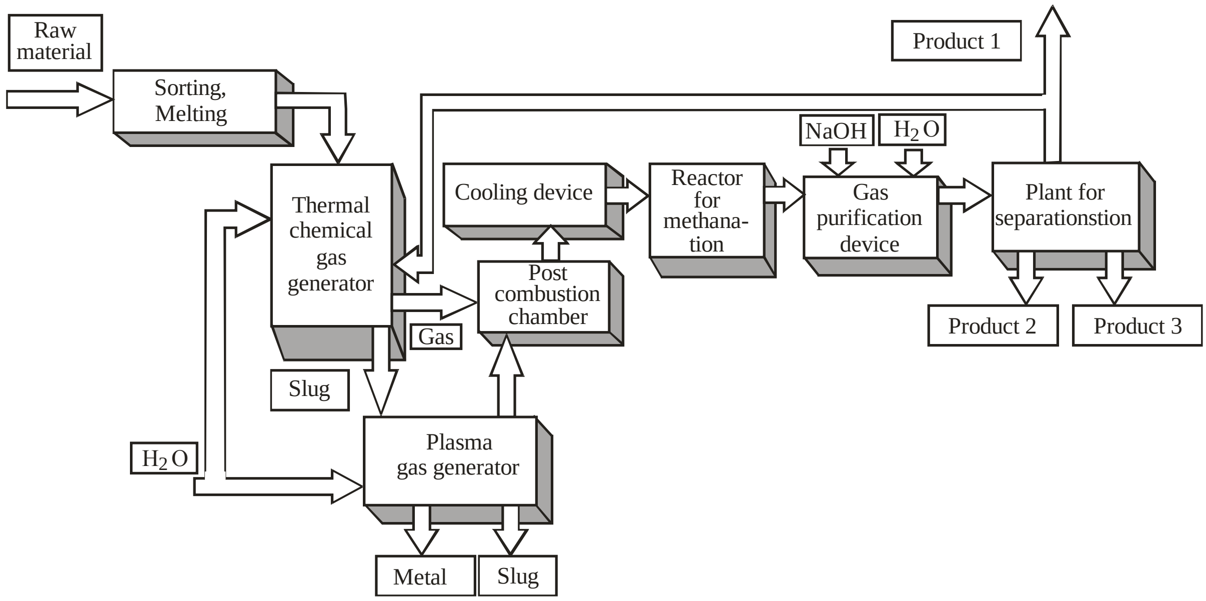


Fig. 5.1 – Scheme of waste utilization plant

During afterburning process in a plasma reactor, the slag is converted into an ecologically safe glassy mass and synthesis gas contains mainly carbon monoxide and hydrogen. This gas can be used as a fuel instead of methane for heating and maintaining the gasification process. The “Technology 2” also suggests further methane-enriching of obtained synthesis gas by implementing the process of methanation [5.3, 5.4] and further its purification and low-temperature separation to produce fuel products suitable for sale [5.5]. Thus, the products of waste processing by “Technology 2” in contrast to “Technology 1” are, in addition to heat and electricity, liquefied or gaseous methane and synthesis gas containing methane, to compensate unevenness daily and annual energy consumption by stockpiling.

To carry out the energy assessment of the appropriateness of “Technology 2” a comparative calculation was made at the standard conditions, and namely has been chosen the most typical variant and type of waste – processing of municipal solid waste with productivity of 1.6 tons per day (66.8 kg/h, 529 t/year). Initial data and results of comparative calculations are presented in Table. 5.1.

As a result, waste disposal by “Technology 1” is formed of 60 kg/h of fuel gas and 6.8 kg/h of slag. The products of this technology are heat or electricity. When implementing the “Technology 2” we obtain the following products: liquefied or gaseous methane at a pressure of 25 MPa – 16,8 kg/day, liquefied or gaseous synthesis gas (94 % methane) – 6.2 kg per h, the fuel gas – 37.1 kg/h, slag – 6.8 kg/h.

Table 5.1. Comparing evaluation of Technologies by amount of produced energy [5.3, 5.4]

Indicators	**Technology 1**	**Technology 2**
Amount of raw materials kg/hour	66,80	66,80
Amount of raw materials tons/day	1,60	1,60
Amount of raw materials tons/year	529,06	529,06
Yield of products per hour		
methane liquefied, kg/day		16,80
synthetic gas (94 % methane), kg/hour		6,20
fuel gas for heating, kg/hour	60	37,10
slug, kg/hour	6,8	6,68
Yield of products per hour (330 days)		
methane liquefied, tons/year		133,06
synthetic gas (94 % methane), tons/year		49,10
fuel gas for heating, tons/year	380,16	235,07
Composition, %		
N_2 / CH_4 / H_2	3 / 11 / 31	20,6 / 0,1 / 31,14
CO / C_2H_4 / CO_2	23 / 4 / 28	48,16 / 0 / 0
Net calorific value, kJ/м^3	12584	9467
density, kg/м^3	0,96	0,827
Net calorific value, kJ/kg	12081	7829
Net calorific value, kW·h/kg	3,36	2,17
Efficiency factor of steam generator	0,9	0,9
Heat energy, kW·h/h	181,21	72,62
Heat energy, kW·h/year	1435180	575123
Efficiency factor of steam cycle	0,3200	0,3200
Electric energy in steam cycle, kW·h/year	459258	184039
or Efficiency factor of gas turbine cycle	0,45	0,45
Electric energy in gas turbine cycle, kW·h/year	645831	258805
slug, tons/year	53,86	52,91
Recalculation to 1 tons of raw materials		
Products tons per 1 ton of raw materials		
methane liquefied, tons/ton of raw		0,25
synthetic gas (94 % methane), tons/ton of raw		0,09
fuel gas for heating, tons/ton of raw		0,44
Heat energy, kW·h/ton of raw	2713	1087
Electric energy in gas turbine cycle, kW·h/ton of raw	868,07	347,86
or **Electric energy in gas turbine cycle**, kW·h/ton of raw	1220,72	489,18
slug, tons/ton of raw	0,10	0,10

To compare the two technologies the amount of heat we expressed in an amount of equivalent electricity. To determine the amount of electricity and heat, which can be obtained from the fuel gas, it is necessary to set the calorific value of which is determined by the composition of the gas. For “Technology 1” typical composition of the synthesis gas which is produced during the gasification of municipal solid waste includes components: N_2 – 3 %, CH_4 – 11 %, H_2 – 31 %, CO – 23 %, C_2H_4 – 4 %, CO_2 – 28 %. The “Technology 2” accepted the worst scenario, when as a plasma gas used air, because in this case formed much amount of nitrogen which is ballasted fuel gas and reduce its heating value. More appropriate variant is the use of water vapor because in this case nitrogen and its oxides virtually absent. Composition of fuel gas obtained by “Technology 2” after the separation of useful product in the form of methane and synthesis-gas: N_2 – 20,6 %, CH_4 – 0.1 %, H_2 – 31,14 %, CO – 48,16 %. Net calorific value of the fuel additive function is a defined as the amount of calorific values of combustible components, constituting the fuel:

$$Q_n = Q_n^{CH_4} \cdot \mathrm{r}^{CH_4} + Q_n^{H_2} \cdot \mathrm{r}^{H_2} + Q_n^{CO} \cdot \mathrm{r}^{CO} + Q_n^{C_2H_4} \cdot \mathrm{r}^{C_2H_4}, \qquad (5.1)$$

where $Q_n^{\,i}$ – net calorific value of the *i*-th component; $\mathrm{r}^{\,i}$ – volume fraction of the *i*-th component.

Net calorific value of 1 kg of fuel is equal:

$$Q_{nm} = Q_n / \rho, \qquad (5.2)$$

where ρ – density of fuel that equal to amount of density portions of fuel components. Their values are given in Table 5.1.

The calculation results show that the net calorific value of gas obtained by “Technology 1” is 12584 kJ/m^3 (12081 kJ/kg), and obtained by “Technology 2” – 9467 kJ/m^3 (7829 kJ/kg). Conventional gasification provide more calorific value due to the presence of significant amounts of nitrogen in the plasma gasification process.

Fuel gas is sent to a steam generator for burning in the combustion chamber and further to the turbine to produce electricity. Energy comparison is made of the equivalent number of electric power produced by the fuel gas. We consider production of electricity in the steam cycle and at direct fuel combustion using a gas turbine. In the calculation of the steam cycle is accepted that the efficiency factor of the steam generator is equal to 90 %, the efficiency factor of the steam cycle is 32 %, then the amount of obtained of electricity is given by follow formula:

$$E_{EP} = \mathrm{Q_n} \cdot \eta_{SG} \cdot \eta_{SC}, \qquad (5.3)$$

where Q_n – net calorific value of fuel (synthesis) gas; η_{SG} – efficiency factor of steam generator; η_{SC} – efficiency factor of steam cycle.

Upon receipt of electric power on gas turbine plant it is assumed that thermal energy loss is 10 %, and the efficiency of the gas turbine plant is 50 %. The amount of obtained electricity is equal to:

$$E_{EP} = 0{,}9\ Q_n \cdot \eta_{GTC}, \quad (5.4)$$

where η_{GTC} – efficiency factor of gas turbine cycle.

Calculations showed that the electricity produced in "Technology 1" in the steam cycle amounts to 868 kW·h/ton of raw materials, in a gas turbine cycle – 1221 kW·h/ton of raw materials. In the "Technology 2" electricity amounts to – 348 kW·h/ ton of raw materials and 489 kW·h/ton of raw material respectively.

5.2.4.2. Evaluation of economic indicators.

Products of waste utilization by "Technology 1" is electricity and for "Technology 2" – electricity, liquefied methane and liquefied synthesis gas. The wholesale price of the products obtained, was chosen based on the prices listed in the Internet resources. The price of products for technology 1 is determined by the cost of electricity and equivalent amounts to $ 0.11 per 1 kW/h for 2 technology – accepted the same price for all products – $ 400 per ton. In addition to both technologies have a solid residue – slag.

The total annual income we define as the sum of products of product price and the quantity of the produced product of this denomination per ton of raw material. All calculations are carried out in US dollars, and assess the effectiveness per ton of processed raw materials. When assessing the cost of electricity based on the received steam-gas cycle because it gives less income than the gas turbine cycle. In addition, income includes revenues from the payment of municipal services for waste treatment. Then, the total annual income of "Technology 1" will be $ 84,961, and in "Technology 2" – 127,550 $. The increase in annual income is ensured by an additional product – liquid methane.

Plants made for the implementation of "Technology 1" and "Technology 2" are different first of all by capital investment. Plant for "Technology 2" has a larger capital investments than for "Technology 1". This is attributed with presences in the plant for implementing "Technology 2" two additional blocks: for methanation and for gas separation. Furthermore, plasma generators require powerful power sources and control system. The results of calculations of profit and payback period of plants using both technologies are presented in Table 5.2. The results of calculations (columns 2 and 3 of Table 5.2) are shown taking into account the capital investments required for the manufacture of a particular plant with setting performance in processed raw material. Capital investments of serial processing plant waste using plasma was determined by compiling a cost calculations based on current prices for completing parts, manufacturing of non-standard equipment, salaries and other expenses in view of VAT. To plant for conventional gasification to produce synthesis gas for power generation capital investments accepted by 1.5 times smaller. Accordingly, the construction and assembly works and pre-production costs are accepted by value in 2 times more, as associated with a lot of equipment.

Total capital investment in the use of “Technology 1” amount to 108, “Technology 2” – 176 th $, that 1.63 times greater. Subjects to amortization cost are of equipment and construction and installation works.

Operating expenses include: depreciation charges, 10 % of the capital investments subject to amortization; the cost of capital repairs – 5 %; costs of minor repairs – 1.6 %; the cost of electricity. Electricity consumption in the use of “Technology 2” is much larger. This takes into account the power consumption of the plasma generators, gas separation unit and other consumers. In the “Technology 2” of plasma generators electricity consumption is accepted on the basis of experimental data for plants of “Europlasma” – 240 kW·h/ton of raw material.

Electricity consumption in the separation unit together with other consumers (the plasma gas compressor) is determined on the basis of calculation and amounted to 246 kW·h/ton of raw material. The total electricity power consumption is about 486 kW·h/ton of raw material. In the “Technology 1” power consumption assumed to be equal 50 kW·h/ton of raw material, which is almost 10 times less. Accordingly, the cost of electricity is also 10 times less than in plasma process.

Salaries accepted the same for both technologies. Maintenance staff consists of 6 people, working for 12 months with an average salary of 500 $ per month. Accruals for salaries is 37.5 % in both cases. Additional costs associated with payments to the Innovation Fund, the cost of roads maintaining and other costs taken the same.

Total operating expenses amounted to 72,300 $ for “Technology 1” and 107,000 $ for “Technology 2”. Thus, capital investment and operating costs for the implementation of “Technology 2” (plasma technology) significantly higher than for the “Technology 1” (conventional gasification)

Profit P and the payback period is calculated by the formulas:

$$P = D - E, \tag{5.5}$$

$$T = \text{КВ}_\text{о} / \text{P}, \tag{5.6}$$

where D – year profit; E – maintain costs; $\text{КВ}_\text{о}$ – total investment.

Comparison of the two techniques indicates that in a conventional gasification “Technology 1” profit is $ 12615, in “Technology 2” – in 1.6

times higher, 20,534.5 $. Payback period, calculated according to the above formula, is 8.6 years.

Table 5.2 – Compurgation of economic indicators
for two Technologies [5.3, 5.4]

Indicators	**Techno-logy 1**	**Techno-logy 2**	**Techno-logy 1**	**Techno-logy 2**
1	2	3	4	5
Product wholesale price				
methane liquefied, $/ton of raw		400,00		400,00
synthetic gas liquefied (94 % methane), $/ton of raw		400,00		400,00
electricity, $/kW·h	0,11	0,11	0,11	0,11
slug, $/ton of raw	1,00	1,00	1,00	1,00
Product quantity				
methane liquefied, $/ton of raw		100,60		100,60
synthetic gas liquefied (94 % methane), $/ton of raw		37,13		37,13
electricity, $/ton of raw (steam-gas cycle)	95,49	38,26	95,49	38,26
or electricity, $/ton of raw (gas turbine cycle)	134,3 / 0,1	53,81 / 0,1	134,3 / 0,1	53,81 / 0,1
slug / metal, $/ton of raw	0,10	0,10	0,10	0,10
Proceeds of waste treatment, $/ton of raw	65,00	65,00	65,00	65,00
Income of products sale, $/ton of raw	160,59	241,09	160,59	241,09
Total annual income, $	84961	127550	84961	127550
Capital investments				
cost of equipment, 1000 $	80	120,00	31,74	40,63
construction and installation works, 1000 $	16	32,00	16	32,00
pre-production costs, 1000 $	12	24,00	12	24,00
Total capital investments, 1000 $	108,00	176,00	59,74	96,63
subject to amortization, 1000 $	96,00	152,00	47,74	72,63
Operational costs, 1000 $				
amortization expense (10 %), 1000 $	9,60	15,20	4,77	7,26
capital repairs (5 %), 1000 $	4,80	7,60	2,39	3,63
current repair (1,6 %), 1000 $	1,54	2,43	0,76	1,16
Electricity consumption				
plasma generators, kW·h/ton		240,00		240,00
separation bloc and other consumers, kW·h/ton	50	246,00	50	246,00
Sum of consumption electricity, kW·h/ton	50,00	486,00	50,00	486,00
Electricity tariff, $/kW·h	0,11	0,11	0,11	0,11
Electricity costs, 1000 $	2,91	28,28	2,91	28,28
Salaries, 1000 $	36,00	36,00	36,00	36,00
Accruals for salaries (37,5 %), 1000 $	13,50	13,50	13,50	13,50
Additional costs, 1000 $	4,0	4,0	4,0	4,0
including:				
innovation fund, 1000 $	1,3	1,3	1,3	1,3
allocations for road maintenance, 1000 $	1,2	1,2	1,2	1,2
other, 1000 $	1,5	1,5	1,5	1,5
Total operational costs, 1000 $	72,3	107,0	64,3	93,8
Profit, $/ton of raw	12615,0	20534,5	20625,6	33709,7
Recoupment, year	8,6	8,6	2,9	2,9

To verify the obtained results carried out additional calculations of economic indicators (columns 4 and 5, Tab. 5.2). In this case, the assessment of capital investments made on the basis of Nickolas J. Themelis, Marco J. Castaldi, according to which the capital investment for a conventional gasification technology is 60 $/ton of raw materials and for plasma technology – 96.63 $/ton of raw material, which is 1.6 times higher compared with a conventional gasification technology, and 1.8 times less than that taken earlier for plasma technology. Total investments were lower than in the first case, since it does not take into account the increase in their performance decreases. All other payments are made in accordance with the above data and formulas. Payback period in this case amounted to 2.9 years.

5.2.5. Conclusions

1. Based on analysis of research in this field shows the ecological efficiency of the plasma waste utilization technology as compared with other thermal techniques.
2. The proposed improved plasma waste utilization technology more promising from the viewpoint of minimizing energy consumption, due to the fact that in a plasma reactor is processed not all raw materials but only part of it (20 %).
3. When implementing improved plasma waste utilization technology quantity of received electric power is less than “Technology 1”. However, during the waste treatment by “Technology 2”, unlike “Technology 1”, the useful products, such as liquefied methane, synthetic gas (94 % methane) and fuel for heating gas suitable for sale.
4. The calculation results showed that the payback period is the same in both cases, however, the profit in the implementation of improved plasma waste utilization technology higher due to producing fuel product
5. Plant for improved plasma waste utilization technology allows to compensate the daily and seasonal fluctuations of electricity and heat consumption by creating fuel products suitable for storage and subsequent implementation.

5.3. CALCULATED SUBSTANTIATION OF CHOICE OF UNITS OF MONETARY EQUIVALENTS OF COMPLEX FUEL AND ECOLOGICAL CRITERIA COMPONENTS [A.5.2]

Relevance of the study, problem statement and literature analysis. Exploitation process of any power plants (PP) units, which are in commercial or personal use and equipped with diesel piston internal combustion engines (PICE), as it can be seen in article [1], may be characterized by certain ecological safety (ES) level [1.11, 1.13, 5.7] with the prof. Parsadanov complex fuel and ecological criteria K_{FE}, described in [3.40] and taking into account legislative established on Ukraine territory requirements, contained in [1.14]. ES factors for such objects is pollutants mass hourly emissions with its engines exhaust gas (EG) flow, which produces in large quantities during normal (with no accident) exploitation process. Values of that criteria may be used for calculated assessment of functioning effectiveness of ecological safety management system (ESMS) and described in [1.11] in accordance with evaluation conception which was developed in study [1.13]. Also values of that criteria may be used for calculated assessment of activities for increasing of PP with PICE ES level [5.6]. But monetary equivalents of K_{FE} criteria components in monograph [1.14] are expressed in UAH, that assciated with some problems described in article [3.35], where was some hypotheses have been put forward. In present paper that hypotheses will be find its confirmation by the results of calculated study. It will be carried out for example of autotractor diesel engine 2Ch10.5/12, description and technical characteristics of which are given in [1.14]. Initial data for calculated assessment were obtained in studies [3.29, 3.30].

Purpose of the study is calculated choice substantiation of monetary equivalents units of prof. Parsadanov complex fuel and ecological criteria components.

Object of the study is mathematical apparatus of prof. Parsadanov complex fuel and ecological criteria.

Subject of the study is monetary equivalents units of components of object of the study.

Tasks of the study is:

1. Analysis of methodic and mathematical apparatus of prof. Parsadanov complex fuel and ecological criteria taking into account the essence of put in study [1.11] forward hypotheses.

2. Modification of mathematical apparatus of K_{FE} criteria in order to be able assess its value for the individual representative modes of the diesel operation in its exploitation model as well, as in study [5.6], based on the initial data obtained in studies [1.14, 3.35].

3. Calculated choice substantiation of monetary equivalents units of prof. Parsadanov complex fuel and ecological criteria components on example of autotractor diesel engine 2Ch10.5/12 for regimes of 13-mode standardized steady testing cycle.

4. Analysis of results of the study.

Methods of the study is analysis of specialized science and technical literature, processing of motor bench experimental testing data, calculating of middle exploitation values of technical, economical and ecological diesel engine operational indicators, mathematical apparatus of prof. Parsadanov complex fuel and ecological criteria, instruments for analysis of the dynamics of exchange rates, the mathematical apparatus of Consumer Price Index.

Solution of problem of the study. Mathematical apparatus of prof. Parsadanov complex fuel and ecological criteria K_{FE}, which described in [3.40] and modified in [5.6] for separately taken individual representative *i*-th operational regime of exploitation model can be and described by following formulas.

$$K_{FEi} = \eta_{ei} \cdot (1 - \beta_i) = \eta_{ei} \cdot (1 - Z_{ei} / (Z_{fi} + Z_{ei})); \qquad (5.7)$$

$$Z_{fi} = g_{ei} \cdot P_f ; \qquad (5.8)$$

$$Z_{ei} = G_{fi} \cdot U_{Ei} = G_{fi} \cdot \delta \cdot P_f \cdot f \cdot g_{pri} ; \qquad (5.9)$$

where η_e – effective efficiency coefficient of diesel engine; g_{pr} – specific effecttive mass hourly pollutant emission by diesel engine, kg/(kW·h); G_f – mass hourly fuel consumption by diesel engine, kg/h; β – coefficient of relative exploitation ecological monetary costs; Z_e, Z_f and Z_{fe} – ecological damage compensation monetary costs, motor fuel monetary costs and total fuel and ecological monetary costs, $/(kW·h); g_e – specific effective mass hourly fuel consumption by diesel engine, kg/(kW·h); U_{Ei} – ecological damage compensation monetary valuation, $/kg; δ – dimensionless index of relative dangerous of pollution for various territories; *f* – dimensionless coefficient, which taking into account the character of EG dispersion in atmosphere; σ – dimension coefficient for converting scoring assessment of damage in the monetary (σ = P_f [3.40]); P_f – price of motor fuel mass unit (results of choice of monetary equivalents units of K_{FE} criteria components given in [1.11], P_f = 0,871 $/kg at P_f = 20,0 UAH/l, ρ_f = 0,85 kg/m^3 and currency exchanging course at December 2016 27,0 UAH/$).

Features of engine test bench and methodic of experimental researches with it, which are used for determination of 2Ch10.5/12 diesel engine and its DPF operational characteristics, described in articles [5.6, 3.35, 3.29]. Operational characteristics of autotractor diesel engine 2Ch 10.5/12 described in [3.35]. Parameters of 13-mode standardized steady testing cycle as an autotractor diesel engine exploitation model described in UNECE Regulations № 49 [3.40]. Legislative established on Ukraine territory requirements to PP with PICE ES level indicators in historical dynamic shown in article [5.6].

Results of calculated assessment of K_{FE} criteria values, which based on experimental data obtained in articles [3.29, 3.30], for autotractor diesel engine 2Ch10.5/12, that operates on 13-mode standardized steady testing cycle, as well for its individual regimes as for whole cycle, shown in article [5.6].

Verbal justification and logical substation of measurement units choice for K_{FE} criteria as an as the nearest of the known analogues of ESMS of PP with PICE exploitation process functioning efficiency criteria Ω_{ESMS} – US Dollars ($, USD) as a freely convertible global reserve currency units, whose history completely covers the history of PICE – in form of hypothesis proposed and presented in [5.7].

This decision is due to the following circumstances.

Firstly, by definition, money is the commodity of maximum liquidity and the universal equivalent of the value of goods and services [1.16].

Secondly, the presence of the successful experience of applying well-known approach to assessment of technical, economic and ecological indicators of PICE developed by prof. I.V. Parsadanov as part of the methodology of calculation of the fuel and ecological criteria K_{FE} [1.14].

Thirdly, not all of monetary expenses components is possible to bring to form the dimensionless quantity β and, moreover, give them a physical meaning of average operational efficiency specific mass hour fuel consumption g_{eme}, as in the case K_{FE} [1.14].

In monograph [1.14] monetary expenses, which included in K_{FE} criteria structure, expressed in Ukrainian Hryvnia (₴, UAH). But in this case there is the problem of assessing the effectiveness of measures to ensure the ES level of PP with PICE which are in operation for a long time. So, for the case of raising the ES level of diesel 2Ch10.5/12 by equipping it exhaust system with DPF, developed in Piston Power Plants Dept. of A.M. Podgorny Institute for Mechanical Engineering Problems of NAS of Ukraine with the participation of staff members of the Applied Mechanics Dept. of Technogenic and Ecological Safety Faculty of National University of Civil Defense of Ukraine [1.14, 3.29, 3.30, 1.16], a direct comparison of K_{FE} criterion values for the basic (diesel without DPF) and modernized (diesel with DPF) version to perform in the UAH difficult. This is due to the following circumstances.

Firstly, diesel 2Ch10.5/12 (D21A1), which was used as a generator of aerosol of PM in the EG in these studies, released in the middle of the 80-years of the XX century, modern its modification produced by the Vladimir Tractor Plant (Russian Federation) and has significant constructive differences (e.g., electronic fuel supply control system). In this case to accurately estimate total operating time and the residual motoresource, prehistory and features of its exploitation, maintenance and repair measures and also, accordingly, its current technical condition and correlate it with any value indicator is extremely difficult.

Secondly, at the time of its release, such monetary unit as UAH did not exist, and the unit in which to express it cost parameters – USSR Ruble – do not exist at present; monetary unit in which its cost was estimated at the time, when motor test bench was equipped with this diesel engine – Ukrainian Coupon-Karbovanets – also no longer exists; and current modification of this diesel engine is estimated in Russian Rubles(RUB)

Thirdly, for some reason the UAH exchange rate against major freely convertible (so-called hard) currencies is very unstable. So, at the time of introduction into circulation UAH (1996), its rate against the USD amounts to less than 2 ₴/$, at the beginning of development of DPF concept (2008) – about 5 ₴/$, at the time of obtaining experimental data for the study [1.14] (2013) – about 8 ₴/$, at the time of mathematical models

[1.14, 3.29, 3.30, 1.16] creation (2014) – about 12 ₴/$, at the moment (October 2016) – about 26.5 ₴/$. To predict behavior of this macroeconomic indicator with reasonable accuracy for at least six months in advance is impossible, not to mention the longer term.

It confirmed the above by the history of official National Bank of Ukraine average monthly currency exchange rate UAH against USD in the period from 1998 to 2016, shown on Fig. 5.2. The same holds true for rate UAH against EUR and UAH against RUB in the same period, presented on Fig. 5.3 and 5.4 [5.8].

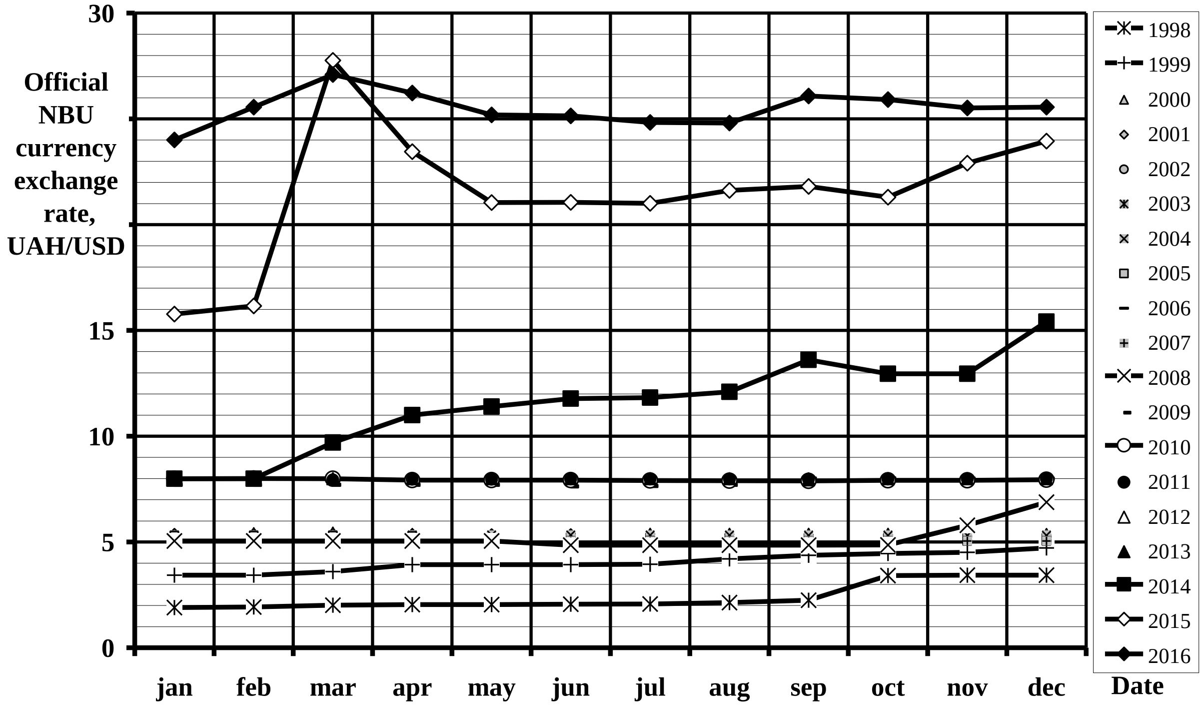


Fig. 5.2 – Official National Bank of Ukraine average monthly currency exchange rate UAH against USD in the period from 1998 to 2016

This is most clearly be demonstrated by the example of official National Bank of Ukraine average annual currency exchange rate UAH against USD, against EUR and against RUB in the period from 1998 to 2016, shown on Fig. 5.5 [5.8].

In connection with the above considerations, it seems rational to express the monetary expenses values Z_e, Z_f and Z_{fe} in the formula (1) – (3), that forming K_{FE} criteria value, in one of the widely used in Ukraine freely convertible world reserve currencies – Euro (€, EUR) or USD. However, only USD has a history, that completely covering the PICE history from birth of the idea (1807 de Rivas engine, 1860 Lenoir engine, 1863 two-stroke Otto engine,1876 four-stroke Otto engine, 1880 Kostovich engine, 1897 Diesel engine) and to the present day. EUR as the currency was introduced in cashless transactions in 1999 alone, and in the cash trade turnover – in 2001. In 1785 USD approved as an USA national currency, in 1794 USD begun to mint in USA, accepted for payment any banknotes and coins issued since 1861, but since 1971 it canceled USD backed by gold reserve.

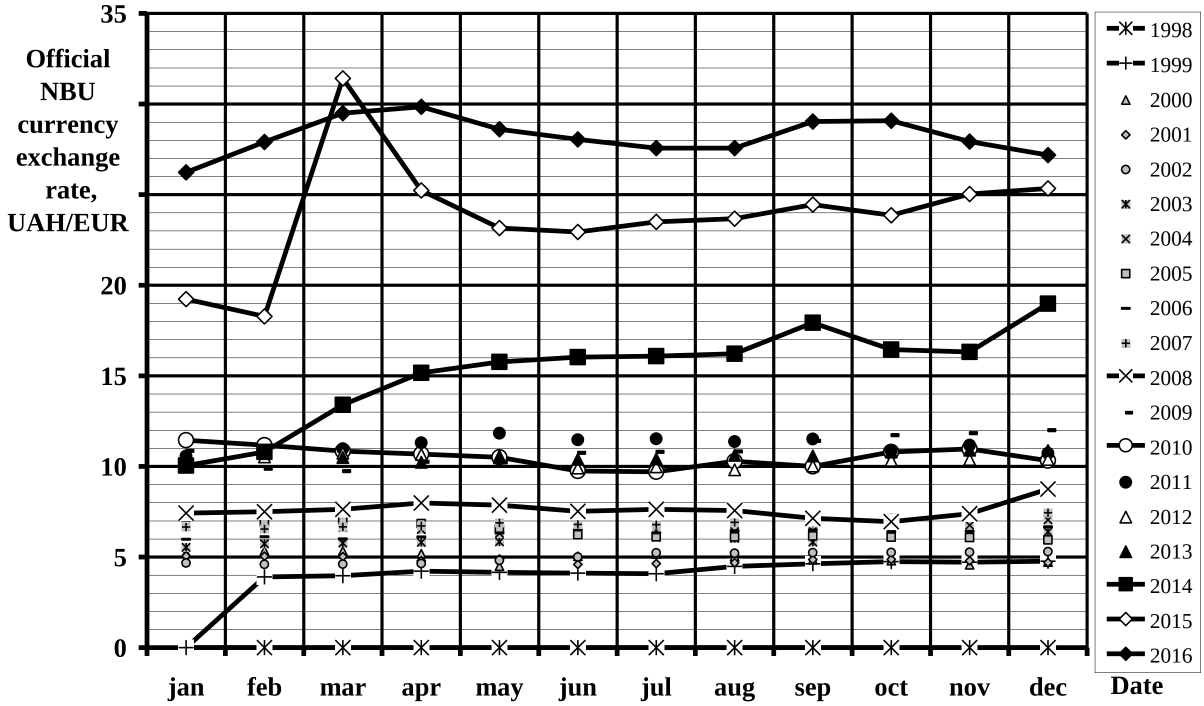


Fig. 5.3 – Official National Bank of Ukraine average monthly currency exchange rate UAH against EUR in the period from 1998 to 2016

In this case should take into account that purchasing capacity of the USD throughout its existence since the creation of the first PICE to the present day was not constant due to manifestations of inflation phenomenon, which can be accounted by applying the Consumer Price Index CPI [1.16]. CPI described by following formula.

$$CPI = \sum\left(Q_i^t \cdot P_i^t\right) / \sum\left(Q_i^0 \cdot P_i^0\right) \cdot 100\%; \qquad (5.10)$$

where index i marked types of products, index 0 marked base year (for USD it is 1982 – 1984); index t marked current year; Q – amount of products issue; P – price of products.

Then Z_e, Z_f and Z_{fe} values with taking into account inflation phenomenon – non-inflationary monetary costs z_e, z_f and z_{fe} – described by following formula.

$$z_j = Z_j(t) \cdot CPI_{\$}(t) / 100, \qquad (5.11)$$

where index j marked types of monetary costs ($j = e$, f of fe); t – date; Z_j – monetary costs as a part of K_{FE} criteria, $.

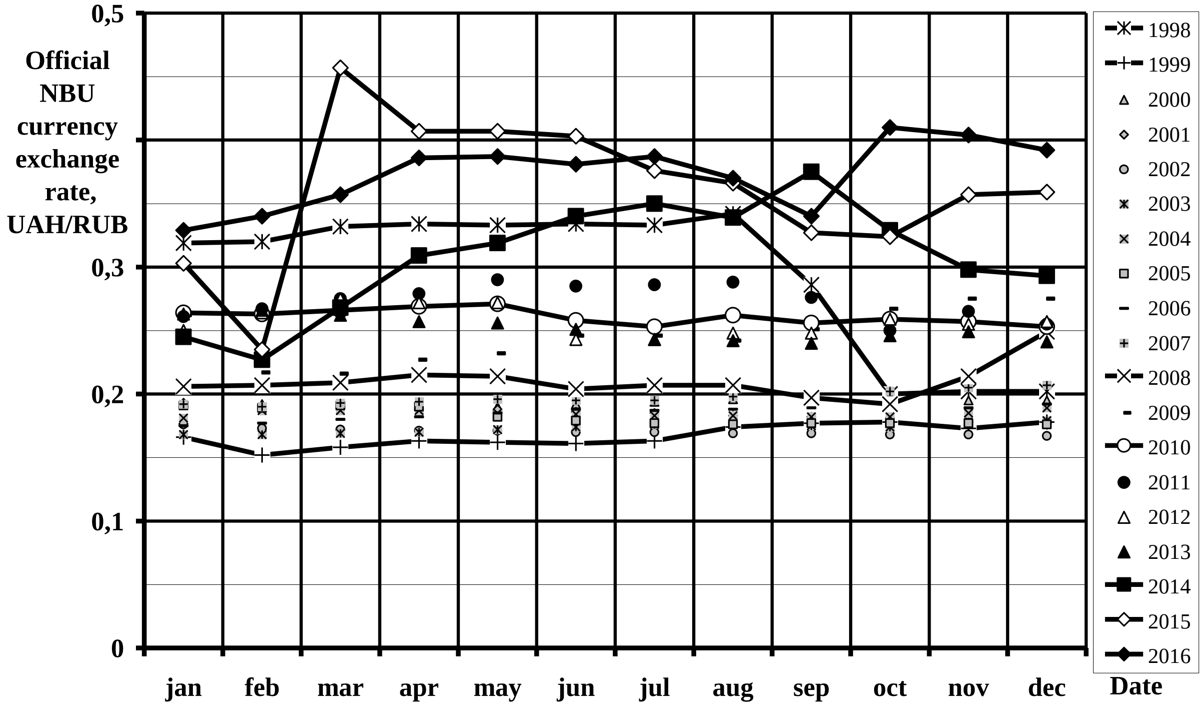


Fig. 5.4 – Official National Bank of Ukraine average monthly currency exchange rate UAH against RUB in the period from 1998 to 2016

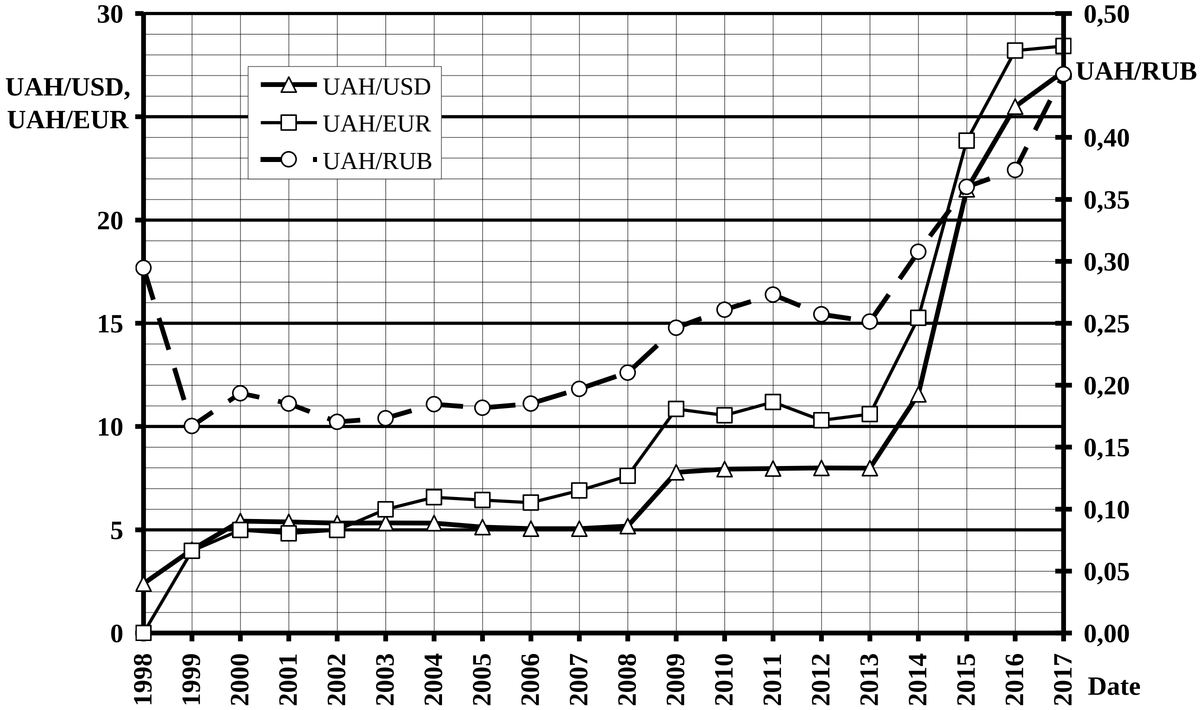


Fig. 5.5 – Official National Bank of Ukraine average annual currency exchange rate UAH against USD, against EUR and against RUB in the period from 1998 to 2016

Annual values of CPI for Ukraine, based on data from [5.9], shown on Fig. 5.6. Annual values of CPI for USA shown on Fig. 5.7 [5.10].

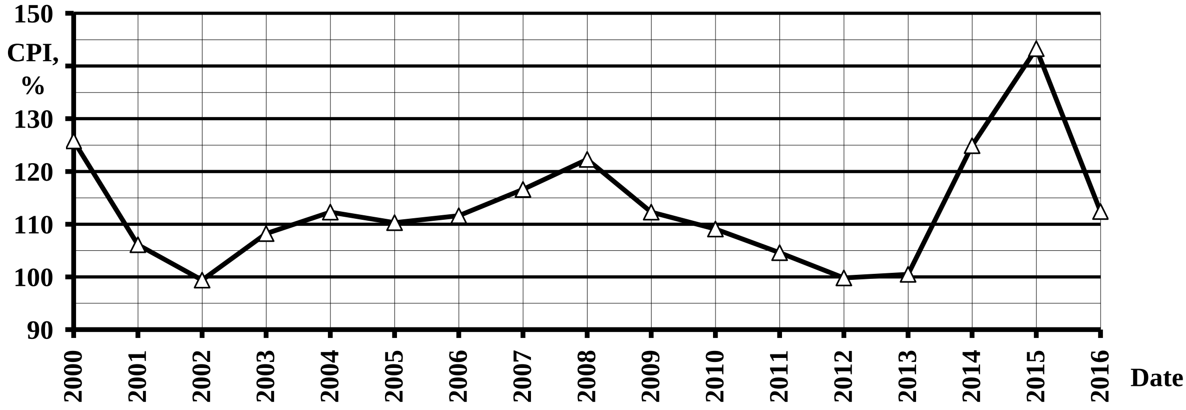


Fig. 5.6 – CPI annual values for Ukraine in 2000 – 2016

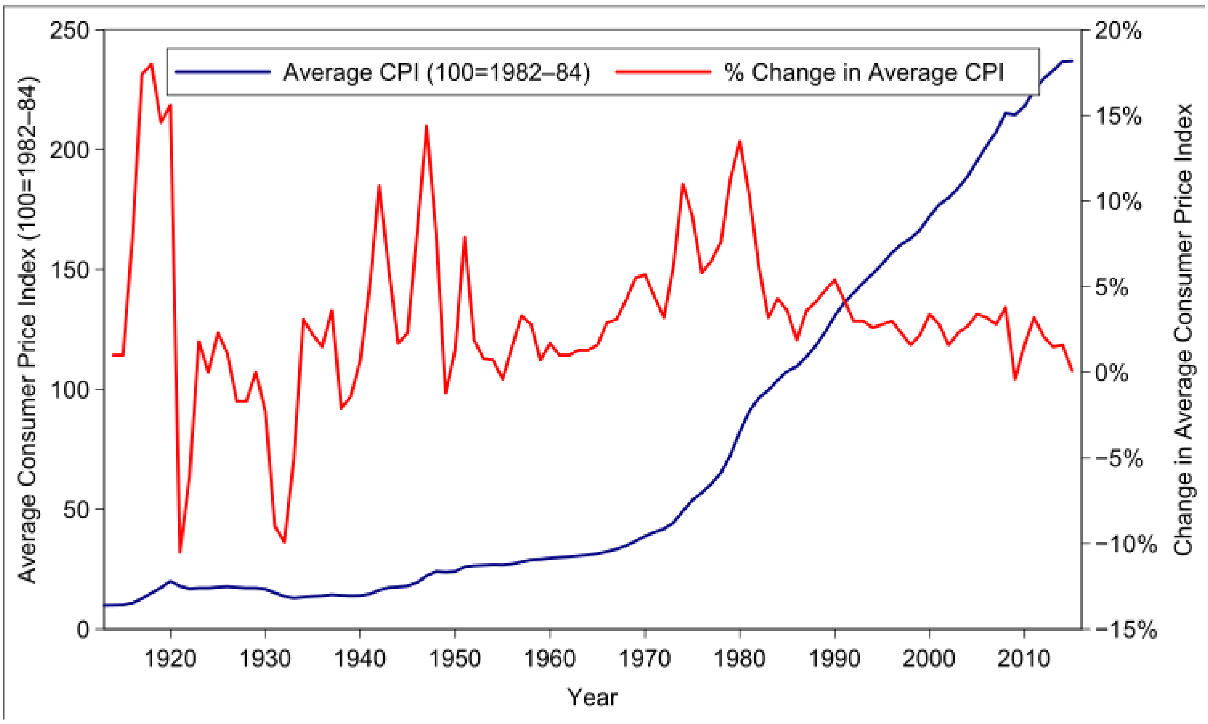


Fig. 5.7 – CPI annual values for USA in 1913 – 2015 [5.10]

In present study carrying out calculating assessment values of K_{FE} criteria components for autotractor diesel engine D21A1 for 13-mode stationary standardized test cycle.

Calculation investigated following cases of expression of weight unit cost of diesel fuel P_f.

– 1.81 UAH/kg (value at the moment of monograph [5] publication –2003);

– 0.34 $/kg (value at the moment of monograph [5] publication – 2003);

– 23.53 UAH/kg (current value);

– 0.871 $/kg (current value).

The results of this assessment calculation shown in Fig. 5.8 – 5.10.

From the Fig. 5.8 follows, that the difference in the monetary of value equivalent of these variables, expressed in the currency selected above (USD and UAH), can reach one order for the present value of their ratio and close to two orders when compared their values for 2003 and 2016 years. This is due to the instability of their course relative one to another, caused by external and internal economic and political factors, as well as the phenomenon of inflation, and can not be unaccounted.

In addition, in Fig. 5.8 – 5.10 shows that the correlation between variables Z_f, Z_e, Z_{fe} and is not constant over different modes of the test cycle.

As it can seen on Fig. 5.6 and 5.7, USD as a world reserve currency due to manifestations of inflation phenomenon can not be an absolute monetary equivalent of K_{FE} criteria components. Than in further studies it necessary to pay attention to changes in the cost of banking gold and oil.

Conclusions. Thus, in present study for the first time carried out calculated substantiation of choice of prof. Parsadanov complex fuel and ecological criteria components monetary equivalents and in what is *scientific novelty* of results of the study.

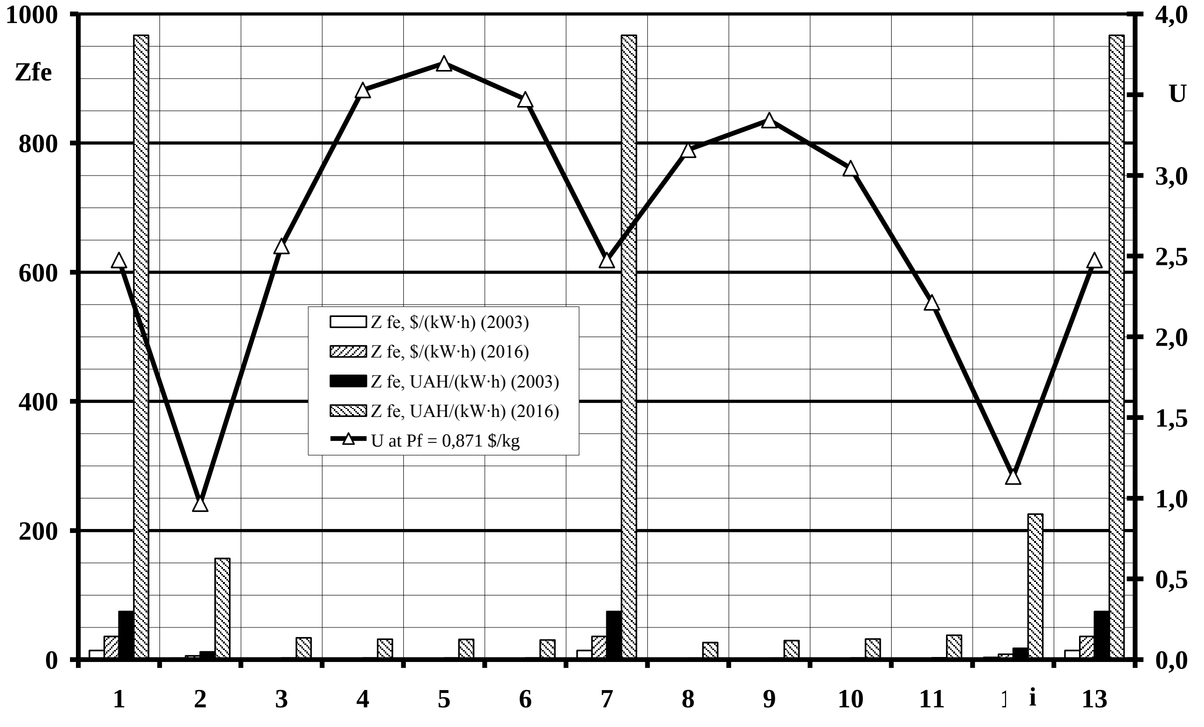


Fig. 5.8 – Distribution of values of fuel and ecological monetary costs Z_{fe} and ecological damage compensation monetary valuation *U* as a K_{FE} criteria components by regimes of 13-mode standardized steady testing cycle for different values and units of fuel price P_f

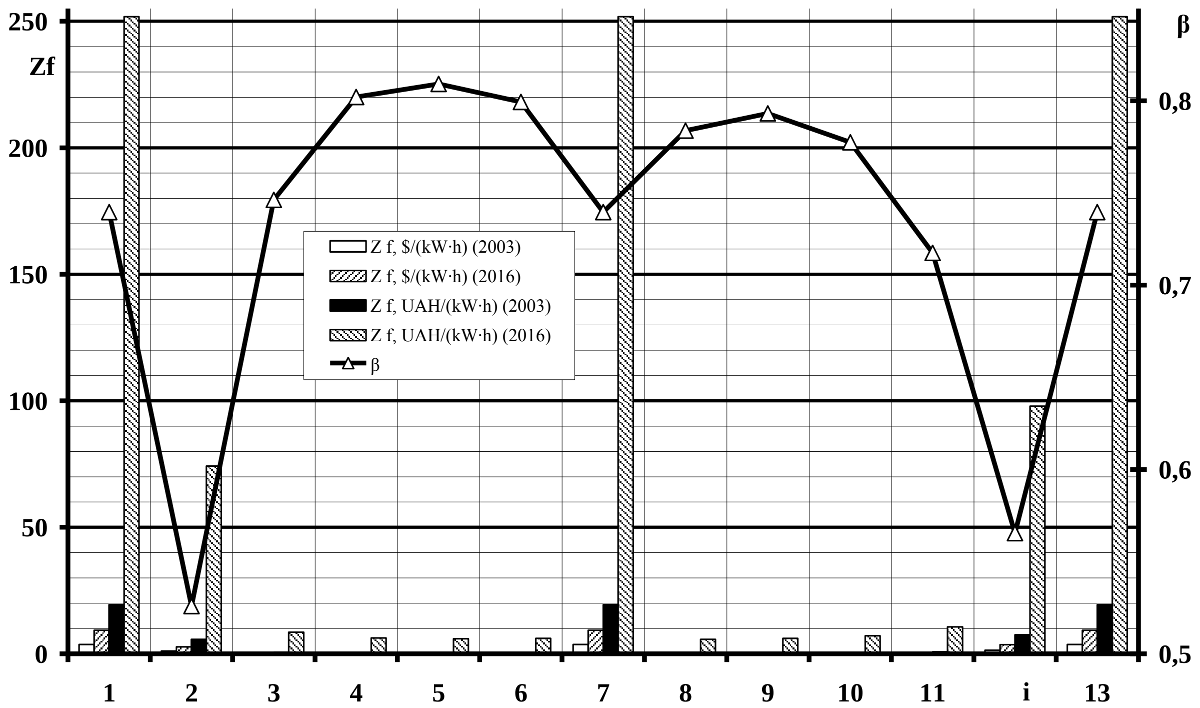


Fig. 5.9 – Distribution of values of fuel monetary costs Z_f and coefficient of relative exploitation ecological monetary costs β as a K_{FE} criteria components by regimes of 13-mode standardized steady testing cycle for different values and units of fuel price P_f

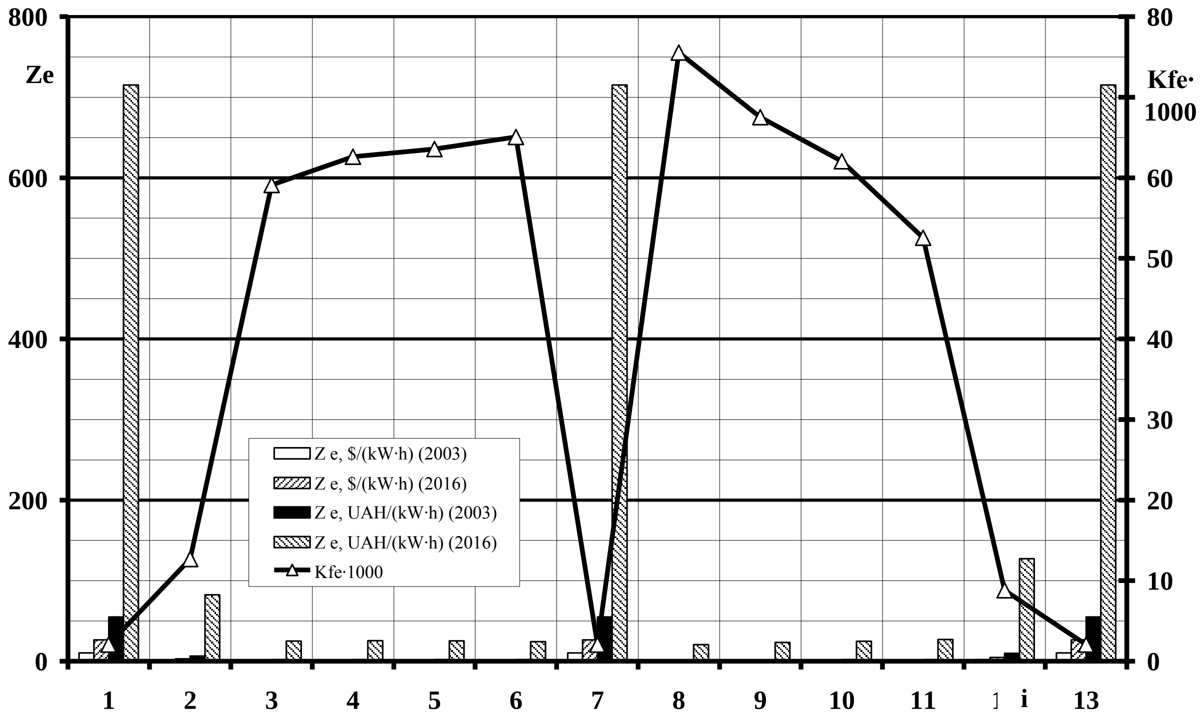


Fig. 5.10 – Distribution of values of ecological monetary costs Z_e and K_{FE} criteria by regimes of 13-mode standardized steady testing cycle for different values and units of fuel price P_f

The study found that difference in the values of monetary equivalent of these variables, expressed in the selected currency – USD and UAH, can reach one order for the present value of their ratio and close to two orders when compared their values for 2003 and 2016 years, due to different economic and political factors. But the study also shows, that USD as a world reserve currency due to inflation can not be an absolute monetary equivalent of prof. Parsadanov complex fuel and ecological criteria components. It was propose to use mathematical apparatus of Consumer Price Index for taking into account inflation phenomenon.

With modified mathematical apparatus can be carried out assessment of ecological safety level of exploitation process of emergency and rescue equipment, which powered with piston ICE of different years of release, and in what is *practical value* of results of the study.

5.4. RESULTS OF COMPLEX CRITERIAL FUEL AND ECOLOGICAL ASSESSMENT OF DIESEL ENGINE 2Ch10.5/12 FOR EMERGENCY AND RESCUE POWER PLANTS [A.5.3]

Relevance of the study, problem statement and literature analysis. Exploitation process of emergency and rescue power plants (PP) units, which are on combat duty of divisions of the State Emergency Service of Ukraine and equipped with diesel piston internal combustion engines (PICE), obviously, must be characterized by certain ecological safety (ES) level [1.11, 1.13, 5.8]. The main ES factors for such objects is pollutants mass hourly emissions with its engines exhaust gas (EG) flow, legislative established on Ukraine territory requirements to which contained in [3.40]. In order to ensuring the necessary ES level of that process was developed corresponding ecological safety management system (ESMS) and described in [1.11]. In study [1.13] was developed evaluation conception of the ESMS functioning efficiency, which involves calculated criterial assessment of ES level of PP with PICE exploitation process, and formulated main requirements for such criteria. But in specialized science and technical literature unitary approach to ES level complex assessment of such objects exploitation process vas not find and that puts the actual task of developing of methodological basis and mathematical apparatus for such assessment [1.13, 5.8]. Most close to meet requirements to that criteria from number of known is prof. Parsadanov complex fuel and ecological criteria K_{FE}, which vas developed for assessment of current competitiveness level of diesel PICE and activities for its increasing [1.14]. Calculated assessment of fuel and ecological effectiveness of PP exploitation process, the results is present in these paper, carried out for example of autotractor diesel engine 2Ch10.5/12, description and technical characteristics of which are given in [3.35]. Initial data for calculated assessment were obtained in studies [3.29, 3.30].

Purpose of the study is calculated assessment of ES level of exploitation process of emergency and rescue PP, based on PICE, with using complex fuel and ecological criteria on example of autotractor diesel engine 2Ch10.5/12.

Object of the study is ES level of exploitation process of emergency and rescue PP with PICE.

Subject of the study is values of complex fuel and ecological criteria, which describes object of the study.

Tasks of the study is:

1. Analysis of methodic and mathematical apparatus of prof. Parsadanov complex fuel and ecological criteria.

2. Modification of mathematical apparatus of K_{FE} criteria in order to be able assess its value for the individual representative modes of the diesel operation in its exploitation model.

3. Obtaining the initial data for calculated assessment of K_{FE} criteria values.

4. Calculated assessment of ES level of exploitation process of emergency and rescue PP with PICE on example of autotractor diesel 2Ch10.5/12 for regimes of 13-mode standardized steady testing cycle.

5. Analysis of results of the study.

Methods of the study is analysis of specialized science and technical literature, processing of motor bench experimental testing data, calculating of middle exploitation values of technical, economical and ecological diesel engine operational indicators, mathematical apparatus of prof. Parsadanov complex fuel and ecological criteria.

Solution of problem of the study. Mathematical apparatus of prof. Parsadanov complex fuel and ecological criteria K_{FE} described in [1.14] and assumes calculation middle exploitation value, that is, the only for separately taken exploitation model. For separately taken individual representative *i*-th operational regime of exploitation model it apparatus can be modified and described by following formulas.

$$K_{FEi} = \eta_{ei} \cdot (1-\beta_i) = 3600/(H_u \cdot g_{ei}) \cdot (1 - Z_{ei}/(Z_{fei})) = \\ = 3600/(H_u \cdot G_{fi}/N_{ei}) \cdot (1 - Z_{ei}/(Z_{fi} + Z_{ei})); \qquad (5.12)$$

$$Z_{fi} = g_{ei} \cdot P_f; \qquad (5.13)$$

$$Z_{ei} = G_{fi} \cdot \delta \cdot \sigma \cdot f \cdot \sum_{m=1}^{h} (A_k \cdot G_{mki}/G_{fi})/N_{ei}; \qquad (5.14)$$

$$N_{ei} = M_{кpi} \cdot n_{квi}/9550; \qquad (5.15)$$

where index *i* represent *i*-th operational regime of exploitation model; H_u – motor fuel lower heat of combustion (H_u = 42,7 MJ/kg [1.14]); N_{ei} – diesel engine effective power, kW; G_{fi} – mass hourly fuel consumption by diesel engine, kg/h; G_{mki} – mass hourly pollutant emission with diesel engine EG flow, kg/h; A_m – dimensionless index of relative aggressiveness of *m*-th pollutant as a EG component (A_{NOx} = 41,1; A_{PM} = 200; A_{CnHm} = 3,16;

A_{CO} = 1,0 [1.14]); h – number of legislative normalized pollutants in EG (h = 4 [1.11, 3.40, 1.14]); δ – dimensionless index of relative dangerous of pollution for various territories (for vehicle diesel engine δ = 1,0, for tractor diesel engine δ = 0,25 [1.14]); f – dimensionless coefficient, which taking into account the character of EG dispersion in atmosphere (forUkraine territory f = 1,0 [1.14]); σ – dimension coefficient for converting scoring assessment of damage in the monetary ($\sigma = P_f$ [1.14]); WF_i – weight factor operational mode in exploitation model (relative lobar engine run time on i-th polygon of exploitation model); η_e – effective efficiency coefficient of diesel engine; β – coefficient of relative exploitation ecological monetary costs; Z_e, Z_f and Z_{fe} – ecological damage compensation monetary costs, motor fuel monetary costs and total fuel and ecological monetary costs, \$/(kW·h); g_e – specific effective mass hourly fuel consumption by diesel engine, kg/(kW·h); P_f – price of motor fuel mass unit (results of choice of monetary equivalents units of K_{FE} criteria components given in [1.13], P_f = 0,871 \$/kg at P_f = 20,0 UAH/l, ρ_f = 0,85 kg/m^3 and currency exchanging course at December 2016 27,0 UAH/\$); $M_{\kappa pi}$ – torque of diesel engine, N·m; $n_{\kappa ei}$ – crankshaft speed of diesel engine, min^{-1}.

Formulas (5.12) – (5.13) for whole diesel engine exploitation model formed in following formula [1.14].

$$K_{FE} = \frac{3600}{H_u \cdot \dfrac{\sum_{i=1}^{z}\left(G_{fi} \cdot \overline{P}_i\right)}{\sum_{i=1}^{z}\left(N_{ei} \cdot \overline{P}_i\right)}} \cdot \frac{\sum_{i=1}^{z}\left(G_{fi} \cdot \overline{P}_i\right)}{\sum_{i=1}^{z}\left(G_{fi} \cdot \overline{P}_i\right) + \delta \cdot f \cdot \sum_{i=1}^{z}\left[G_{fi} \cdot \overline{P}_i \cdot \sum_{m=1}^{h} \dfrac{A_m \cdot G_{mi}}{G_{fi}}\right]}, \quad (5.16)$$

$$\eta_{e.me} = 3600 / \left(H_u \cdot g_{e.me}\right); \quad (5.17)$$

$$g_{e.me} = \sum_{i=1}^{z}\left(G_{fi} \cdot WF_i\right) / \sum_{i=1}^{z}\left(N_{ei} \cdot WF_i\right); \quad (5.18)$$

$$Z_f = g_{e.me} \cdot P_f; \quad (5.19)$$

$$Z_e = \sum_{i=1}^{z}\left(G_{fi} \cdot WF_i \cdot U_{Ei}\right) / \sum_{i=1}^{z}\left(N_{ei} \cdot WF_i\right); \quad (5.20)$$

$$U_{Ei} = \delta \cdot \sigma \cdot f \cdot g_{pri}; \quad (5.21)$$

$$g_{pri} = \sum_{m=1}^{h}\left(A_k \cdot G_{pki} / G_{fi}\right), \quad (5.22)$$

where $\eta_{e.me}$ – middle exploitation values of effective efficiency coefficient of diesel engine; $g_{e.me}$ – middle exploitation values of specific effective mass hourly fuel consumption by diesel engine, kg/(kW·h); U_{Ei} – ecological damage compensation monetary valuation, \$/kg; $g_{pr.i}$ – specific effective mass hourly pollutant emission by diesel engine, kg/(kW·h); Z_e i Z_f – middle exploitation values of motor fuel and ecological damage compensation monetary costs, \$/(kW·h).

Features of engine test bench and methodic of experimental researches with it, which are used for determination of 2Ch10.5/12 diesel engine and its DPF operational characteristics in articles [1.11, 3.29, 3.30], involves the following activities. Firstly, the G_{PMi} value in kg/h for *i*-th exploitation mode obtained with using following known conversion formula, which described and grounding in the study [1.14], depended on value of light flow weakening coefficient in EG probe N_D (indicator of EG opacity), %, unburned hydrocarbons of motor fuel and oil C_nH_m volume concentration in EG flow C_{CH}, ppm, mass hourly consumption of fuel and air G_{air} i G_f, kg/h.

$$G_{PMi} = \left(2{,}3 \cdot 10^{-3} \cdot N_{Di} + 5 \cdot 10^{-5} \cdot N_{Di}^2 + 0{,}145 \cdot \frac{C_{CHi} \cdot 4{,}78 \cdot 10^{-7} \cdot (G_{airi} + G_{fi})}{0{,}7734 \cdot G_{airi} + 0{,}7239 \cdot G_{fi}} + \right.$$
$$\left. + 0{,}33 \cdot \left(\frac{C_{CHi} \cdot 4{,}78 \cdot 10^{-7} \cdot (G_{airi} + G_{fi})}{0{,}7734 \cdot G_{airi} + 0{,}7239 \cdot G_{fi}} \right)^2 \right) \cdot \frac{(0{,}7734 \cdot G_{airi} + 0{,}7239 \cdot G_{fi})}{1000}, \tag{5.23}$$

Secondly, values of mass hourly emissions of NO_x, C_nH_m and CO G_{mNOx}, G_{mCH} and G_{mCO} in kg/h converts from experimentally obtained values of volume concentrations in EG probe C_{VNOx} C_{VCOi} and C_{VCnHmi} in ppm with using methodic in [1.14] by following formulas, which taking into account correction coefficients of laboratory air humidity F_{NOxi} and F_{COi}.

$$G_{NOxi} = 1{,}587 \cdot 10^{-3} \cdot C_{VNOxi} \cdot F_{NOxi} \cdot (G_{палi} + G_{повi}), \tag{5.24}$$
$$G_{COi} = 9{,}66 \cdot 10^{-4} \cdot C_{VCC.i} \cdot F_{COi} \cdot (G_{палi} + G_{повi}), \tag{5.25}$$
$$G_{CnHmi} = 4{,}78 \cdot 10^{-4} \cdot C_{VCnHmi} \cdot (G_{палi} + G_{повi}), \tag{5.26}$$
$$F_{NOxi} = \begin{pmatrix} 1 + (0{,}044 \cdot G_{палi} / G_{повi} - 0{,}0038) \cdot (7 \cdot d - 75) + \\ + (0{,}0053 - 0{,}116 \cdot G_{палi} / G_{повi}) \cdot 1{,}8 \cdot (T_0 - 302) \end{pmatrix}^{-1}, \tag{5.27}$$
$$d = 6{,}21 \cdot \varphi_0 \cdot P_s / (B_0 - 0{,}01 \cdot \varphi_0 \cdot P_s), \tag{5.28}$$
$$F_{COi} = 1 - 1{,}85 \cdot G_{палi} / G_{повi}, \tag{5.29}$$
$$P_s = 6{,}1121 \cdot \exp((18{,}678 - t_0 / 234{,}5) \cdot t_0 / (257{,}14 + t_0)), \tag{5.30}$$

where d = 5,367 g/kg – mass concentration of water steam in air; φ_0 = = 50 % – relative air humidity; B_0 = 995 hPa – barometric pressure; P_s = = 17,052 hPa – water vapor saturated pressure; t_0 = 15 °C – temperature of environmental air.

Diesel engine 2Ch10.5/12 is autotractor naturally aspirated two-cylinder in-line four-stroke two-valve air-cooled piston internal combustion engine with internal mixture formation and compression ignition; with traditional trunk-piston axial crankshaft mechanism, cylinder diameter 105 mm, piston stroke 120 mm, piston-rod length 270 mm, working volume 2.0 l, compression ratio 16.5; with nominal power 21_{-3} kW (at n_{cs} = 1800 min^{-1}), maximal torque 111 N·m (at n_{cs} = 1200 min^{-1}), middle exploitation specific mass hourly fuel consumption 235 g/(kW·h); with direct injection in undivided semispherical combustion chamber in piston by one-plunger high-pressure fuel pump of distributional type with all-regimes mechanical regulator and hydromechanical nozzles; with weight 280 kg, external dimensions 693×687×855 mm; with starting from the starter; made by Vladimir Tractor Plant. It using on tractors, automotive chassis, selecting combines, asphalt and concrete placers, mobile electric welding, water pump and air compressor stations [3.35].

Parameters of 13-mode standardized steady testing cycle as an autotractor diesel engine exploitation model describing in UNECE Regulations № 49 [3.40] and shown on Table 5.3. Legislative established in Ukraine requirements to PP with PICE ES level indicators in historical dynamic shown on Table 5.4 [1.11].

In monograph [1.14] K_{FE} criteria values and its components β, Z_e, Z_f and Z_{fe} was assessed for different models of exploitation as a whole, but not for its individual modes. These due to presents in that exploitation models regimes with zero (idling) and low effective power. For idling regimes $N_{ei} \to 0$ kW and therefore $\eta_e \to 0$, $g_e \to \infty$ kg/(kW·h) and Z_e, Z_f, Z_{fe} $\to \infty$ \$/(kW·h), $\beta \to 1$ and $K_{FE} \to 0$ (see formulas (5.12) – (5.14)). For regimes with low effective power K_{FE} criteria values are not informative.

For obtaining opportunities of assessment K_{FE} criteria values for individual regimes of exploitation models in present paper propose the following method. It is necessary to use interpretation of the term “idle run” is not in adopted in engine theory, but in the engine operating practices as a part of the PP. In this case, the on idling run engine produces non zero effective power that is spent on the needs of secondary energy consumers of PP and on providing comfortable working conditions for the PP operator. The first-mentioned case includes charging an electric battery, powering electronic control systems, powering hydraulic and pneumatic servo systems end others. The second-mentioned case includes lighting of workplace and passenger compartment, powering light indicators and control panel, powering air conditioning, multimedia and navigation systems end etc.

Then we take the following assumption: the effective power N_{ei} on the idle run regime of engine operating models defined by the formula (5.15), in which the torque $M_{кpi}$ is equal to 1 % of the maximum diesel torque (110 N·m), and crankshaft speed $n_{кві}$ equal to the crankshaft speed of minimal idling regime (900 min^{-1}), that is for diesel 2Ch10.5/12, it is equal to 46.1 W.

Results of calculated assessment, which based on experimental data obtained in [3.29, 3.30] (presented on Fig. 5.11 – 5.13), for autotractor diesel engine D21A1 and, that operates on 13-mode standardized steady testing cycle, shown on Fig. 5.13 and 5.15.

Table 5.3 – Parameters of 13-mode standardized steady testing cycle and its values for diesel engine 2Ch10.5/12 [1.11, 3.40, 1.14]

№ of mode	n_{cs}, min^{-1}		M_T, N·m		*WF*
	designation at regime of	value	designation % $M_{T\max}$	value	
13-mode cycle					
1	minimal idle	800	0	0	0,25/3
2	maximal torque	1200	2	2,2	0,08
3	maximal torque	1200	25	27,5	0,08
4	maximal torque	1200	50	55	0,08
5	maximal torque	1200	75	82,5	0,08
6	maximal torque	1200	100	110	0,25
7	minimal idle	800	0	0	0,25/3
8	nominal power	1800	100	95	0,10
9	nominal power	1800	75	71,3	0,02
10	nominal power	1800	50	47,5	0,02
11	nominal power	1800	25	23,8	0,02
12	nominal power	1800	2	1,9	0,02
13	minimal idle	800	0	0	0,25/3

Table 5.4 – Legislative established requirements of ecological indicators of diesel engines [1.11, 3.40, 1.14]

EURO level	Year of goes into effect	Specific mass hourly emission of pollutant, g/(kW·h)			
		PM	NO_x	C_nH_m	CO
I	1992	0,612	8,0	1,1	4,5
II	1996	0,25…0,15	7,0	1,1	4,0
III	2000	0,10	5,0	0,66	2,1
IV	2005	0,02	3,5	0,46	1,5
V	2008	0,02	2,0	0,25	1,5
VI	2012	0,01	0,5	0,2	1,0

From the Fig. 5.12 and 5.13 we can see, that that ratio between monetary equivalents of compensation of ecological damage costs Z_e, motor fuel costs Z_f and total fuel and ecological costs Z_{fe} are vary from mode to mode of testing cycle and reaches maximum on modes of minimal idling (modes № 1, 7, 13).

Values of K_{FE} criteria without taking into account weight factor value *WF* reaches maximum on the mode of nominal power (mode № 8) and with taking into account *WF* value – on the mode of maximal torque (mode № 6).

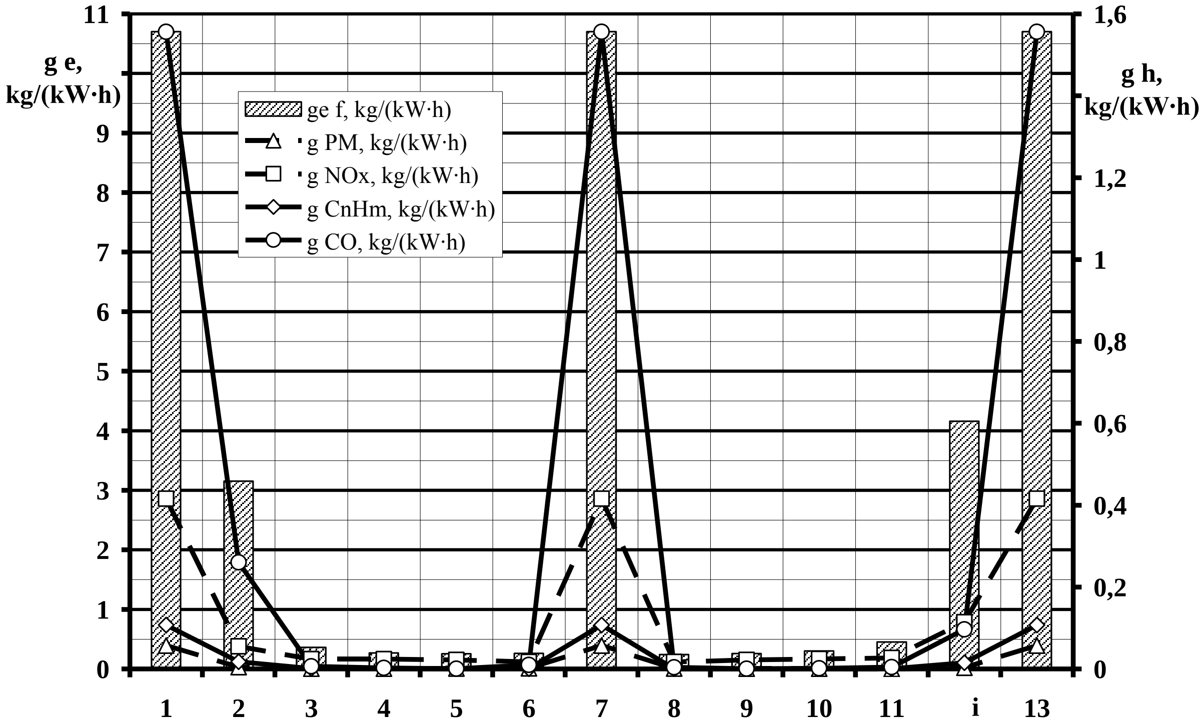


Fig. 5.11 – Initial data for calculated estimation of values of complex fuel and ecological criteria K_{FE} for diesel engine 2Ch10.5/12 and 13-modes testing cycle, experimentally obtained in [3.29, 3.30]

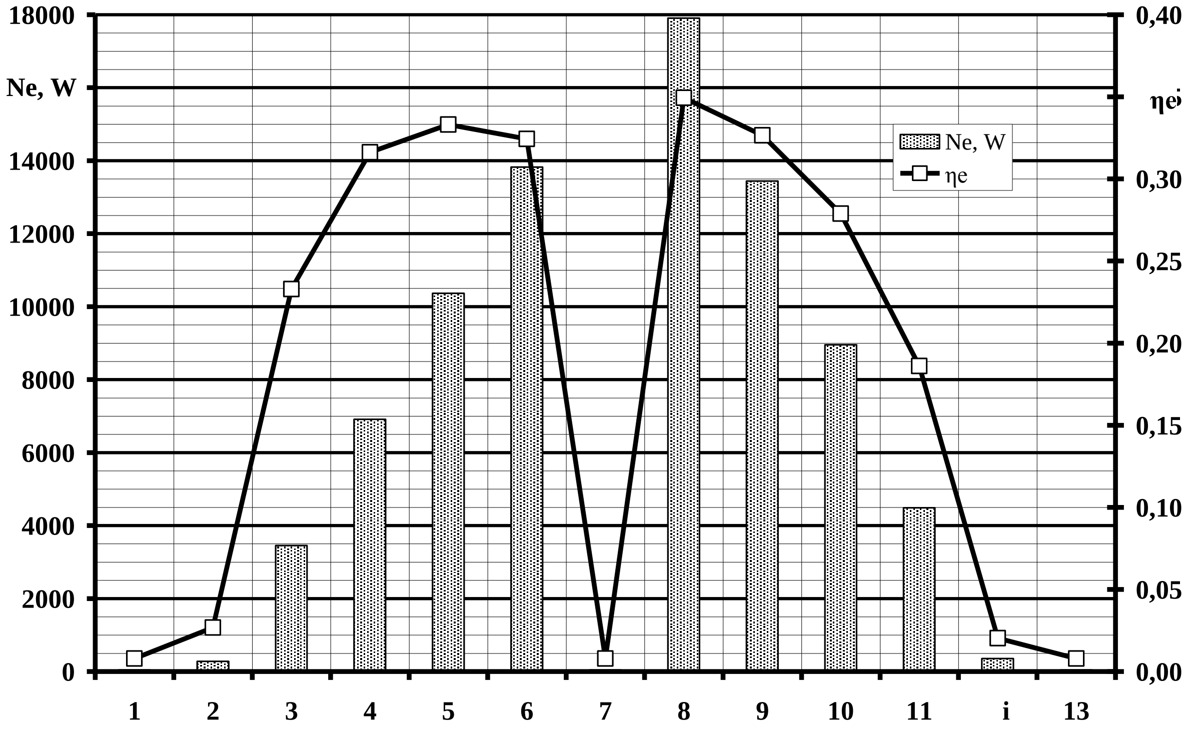


Fig. 5.12 – Initial data for calculated estimation of values of complex fuel and ecological criteria K_{FE} for diesel engine 2Ch10.5/12 and 13-modes testing cycle, experimentally obtained in [3.29, 3.30]

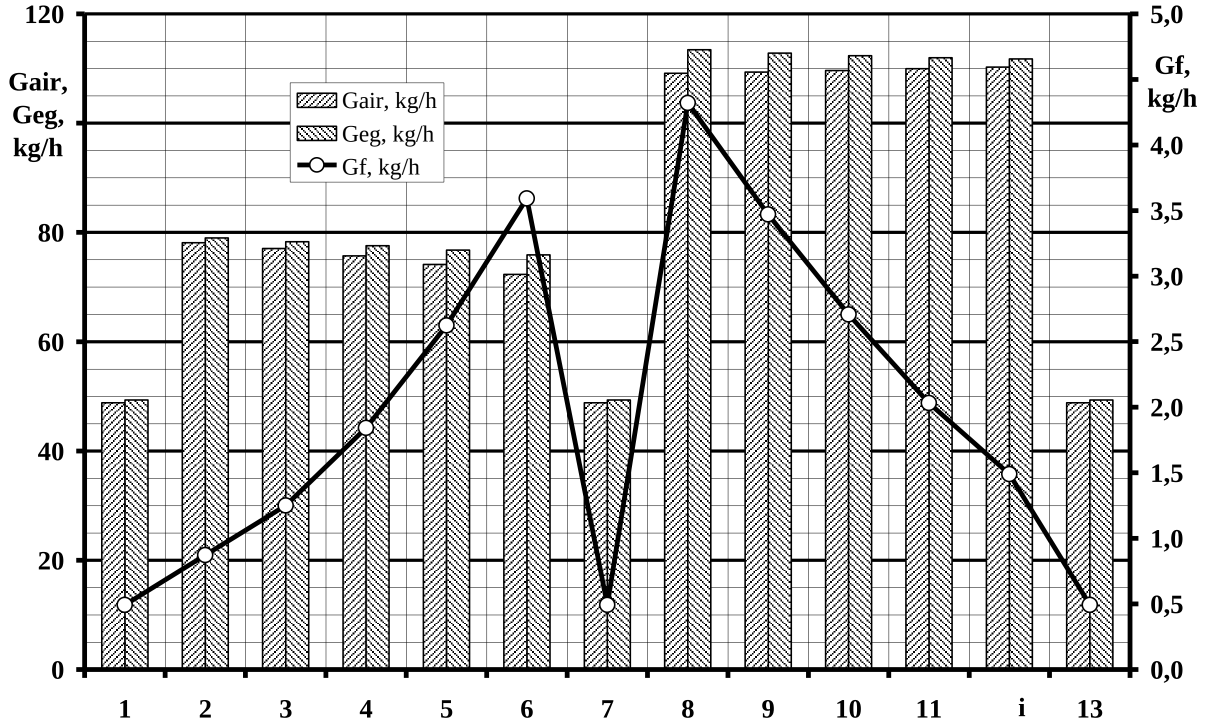


Fig. 5.13 – Initial data for calculated estimation of values of complex fuel and ecological criteria K_{FE} for diesel engine 2Ch10.5/12 and 13-modes testing cycle, experimentally obtained in [3.29, 3.30]

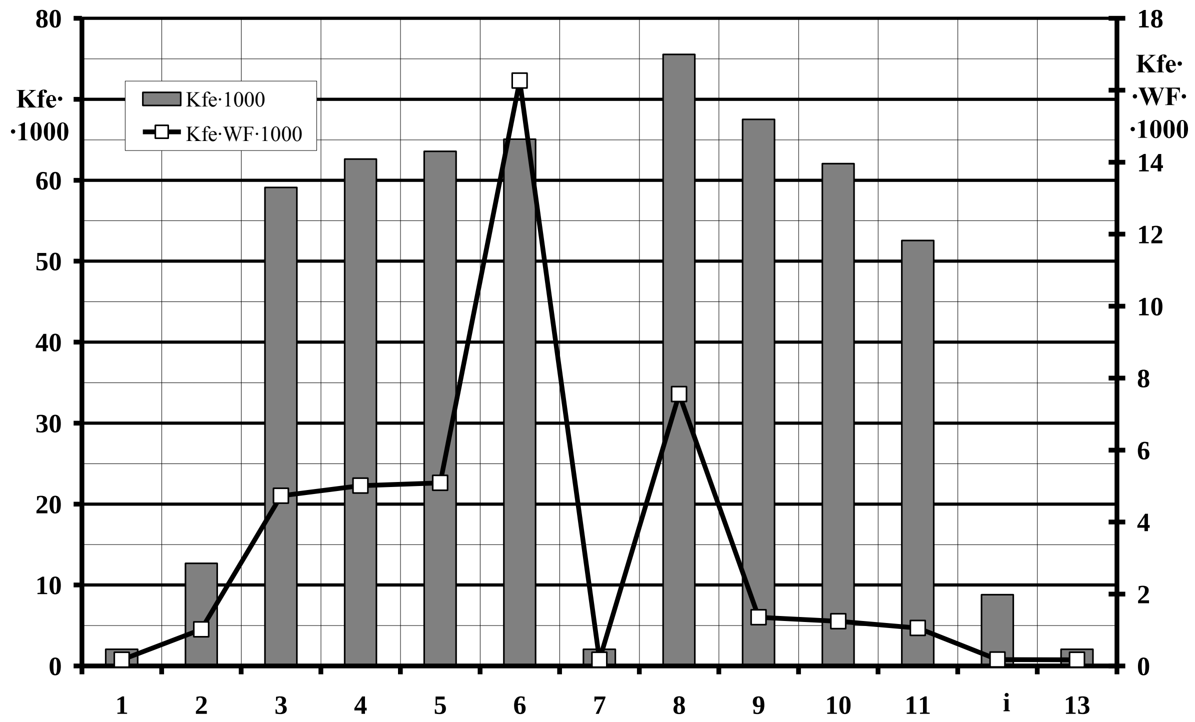


Fig. 5.14 – Results of calculated quantitative estimation of complex fuel and ecological criteria K_{FE} for diesel engine 2Ch10.5/12 and 13-modes testing cycle

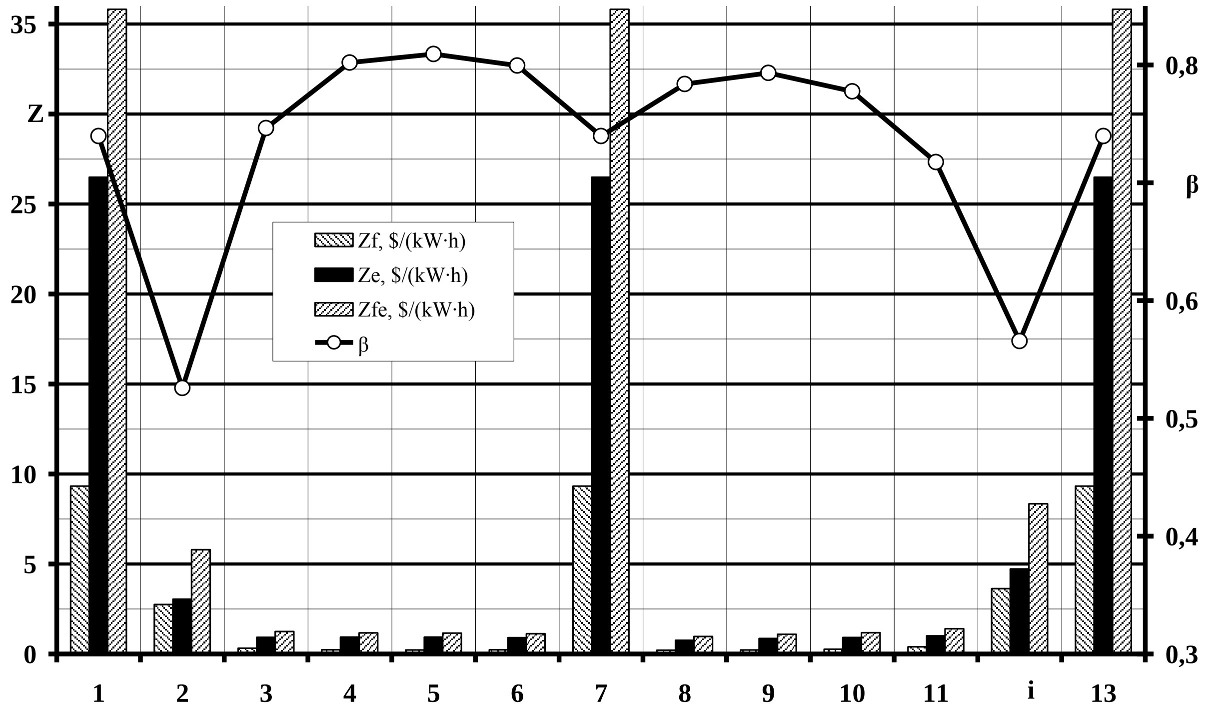


Fig. 5.15 – Results of calculated quantitative estimation of components of complex fuel and ecological criteria K_{FE} for diesel engine 2Ch10.5/12 and 13-modes testing cycle

Exploitation of diesel engine 2Ch10.5/12 on loading characteristic with crankshaft speed of maximal torque mode (modes № 2 – 6) by K_{FE} criteria value is less preferred, than its exploitation on loading characteristic with crankshaft speed of nominal power mode (modes № 8 – 12).

Exploitation of that diesel engine on modes with zero effective power (modes № 1, 7, 13) and also on modes with low effective power (modes № 2, 12) is characterized by extremely low fuel and ecological effectiveness.

Middle exploitation value of K_{FE} criteria (e.i. with taking into account distribution of value *WF* by modes of testing cycle) is $43.989\cdot10^{-3}$, and middle value (e.i. in case of equality of value *WF* for all modes of model of diesel engine exploitation) is $41.204\cdot10^{-3}$.

Obtained in this study middle exploitation value of K_{FE} criteria for diesel engine 2Ch10.5/12 can be compared with middle exploitation value of that criteria for autotractor diesel engine 6ChN12/14 (SMD-31), assessed in monograph [1.14] for 18-mode testing cycle, which equal $106.0\cdot10^{-3}$. In this case fuel and ecological efficiency of exploitation process of the investigated diesel engine can be characterized as relatively low.

This conclusion is explained by high values of hourly mass emissions of normative pollutants with its EG flow against the background of acceptable fuel efficiency.

Such results caused by significant differences in technical level of compared diesel engines, namely presence of turbo charging liquid cooling system, individual sections of high pressure fuel pump, much higher nominal power and crankshaft speed in the second one engine and also significant difference in the date of implementation in series production of this engines.

Conclusions. Thus, in present study describes methodology, modified mathematical apparatus and results of application of prof. Parsadanov complex fuel and ecological criteria and its components.

The study found that ratio between monetary equivalents of criteria components are vary from mode to mode of testing cycle and reaches maximum on minimal idling modes. Values of criteria reaches maximum on the mode of nominal power. Exploitation of diesel engine on loading characteristic with crankshaft speed of maximal torque mode is less preferred, than its exploitation on loading characteristic with crankshaft speed of nominal power mode. Exploitation of that diesel engine on modes with zero and low effective power is characterized by extremely low fuel and ecological effectiveness.

With modified mathematical apparatus can be carried out assessment of ecological safety level of exploitation process of emergency and rescue equipment, which powered with piston ICE of any type, and in what is *practical value* of results of the study. The study carried out using experimental data of motor bench tests on example of autotractor diesel engine 2Ch10.5/12, that operates on 13-mode standardized steady testing cycle both for the whole cycle, and for its individual modes, and in what is *scientific novelty* of results of the study.

Obtained in this study middle exploitation value of KFE criteria for diesel engine 2Ch10.5/12 was compared with that value for autotractor diesel engine 6ChN12/14.

5.5. REFERENCES

5.1. Nechiporuk N.V., Kobrin V.N., Vambol V.V. (2014), “Utilization of aircraft: monograph” [Text], Kharkiv, Publ. NAKU “KhAI”, 303 p. ISBN 978-966-662-355-6.

5.2. Kobrin V.N., Nechiporuk N.V., Vambol V.V. (2014), “Ecological safety management system during utilization of solid domestic and industrial waste” [Text], Kremenchuk, Scientific journal “Ecological Safety”, issue 2 (18), Publ. KrNU, pp. 25 – 30.

5.3. Chubenko A.S., Kobrin V.N., Vambol V.V. (2013), “Ecological safety utilization of waste of vital activity” [Text], Open information and computer integrated technologies: collection of scientific works, issue 62, Kharkiv, Publ. NAKU “KhAI”, pp. 98 – 102.

5.4. Chubenko A.S., Vambol V.V. (2014), “Environmentally friendly treatment of waste with following methanation of products of plasma gasification” [Text], Materials of International scientific and practical conference “Technosphere safety problems”, Moscow, Publ. ASFS of EMER-

COM of RF, pp. 230 – 232.

5.5. Shahov Ju.V., Petuhov I.I., Vambol V.V. (2015), “Mathematical model of energy and technology plant for separation multi component gas mixtures” [Text], Herald of NTU “KhPI”. Series: Mathematical modeling in technique and technologies, № 19 (1128), Kharkiv, Publ. NTU “KhPI”, pp. 37 – 46.

5.6. Kondratenko O.M. (2016), “Results of complex criterial fuel and ecological assessment of diesel engine 2ch10.5/12 for emergency and rescue power plants” [Text], Scientific and technical journal “Technogenic and ecological safety”, Kharkiv, Publ. NUCDU, issue 1, pp. 100 – 109.

5.7. Vambol S.O., Kondratenko O.M., Vambol V.V., Mietielov O.V. (2016), “Methodological basics of criterial integrated assessment of ecological safety management system functioning efficiency of power plants with piston ICE exploitation process” [Text], Kremenchuk, Herald of Ostrogradsry KrNU, Publ. KrNU, № 6 (101), Part 1, pp. 104 – 110.

5.8. Official exchange rate of Hryvnia against foreign currencies. National Bank of Ukraine: Official website [Electronic recourse], Access mode: https:// bank.gov.ua/ control/en/curmetal/detail/currency?period= daily, date of last access 30-01-2017.

5.9. Inflation index (Ukraine). Minfin: financial portal [Electronic recourse], Access mode: http://index.minfin.com.ua/index/infl, date of last access 30-01-2017.

5.10. Akaev A.A., Korotaev A.V., Fomin A.A. (2012), “Dynamics of the global rate of: regularities and predictions” [Dinamika tempov global’noj infljatsyi: zakonomernosti i prognozy] [Text], Moscow, Publ. “Knizhny Dom”, 32 p.

G E N E R A L   C O N C L U S S I O N S

Thus, main results of the study, presented in Chapter 1 – 5 of these monograph, can be summarized by following provisions.

1. Created scientific basis of methodological maintains of ecological safety management systems during life cycle of technics with taking into account specific features of technologies on which based on its exploitation and utilization.

2. Carried out mathematical modeling of processes of ensuring of ecological safety as the base of rationalization of technical decisions of construction, exploitation and utilization of technics units.

3. Detected and decrypted technogenic, ecological and metrological aspects of experimental researches of indicators of level of ecological safety of technics and technologies as source of initial data for physical and mathematical modeling and identification of models.

4. Detected and studied features of ways of ensuring of ecological safety of products of nanotechnology during its life cycle as most probability alternative for traditional technologies.

5. Created scientific basis of methodological maintains of criterial and economical assessment of efficiency of functioning process of ecological safety management systems as basis of monitoring and feedback of such systems.

6. Presented above can be systemized with logical apparatus of SWOT-analysis, results of what is shown bellow.

Strengths (**S**). Developed scientific basis of methodological maintains of ecological safety management systems during life cycle of technics of various porpuse, wich taking into account specific features of technologies and also technologies of threatment of nanotechnologies products. These scientific basis developed for the first time with using of principals of systematic approach, multilevel decomposition, analysis of hierarchical structures, decimal division and because of that it possible to solve in complex the task of ensuring of legislative established level of ecological safety indicators of management objects. With using of such achievements it can be ensure compliance with legislative established requirements for ecological safety level of technics, technologies and its products during their life cycle and also to implement assessment of functioning efficiency of such management systems.

Weaknesses (**W**). Developed scientific basis of methodological maintains of ecological safety management systems in its hierarchical structure contains stages and levels that needs of specially created mathematical models and methodics of calculated assessment, which in its turn needs of experimentally achieved data specific for management objects. Both of named components is highly scientific and require significant material and time resources. In addition, not all of ecological safety indicators are legislative established, that is mandatory for execution, and due to these implementation in practice of results of created management systems depends of level ecological consciousness of target audience.

Opportunities (**O**). Implementation in practice of created ecological safety management systems in all complex of stages and levels of its hierarchical structure allows to solve in complex of urgent and actual science and practical problem of ensuring of legislative established level of ecological safety indicators of technics, technologies using in it and products of nanotechnology during their life cycle. Such results can be using as basis of significant improvement of technogenic and ecological safety on local (within of particular urbanic system), regional (within of particular country) and global (within of whole ecumene) levels.

Threats (**T**). Implementation in practice of created ecological safety management systems requires developing, manufacturing application and equipping of units of technics with elements of systems of ensuring of ecological level indicators and its control systems. Such designing, technological, organizational and technical measures associated with significant amount of science, research, engineering and designing works. That circumstance causes the high cost of the finished product. Without of legislative maintains of measures of ensuring of ecological safety level of management objects, for example compulsion and stimulation of both the manufacturer and consumers, real implementation of named activities it may be an impossible task the territory of Ukraine.

ЗАГАЛЬНІ ВИСНОВКИ

Таким чином, за результатами проведених досліджень, що відображені у розділах 1 – 5 даної монографії, можна зробити наступні загальні висновки.

1. Створено наукові основи методологічного забезпечення систем управління екологічною безпекою протягом життєвого циклу техніки з урахуванням особливостей технологій, покладених у основу її роботи й утилізації.

2. Здійснено математичне моделювання процесів забезпечення екологічної безпеки як основи раціоналізації технічних рішень щодо конструкції, експлуатації й утилізації одиниць техніки.

3. Виявлено і описано техногенно-екологічні й метрологічні аспекти експериментальних досліджень показників рівня екологічної безпеки техніки і технологій як джерела вихідних даних для моделювання й ідентифікації відповідних математичних моделей.

4. Виявлено і досліджено особливості шляхів забезпечення екологічної безпеки продуктів нанотехнологій протягом їх життєвого циклу як найімовірнішої альтернативи традиційним технологіям.

5. Створено наукові основи методологічного забезпечення критеріального та економічного оцінювання ефективності процесу функціонування систем управління екологічною безпекою як основа моніторингу ефективності функціонування й зворотного зв'язку систем управління екологічною безпекою.

6. Вищенаведене можливо систематизувати за допомогою логічного апарату SWOT-аналізу, результати застосування якого наведено далі.

Переваги (**S** – *Strengths*). Розроблено наукові основи методологічного забезпечення систем управління екологічною безпекою усіх етапів життєвого циклу техніки різноманітного призначення, що враховують особливості застосовуваних технологій, а також технологій поводження з продуктами нанотехнологій. Вказані наукові основи розроблено вперше із застосуванням принципів системного підходу, багаторівневої декомпозиції, аналізу ієрархічних структур, десятинного поділу і тому дозволяють комплексно вирішувати проблему забезпечення законодавчо встановленого рівня показників екологічної безпеки об'єктів управління. Із застосуванням такого доробку стає можливим забезпечити виконання законодавчо встановлених вимог до рівня показників екологічної безпеки техніки, технологій та їх продуктів вродовж життєвого циклу цих об'єктів управління та заходів із забезпечення екологічної безпеки, а також здійснити оцінювання ефективності функціонування самих систем управління.

Недоліки (**W** – *Weaknesses*). Розроблені наукові основи методологічного забезпечення систем управління екологічною безпекою у своїй ієрархічній структурі містять етапи і рівні, що потребують спеціально розроблених математичних моделей і методик розрахункових досліджень, які у свою чергу потребують експериментально отримані дані саме для обраних об'єктів управління. Обидві названі складові є наукоємними і потребують значних матеріально-часових ресурсів. Крім того, далеко не усі з показників екологічної безпеки є законодавчо нормованими, тобто обов'язковими до виконання, і тому впровадження у практику результатів застосування створених систем управління залежить від рівня екологічної свідомості цільової аудиторії.

Можливості (**O** – *Opportunities*). Впровадження у практику розроблених систем управління екологічною безпекою в усій сукупності етапів і рівнів їх ієрархічної структури дозволяє комплексно вирішити нагальну й актуальну науково-прикладну проблему забезпечення законодавчо встановленого рівня показників екологічної безпеки усіх етапів життєвого циклу різних видів техніки, технологій у ній застосовуваних та продуктів нанотехнологій. Такі результати можуть стати основою значного покращення техногенно-екологічної безпеки на місцевому (у межах окремо взятої урбосистеми), регіональному (у межах окремо взятої країни) та глобальному (у межах всієї біосфери) рівнях.

Ризики (**T** – *Threats*). Впровадження у практику розроблених систем управління екологічною безпекою потребує розробки і впровадження у виробництво й оснащення одиниць техніки агрегатів пристроїв систем забезпечення екологічних показників і систем управління ними. Такі конструкторсько-технологічні й організаційно-технічні заходи пов'язані зі значними об'ємами науково-дослідних й конструкторсько-проектувальних робіт. Остання обставина зумовлює високу собівартість готового продукту. Без законодавчого забезпечення заходів із забезпечення екологічної безпеки об'єктів управління – примусу й стимулювання як виробника, так і споживача – реальне впровадження вказаних заходів може виявитись нездійсненним завданням на теренах України.

Team of authors
(Авторський коллектив)

Vambol Sergij Olexandrovych,

Dr.Sci.(Tech.), Professor, Head of Dept. of Applied Mechanics of Technogenic and Ecological Safety Faculty of National University of Civil Defence of Ukraine of State Emergency Service of Ukraine

Area of scientific interests: mechanics of deformable solids, applied mechanics, mechanics of liquids, ecological safety

Вамболь Сергій Олександрович,

доктор технічних наук, професор, завідувач кафедри прикладної механіки факультету техногенно-екологічної безпеки Національного університету цивільного захисту України Державної служби України з надзвичайних ситуацій

Область наукових інтересів: механіка деформованого твердого тіла, прикладна механіка, механіка текучих середовищ, екологічна безпека

ORCID ID: 0000-0002-8376-9020

e-mail: sergvambol@gmail.com

Vambol Viola Vladyslavivna,

Dr.Csi.(Tech.), Associate Professor, Professor of Dept. of Occupational, Technogenic and Environmental Safety of Technogenic and Ecological Safety Faculty of National University of Civil Defence of Ukraine of State Emergency Service of Ukraine

Area of scientific interests: labour protection, utilization, waste threatment, ecological safety

Вамболь Віола Владиславівна,

доктор технічних наук, доцент, професор кафедри охорони праці та техногенно-екологічної безпеки факультету техногенно-екологічної безпеки Національного університету цивільного захисту України Державної служби України з надзвичайних ситуацій

Область наукових інтересів: охорона праці, утилізація, поводження з відходами, екологічна безпека

ORCID ID: 0000-0002-8229-3956

e-mail: violavambol@gmail.com

Suchikova Yana Olexandrivna,

Cand.Csi. (Phis. and Math.), Associate Professor, Associate Professor of vocational education Berdyansk State Pedagogical University, Ukraine Excellent Education

Area of scientific interests: nanoctructured materials, energy saving technologies, alternative energetics, ecological safety

Сичікова Яна Олександрівна,

кандидат фізико-математичних наук, доцент, доцент кафедри професійної освіти Бердянського державного педагогічного університету, відмінник освіти України

Область наукових інтересів: наноструктуровані матеріали, енергоефективні технології, альтернативна енергетика, екологічна безпека

ORCID ID: 0000-0003-4537-966X

e-mail: yanasuchikova@gmail.com

Mishchenko Igor Viktorovych

Cand.Csi.(Tech.), Associate Professor, Associate Professor of Dept. of Applied Mechanics of Technogenic and Ecological Safety Faculty of National University of Civil Defence of Ukraine of State Emergency Service of Ukraine

Area of scientific interests: dynamics and strength of machines, metrology, applied mechanics, mechanics of liquids

Міщенко Ігор Вікторович

кандидат технічних наук, доцент, доцент кафедри прикладної механіки факультету техногенно-екологічної безпеки Національного університету цивільного захисту України Державної служби України з надзвичайних ситуацій

Область наукових інтересів: динаміка та міцність машин, метрологія, прикладна механіка, технічна механіка текучих середовищ

ORCID ID: 0000-0001-8617-7023

e-mail: ivmishch@mail.rua

Kondratenko Olexandr Mykolajovych,

Cand.Csi.(Tech.), Associate Professor of Dept. of Applied Mechanics of Technogenic and Ecological Safety Faculty of National University of Civil Defence of Ukraine of State Emergency Service of Ukraine, Lead Researcer of Youth Research Project of Berdyansk State Pedagogical University of Ministry of Education and Science of Ukraine

Area of scientific interests: internal combustion engines, applied mechanics, mechanics of liquids, ecological safety

Кондратенко Олександр Миколайович,

кандидат технічних наук, доцент кафедри прикладної механіки факультету техногенно-екологічної безпеки Національного університету цивільного захисту України Державної служби України з надзвичайних ситуацій, провідний науковий співробітник за молодіжним науковим проектом Бердянського державного педагогічного університету Міністерства освіти і науки України

Область наукових інтересів: двигуни внутрішнього згоряння, прикладна механіка, механіка текучих середовищ, екологічна безпека

ORCID ID: 0000-0001-9687-0454

e-mail: kharkivjanyn@i.ua

Appendix A. BIBLIOGRAPHIC DESCRIPTIONS OF THE STUDIES PRESENTED IN MONOGRAPH

Chapter 1

A.1.1. **Vambol V.V.**, Shmandij V.M., **Vambol S.O., Kondratenko O.M.** (2015), “The systematic approach to solving the problem of management of ecological safety during process of biowaste products utilization”, Scientific Journal “Ecological Safety”, Kremenchuk, Publ. KrNU, № 1 (19), C 7 – 11, Print. Access mode: http://nuczu.edu.ua/sciencearchive/Articles/vambol/VambolVV_ShmandiyVM_VambolSO_KondratenkoOM_Ecol-Safety_#1_2015.pdf.

A.1.2. Shmandij V.M., **Vambol V.V., Kondratenko O.M.** (2016), “Conceptual basis of creation of ecological safety management model, which uses multiphase dispearced structures”, Bulletin of Kokshetau Technical Institute of the Committee for Emergency Situations of the Ministry of Internal Affairs of the Republic of Kazakhstan, No 1 (21), Kokshetau, Publ. KTI of KES of MIA of RK, pp. 55 – 61, Print. Access mode:http://nuczu.edu.ua/sciencearchive/Articles/vambol/Shmandiy VM_VambolVV_Kondratenko OM_Herald-KTI_#21_2016.pdf.

A.1.3. **Vambol S.O.**, **Kondratenko O.M.**, **Vambol V.V.**, Mietielov O.V. (2016), “Methodological basics of criterial integrated assessment of ecological safety management system functioning efficiency of power plants with piston ICE exploitation process”, Bulletin of M. Ostrogradsky Kremenchuk National Univercity, № 6 (101), Part 1, pp. 104 – 110, Print. Access mode: http://nuczu.edu.ua/sciencearchive/Articles/vambol/VambolSO_KondratenkoOM_VambolVV_Mietielov VO_Herald-KrNU_#6_2016.pdf.

Chapter 2

A.2.1. **Kondratenko O.M.**, Burmenko O.A., **Vambol S.O.**, **Mischenko I.V.** (2015), “Application of beta-distribution in numerical simulation of environmental safety ensuring process”, Materials of the All-Ukrainian scientific conference of students and young scientists "Metrological aspects of decision-making under conditions of work on technologically dangerous objects" dedicated to the 85th anniversary KhNADU (28 – 29 oct. 2015), Kharkiv, Publ. KhNADU, pp. 243 – 244, Print. Access mode: http://nuczu.edu.ua/sciencearchive/Articles/vambol/VambolSO_MishchenkoIV_Kondratenko OM_BurmenkoOA_Konf-KhNADU-Metrology_ 2015.pdf

A.2.2. **Vambol S.O.**, **Mishchenko I.V.**, **Kondratenko A.N.** (2016), “Background of mathematical tools beta distribution application to certain characteristics of aerosol diesel exhaust gases dispersed phase”, Materials of the All-Ukrainian scientific and practical conference «Problems of technogenic and ecological safety: education, science, practice» (24 nov. 2016), Kharkiv, Publ. NUCDU, pp. 23 – 25, Print. Access mode: http://nuczu.edu.ua/sciencearchive/Articles/vambol/VambolSO_MishchenkoIV_Kondratenko

OM_BurmenkoOA_Konf-PM-NUCDU_ 2016.pdf

A.2.3. **Mishchenko I.V.**, **Kondratenko A.N.** (2016), Relationship between regulatory manufacturing precision of fire nozzle and its water jet trajectory geometric characteristics, Bulletin of Kokshetau Technical Institute of the Committee for Emergency Situations of the Ministry of Internal Affairs of the Republic of Kazakhstan, No 3 (23), Kokshetau, Publ. KTI of KES of MIA of RK, pp. 38 – 46, Print. Access mode: http://nuczu.edu.ua/science archive/Articles/vambol/MishchenkoIV _KondratenkoOM_Herald-KTI_#23 _2016.pdf.

A.2.4. **Mishchenko I.V.**, **Kondratenko A.N.** (2016), Relationship between real manufacturing precision of fire nozzle and its water jet trajectory geometric characteristics, Bulletin of Kokshetau Technical Institute of the Committee for Emergency Situations of the Ministry of Internal Affairs of the Republic of Kazakhstan, No 4 (24), Kokshetau, Publ. KTI of KES of MIA of RK, pp. 52 –61, Print. Access mode: http://nuczu.edu.ua/sciencearchive/ Articles/vambol/MishchenkoIV_KondratenkoOM_Herald-KTI_#24_ 2016.pdf.

A.2.5. **Vambol V.V.** (2016), Numerical integration of gas cooling, formed by thermal recycling of waste, Eastern-European Journal of Enterprise Technologies, № 6/8 (84), Kharkiv, Publ. USURT, pp. 48 – 53, Print. Access mode: http://nuczu.edu.ua/sciencearchive/Articles/vambol/VambolVV _EEJET_#6-8_2016.pdf.

Chapter 3

A.3.1. **Kondratenko O.M.**, R.G. Revenko, A.I. Aleynikov (2016), “DPF IPMash on engine test bench as a source of technogenic danger”, Information technologyes: science, engineering, technology, education, health: Proceedings of XXIV International Scientific Conference MICROCAD, Part. I (18 – 20 may 2016), Kharkiv, Publ. NTU "KhPI", p. 173, Print. Access mode: http:// nuczu.edu.ua/sciencearchive/Articles/vambol/KondratenkoOM _RevenkoRG_AleynikovAI_Konf_MicroCAD_2016.pdf.

A.3.2. **Kondratenko O.M.** (2016), “Using diesel particulate matter filter as a spark arrestor for fire and rescue vehicles”, "Problems and Prospects for Ensuring of Civil Defense": Materials of International Scientific and Practical Conference of Young Scientists (06 – 07 apr. 2016), Kharkiv,Publ. NUCDU, p. 328, Print. Access mode: http://nuczu.edu.ua/sciencearchive/ Articles/vambol/KondratenkoOM _VambolSO_Konf-NUCDU-YS_2015.pdf.

A.3.3. **Kondratenko O.M.**, Skrynnyk K.V., Gurbanov R. (2015), “Main pollutants in diesel exhaust gases”, XII International Scientific Conference "Problems of Ecological Safety": Collection of abstracts (6 – 8 oct. 2015), Kremenchuk, Publ. M. Ostrogradsky KrNU, p. 25, Print. Access mode: http://nuczu.edu.ua/sciencearchive/Articles/vambol/KondratenkoOM_ SkrynnykKV_GurbanovR_Konf-KrNU_ 2015.pdf.

A.3.4. **Kondratenko O.M., Vambol’ S.O.**, Burmenko O.A. (2015), “Aspects of technogenic and ecological safety of the DPF regeneration process”, XIV International Scientific and Methodological Conference "Safety of Human Life and Activity – Education, Science, Practice": Abstracts (21 – 22 may 2015), Kharkiv, Publ. A. Beketov KhNUUE, p. 139, Print.Access mode: http://nuczu.edu.ua/sciencearchive/Articles/vambol/KondratenkoOM_VambolSO_BurmenkoOA_Konf-KhNUUE_2015.pdf.

A.3.5. **Kondratenko O.M., Vambol’ S.O.**, Stel’makh H.S. (2015), “Basis of classification of methods of regeneration of diesel particulate matter filters”, Eleventh Scientific Conference of I. Kozhedub Kharkiv Air Force University "New technologies for protecting airspace”: Abstracts (08 – 09 apr. 2015), Kharkiv, Publ. I. Kozhedub KhUAF, p. 265, Print. Access mode: http://nuczu.edu.ua/sciencearchive/Articles/vambol/KondratenkoOM_VambolSO_StelmahGS_Konf-KhNUAF_2015.pdf.

A.3.6. **Vambol’ S.O., Kondratenko O.M.**, Burmenko O.A. (2015), “Emulators of exhaust gas cleaning system of internal combustion engines”, Problems and prospects of rail transport: Abstracts of 75th International Scientific and Practical Conference(14 – 15 may 2015), Dnipropetrovsk, Publ. acad. V. Lazarjan DNURW «DIIT», p. 342, Print. Access mode: http://nuczu.edu.ua/sciencarchive/Articles/vambol/VambolSO_KondratenkoOM_BurmenkoOA_Konf-DIIT _2015.pdf.

A.3.7. Bgancev V.M., Avramenko A.M., **Kondratenko O.M.** (2015), “The prospects of using of gasoline and alcohol mixtures pistone for ICE”, International Scientific and Practical Conference "New Technologies in Automotive Industry and Transport", dedicated to the 85th anniversary of KhNADU and 85th anniversary of the Faculty of Automobile (14 – 15 oct. 2015), Kharkiv, Publ. KhNADU, pp. 230 – 232, Print. Access mode: http://nuczu.edu.ua/sciencarchive/Articles/vambol/BgantsevVM_AvramenkoAM_KondratenkoOM_Konf-KhNADU-Auto_2015.pdf.

A.3.8. Stel’makh H.S., **Vambol’ S.O., Kondratenko O.M.** (2015), “Development of scientific thought and global trends in questions of ensure compliance with legislative established norms of vehicle exhaust gas toxity between 1991 and 2010”, Collection of Materials of International Scientific and Practical Conference "Role of Local Antiaircraft Defense and Fire Service during the Great Patriotic War" (27 mar. 2015), Kokshetau, Publ. KTI of ESK of MIA of KR, pp. 238 – 240, Print. Access mode: http://nuczu.edu.ua/sciencearchive/Articles/vambol/StelmahGS_VambolSO_KondratenkoOM_Konf-KTI_2015.pdf.

A.3.9. Stel’makh H.S., **Vambol’ S.O., Kondratenko O.M.** (2015), “Structure of vehicle fleet of Ukraine as a factor of ecological safety”, Collection of Materials IX Scientific and Practical Conference of Young Scientists: Cadets (Students), Graduate Students and Adjuncts (Postgraduates) "Ensuring of vital activity safety: problems and prospects". Part 2 (2 – 3 apr. 2015), Minsk, Publ. GUO KII MChS RB, pp. 140 – 141, Print. Access mode: http://nuczu.edu.ua/ sciencearchive/Articles/ vambol/ StelmahGS_VambolSO_KondratenkoOM_Konf-KII-Minsk_ 2015.pdf.

A.3.10. **Vambol S.O., Kondratenko O.M.**, Deyneko N.V. (2015), “Description of engine test bench as a source of danger factors in experimental researches”, Bulletin of Kokshetau Technical Institute of the Committee for Emergency Situations of the Ministry of Internal Affairs of the Republic of Kazakhstan, No 3 (19), Kokshetau, Publ. KTI of KES of MIA of RK, pp. 7–12, Print. Access mode: http:// nuczu.edu.ua/sciencearchive/Articles/ vambol/VambolSO_KondratenkoOM_DeynekoNV_Herald-KTI_#19_ 2015.pdf.

A.3.11. Skrynnyk K.V., Ruban D.V., **Kondratenko O.M.** (2016), “Classification of gravimetric methods for determination of particulate matter mass emission in exhaust gas flow of diesel internal combustion engines”, Materials of II International scientific and practical conference of students, undergraduates, postgraduate students “Sectoral issues of ecolgical safety” (20 – 21 oct. 2016), Kharkiv, Publ. KhNADU, pp. 201 – 203, Print. Access mode: http://nuczu.edu.ua/sciencearchive/Articles/vambol/SkrynnykKV_ RubanDV_KondratenkoOM_Konf-KhNADU-Ecol_2016.pdf.

A.3.12. Zakrenychna D.Ju., Tsoy L.O., **Kondratenko O.M.** (2016), “Classification of instruments for determination of gaseous pollutants concentrations in ICE exhaust gases”, Materials of II International scientific and practical conference of students, undergraduates, postgraduate students “Sectoral issues of ecolgical safety” (20– 21 oct. 2016), Kharkiv, Publ. KhNADU, pp. 82 – 83, Print. Access mode: http://nuczu.edu.ua/science archive/Articles/vambol/ZakrenychnaDY_TsoyLO_ KondratenkoOM_Konf-KhNADU-Ecol_2016.pdf.

A.3.13. **Kondratenko O.M., Vambol S.O.**, Semykin V.M. (2015), “The problems of experimental determination of mass emission of particulate matter in exhaust flow of diesel engine”, International scientificand practical conference "New technologies in automotive industry and transport", dedicated to the 85th anniversary of KhNADU and 85th anniversary of the Faculty of Automobiles (14 – 15 oct 2015), Kharkiv, Publ. KhNADU, pp. 232 – 234, Print. Access mode: http://nuczu.edu.ua/sciencearchive/Articles/ vambol/VambolSO_KondratenkoOM_SemykinVM _Konf-KhNADU-Auto_ 2015.pdf.

A.3.14. **Kondratenko A.N.**, N.V. Khokhlova, A.S. Stel’makh (2015), “Fire safety of engine bench researches”, Emergency Situations: Theory, Practice: Proceedings of International Scientific and Practical Conference of Cadets (Students), Graduates, Adjuncts (Postgraduates), Gomel, Publ. GUO GIU MChS RB, P.O. Sukhoy GGTU, pp. 215 – 216, Print. Access mode: http:// nuczu.edu.ua/sciencearchive/Articles/vambol/KondratenkoOM_ KhohlovaNV_StelmahGS_Konf-GGTU_ 2015.pdf

A.3.15. **Kondratenko O.M.**, Burmenko O.A. (2015), “Optical devices for particulate matter content in internal combustion engines exhaust gas determination”, Proceedings of the International Scientific and Practical Conference “Urban and regional transport problems” (17 – 19 nov. 2015), Kharkiv, Publ. O.M. Beketov KhNUUE, p. 6, Print. Access mode: http:// nuczu.edu.ua/sciencearchive/Articles/vambol/KondratenkoOM_Burmenko OA_Konf-KhNUUE_ 2015.pdf.

A.3.16. **Vambol S.O.**, **Mischenko I.V.**, **Kondratenko O.M.**, Burmen-

ko O.A. “Metrological maintenance of exhaust gas sampling system of engine test bench as an object of researches”, Bulletin of Kokshetau Technical Institute of the Committee for Emergency Situations of the Ministry of Internal Affairs of the Republic of Kazakhstan, No 4 (20), Kokshetau, Publ. KTI of KES of MIA of RK, pp. 17 – 25, Print. Access mode: http://nuczu.edu.ua/sciencearchive/Articles/vambol/Vambol SO_MishchenkoIV_Kondratenko OM_BurmenkoOA_Herald-KTI _#20_2015.pdf.

Chapter 4

A.4.1. **Suchikova Y.O.** (2015), Porous Indium Phosphide: Preparation and Properties / Handbook of Nanoelectrochemistry: Electrochemical Synthesis Methods, Properties and Characterization Techniques, Springer International Publishing, 1452 p., pp. 201 – 220 Print. Access mode: http://nuczu.edu.ua/sciencearchive/Articles/vambol/SuchikovaYO_Handbook-of-Nanoelectrochemistry_2015.pdf.

A.4.2. **Suchikova Y.O.** (2016), Development of efficiency improvement method of photovoltaic converters by nanostructurization of silicon wafers, Technology audit and production reserves, № 6/5 (84), Kharkiv, Publ. PSAA, pp. 16 – 20, Print. Access mode: http://nuczu.edu.ua/sciencearchive/Articles/vambol/ SuchikovaYO_TARP_#6-5_2016.pdf.

A.4.3. **Suchikova Y.O.** (2016), Provision of environmental safety through the use of porous semiconductors for solar energy sector, Eastern-European Journal of Enterprise Technologies, № 6/8 (84), Kharkiv, Publ. USURT, pp. 26 – 33, Print. Access mode: http://nuczu.edu.ua/sciencearchive/Articles/vambol/ SuchikovaYO_EEJET_#6-8_2016.pdf.

Chapter 5

A.5.1. **Vambol S.A., Vambol V.V.** (2015), “Economic and energetic analysis of improved waste utilization plasma technology”, Economie şi Sociologie, Chișinău, № 3, P. 31 – 38, Print. Access mode: http://nuczu.edu.ua/sciencearchive/ Articles/vambol/VambolSO_VambolVV_Econ-socio_#3_2015.pdf.

A.5.2. **Vambol S.O., Kondratenko O.M.** (2017), “Calculated substantiation of choice of units of monetary equivalents of complex fuel and ecological criteria components”, Science and Technical Journal “Technogenic and ecological Safety”, Kharkiv, Publ. NUCDU, № 2, pp. 99 –109, Print. Access mode: http://nuczu.edu.ua/sciencearchive/Articles/vambol/VambolSO_KondratenkoOM_TES_#2_ 2016.pdf.

A.5.3. **Vambol S.O., Kondratenko O.M.** (2017), “Results of complex criterial fuel and ecological assessment of diesel engine 2Ch10.5/12 for emergency and rescue power plants”, Science and Technical Journal “Technogenic and ecological Safety”, Kharkiv, Publ. NUCDU, №1, pp. 100 – 109, Print. Access mode: http:// nuczu.edu.ua/science archive/Articles/vambol/VambolSO_KondratenkoOM_TES_ #1_2016.pdf.

Додаток А. БІБЛІОГРАФІЧНИЙ ОПИС ДОСЛІДЖЕНЬ, ЩО ПРЕДСТАВЛЕНІ У МОНОГРАФІЇ

Розділ 1

А.1.2. Вамболь В.В. Системний підхід до вирішення задачі управління екологічною безпекою процесу утилізації відходів біологічного походження [Текст] / **В.В. Вамболь,** В.М. Шмандій, **С.О. Вамболь, О.М**. **Кондратенко** // Науковий журнал «Екологічна безпека». – Кременчук: КрНУ ім. М. Остроградського, 2015. – № 1 (19). – С. 7 – 11.

А.1.1. Шмандій В.М. Концептуальні основи створення системи управління екологічною безпекою, що використовує багатофазні дисперсні структури [Текст] / В.М. Шмандій, **В.В. Вамболь, О.М. Кондратенко** // Вісник Кокшетауського технічного інституту Комітету з надзвичайних ситуацій МВС Республіки Казахстан. – Кокшетау: КТІ КНС МВС РК, 2016. – No 1 (21). – С. 55 – 61.

А.1.3. Вамболь С.О. Методологічні основи комплексного критеріального оцінювання функціонування системи управління екологічною безпекою процесу експлуатації енергетичних установок з поршневим ДВЗ [Текст] / **С.О. Вамболь, О.М. Кондратенко, В.В. Вамболь,** О.В.Мєтєльов // Вісник Кременчуцького національного університету імені Михайла Остроградського. – Кременчук: КрНУ ім. М. Остроградського, 2016. – № 6 (101), Част. 1. – С. 104 – 110.

Розділ 2

А.2.1. Кондратенко О.М. Застосування бета-розподілу для числового моделювання процесів забезпечення екологічної безпеки [Текст] / **О.М. Кондратенко,** О.А. Бурменко, **С.О. Вамболь, І.В. Міщенко** // Матеріали Всеукраїнської науково-практичної конференції студентів та молодих вчених «Метрологічні аспекти прийняття рішень в умовах роботи на техногенно небезпечних об’єктах», присвяченої 85-річчю ХНАДУ (28 – 29 жовтня 2015 р.). – Х.: ХНАДУ, 2015. – С. 243 – 244.

А.2.2. Вамболь С.О. Передумови застосування математичного апарату бета-розподілу до деяких характеристик дисперсної фази аерозолю відпрацьованих газів дизельних двигунів [Текст] / **С.О. Вамболь, І.В. Міщенко**, **О.М. Кондратенко** // Матеріали Всеукраїнської науково-практичної конференції «Проблеми техногенно-екологічної безпеки: освіта, наука, практика» (24 листопада 2016 р.). – Х.: НУЦЗУ, 2016. – С. 23 – 25.

А.2.3. **Міщенко І.В.** Взаємозв’язок між нормативною точністю виготовлення ручного пожежного ствола та геометричними характеристиками струменя води з нього [Текст] / **І.В. Міщенко**, **О.М. Кондратенко** // Вісник Кокшетауського технічного інституту Комітету з надзвичайних ситуацій МВС Республіки Казахстан. – No 3 (23). – Кокшетау: КТІ КНС МВС РК, 2016. – С. 38 – 46.

А.2.4. **Міщенко І.В.** Взаємозв’язок між реальною точністю виготовлення ручного пожежного ствола та геометричними характеристиками струменя води з нього [Текст] / **І.В. Міщенко**, **О.М. Кондратенко** // Вісник Кокшетауського технічного інституту Комітету з надзвичайних ситуацій МВС Республіки Казахстан. – No 4 (24). – Кокшетау: КТІ КНС МВС РК, 2016. – С. 52 – 61.

А.2.5. **Вамболь В.В.** Чисельне інтегрування процесу охолодження газу, що утворюється під час термічної утилізації відходів [Текст] / **В.В**. **Вамболь** // Східно-Європейський журнал передових технологій. – № 6/8 (84). – Харків: УкрДУЗТ, 2016. – С. 48 – 53.

Розділ 3

А.3.1. **Кондратенко О.М.**, ФТЧ ІПМаш на моторному випробувальному стенді як джерело техногенної небезпеки [Текст] / **О.М. Кондратенко**, Р.Г. Ревенко, А.И. Алейников // Інформаційні технології: наука, техніка, технологія, освіта, здоров'я: Тези доповідей XXIV Міжнародної науково-практичної конференції MICROCAD, Ч. I (18 – 20.05 2016 р.). – Харків: НТУ «ХПІ», 2016. –С. 173.

А.3.2. **Кондратенко О.М.** Використання дизельного фільтра твердих частинок у якості іскрогасника для пожежних і аварійно-рятувальних транспортних засобів [Текст] / **О.М. Кондратенко** // «Проблеми та перспективи забезпечення цивільного захисту»: матеріали Міжнародної науково-практичної конференції молодих учених (06 – 07 квітня 2016 р.). – Харків: НУЦЗУ. – С. 328.

А.3.3. **Кондратенко О.М.** Основні полютанти у відпрацьованих газів дизельних двигунів [Текст] / **О.М. Кондратенко**, К.В. Скринник, Р. Гурбанов // XII Міжнародна науково-практична конференція «Проблеми екологічної безпеки»: Збірник тез доповідей (6 – 8 жовтня 2015 р.). – Кременчук: КрНУ ім. М. Остроградського, 2016. – С. 25.

А.3.4. **Кондратенко О.М.** Аспекти техногенної та екологічної безпеки процесу регенерації ФТЧ [Текст] / **О.М. Кондратенко**, **С.О. Вамболь**, О.А. Бурменко // XIV Міжнародна науково-методична конференція «Безпека життя і діяльності людини – освіта, наука, практика»: тези доповідей (21 – 22 травня 2015 р.). – Харків: ХНУМГ ім. А.Н. Бекетова, 2015. – С. 139.

А.3.5. **Кондратенко О.М.** Основа класифікації методів регенерації дизельних фільтрів твердих частинок [Текст] / **О.М. Кондратенко**, **С.О. Вамболь**, Г.С. Стельмах // Одинадцята наукова конференція Харківського університету Повітряних Сил ім. Івана Кожедуба «Новітні технології для захисту повітряного простору»: тези доповідей (08 – 09 квітня 2015 р.). – Харків: ХНУПС ім. І. Кожедуба, 2015. – С. 265.

А.3.6. **Вамболь С.О.** Емулятори системи очищення відпрацьованих газів двигунів внутрішнього згоряння [Текст] / **С.О. Вамболь**, **О.М. Кондратенко**, О.А. Бурменко // Проблеми та перспективи розвитку залізничного транспорту: Тези доповідей 75 Міжнародної науково-практичної конференції (14 – 15 травня 2015 р.). – Дніпропетровськ: ДНУЗТ ім. акад. В. Лазаряна «ДІІТ», 2015. – С. 342.

А.3.7. Бганцев В.М. Перспективи використання бензоспиртових

сумішей у поршневих ДВЗ [Текст] / В.М. Бганцев, А.М. Авраменко, **О.М. Кондратенко** // Матеріали Міжнародної науково-практичної конференції «Новітні технології в автомобілебудуванні і на транспорті», присвяч. 85-річчю заснування ХНАДУ та 85-річчю заснування автомобільного факультету (14 – 15 жовтня 2015 р.). – Харків: ХНАДУ, 2015. – С. 230 – 232.

А.3.8. Стельмах Г.С. Розвиток наукової думки та глобальні тенденції у питаннях забезпечення законодавчо встановлених норм токсичності відпрацьованих газів автотранспортних установок у період з 1991 по 2010 рр. [Текст] / Г.С. Стельмах, **С.О. Вамболь**, **О.М. Кондратенко** // Збірник матеріалів Міжнародної науково-практичної конференції «Роль місцевої протиповітряної оборони та пожежної охорони у роки великої вітчизняної війни» (27 березня 2015 р.). – Кокшетау: КТІ КНС МВС РК, 2015. – С. 238 – 240.

А.3.9. Стельмах Г.С. Структура парку автотранспортних засобів України як фактор екологічної безпеки] [Текст] / Г.С. Стельмах, **С.О. Вамболь**, **О.М. Кондратенко** // Збірник матеріалів IX Науково-практичної конференції молодих вчених: курсантів (студентів), слухачів магістратури та ад'юнктів (аспірантів) «Забезпечення безпеки життєдіяльності: проблеми та перспективи». Частина 2 (2 – 3 квітня 2015 р.). – Мінськ: ГУО КІІ МНС РБ, 2015. – С. 140 – 141.

А.3.10. **Вамболь С.О.** Описання моторного випробувального стенду як джерела факторів небезпеки експериментальних досліджень [Текст] / **С.О. Вамболь, О.М. Кондратенко**, Н.В. Дейнеко // Вісник Кокшетауського технічного інституту Комітету з надзвичайних ситуацій МВС Республіки Казахстан. – № 3 (19). – Кокшетау: КТІ КНС МВС РК, 2015. – С. 7 – 12.

А.3.11. Скринник К.В. Класифікація гравіметричних методів для визначення масового викиду твердих частинок у потоці відпрацьованих газів дизельних ДВЗ [Текст] // К.В. Скринник, Д.В. Рубан, **О.М. Кондратенко** // Матеріали II Міжнародної науково-практичної конференції студентів, магістрантів, аспірантів «Галузеві проблеми екологічної безпеки» (20 – 21 жовтня 2016 р.). – Харків: ХНАДУ, 2016. – С 201 – 203.

А.3.12. Закренична Д.Ю. Класифікація приладів для визначення концентрацій газоподібних полютантів у відпрацьованих газах ДВЗ [Текст] / Д.Ю. Закренична, Л.О. Цой, **О.М. Кондратенко** // Матеріали II Міжнародної науково-практичної конференції студентів, магістрантів, аспірантів «Галузеві проблеми екологічної безпеки» (20 – 21 жовтня 2016 р.). – Харків: ХНАДУ, 2016. – С 82 – 83.

А.3.13. **Кондратенко О.М.** Проблеми експериментального визначення масового викиду твердих частинок у потоці відпрацьованих газів дизельного двигуна [Текст] / **О.М. Кондратенко, С.О. Вамболь**, В.М. Семикін // Матеріали Міжнародної науково-практичної конференції «Новітні технології в автомобілебудуванні і на транспорті», присвяч. 85-р заснування ХНАДУ та 85-р заснування автомобільного факультету (14–15 жовтня 2015 р.). – Харків: ХНАДУ, 2015. – С. 232 – 234.

А.3.14. **Кондратенко О.М.** Аспекти пожежної безпеки стендових моторних випробувань [Текст] / **О.М. Кондратенко,** Н.В. Хохлова,

Г.С. Стельмах // Надзвичайні ситуації: теорія, практика: матеріали Міжнародної науково-практичної конференції курсантів (студентів), магістрантів, ад'юнктів (аспірантів) (21 травня 2015 р.). – Гомель: ДЗО ГІІ МНС РБ, ГГТУ ім. П.О. Сухого, 2015. – С. 215 – 216.

А.3.15. **Кондратенко О.М.** Оптичні прилади для визначення вмісту твердих частинок у відпрацьованих газах дизельних двигунів [Текст] / **А.Н. Кондратенко,** О.А. Бурменко // Міські і регіональні транспортні проблеми: матеріали Міжнародної науково-практичної конференції (17 – 19 листопада 2015 р.). – Харків: ХНУМГ ім. О.М. Бекетова, 2015.–С.6.

А.3.16. **Вамболь С.О.** Метрологічне забезпечення системи відбору проб відпрацьованих газів дизеля моторного випробувального стенду як об'єкт дослідження [Текст] / **С.О. Вамболь, І.В. Мищенко**, **О.М. Кондратенко,** О.А. Бурменко // Вісник Кокшетауського технічного інституту Комітету з надзвичайних ситуацій МВС Республіки Казахстан. – № 4 (20). – Кокшетау: КТІ КНС МВС РК, 2015. – С. 17 – 25.

Розділ 4

А.4.1. **Сичікова Я.О.** Поруватий фосфід індію: отримання та властивості / Довідник наноелектрохімії: методи електрохімічного синтезу, властивості та методи отримання характеристик [Текст] / **Я.О. Сичікова** // Springer International Publishing, 2015. – 1452 с. – С. 201 – 220.

А.4.2. **Сичікова Я.О.** Розробка способу підвищення ефективності фотоелектричних перетворювачів шляхом наноструктурування кремнієвих пластин [Текст] / **Я.О. Сичікова** // Технологічний аудит та резерви виробництва. – Харків: ПДАА, 2016. – № 6/1 (32). – С. 16 – 20.

А.4.3. **Сичікова Я.О.** Забезпечення екологічної безпеки шляхом використання пористих напівпровідників для сонячної енергетики [Текст] / **Я.О. Сичікова** // Східно-Європейський журнал передових технологій. – Харків: УкрДУЗТ 2016. – № 6/8 (84). – С. 26 – 33.

Розділ 5

А.5.1. **Вамболь С.О.** Экономикоэнергетический анализ усовершенствованной технологии плазменной утилизации отходов [Текст] / **С.О. Вамболь, В.В. Вамболь** // Економіка та соціологія. – Кишенів: Національний інститут економічних досліджень, 2015. – № 3. – С. 31 – 38.

А.5.2. **Вамболь С.О.**, Розрахункове обгрунтування вибору одиниць вартісних еквівалентів складових комплексного паливно-екологічного критерію [Текст] / **С.О. Вамболь, О.М. Кондратенко** // Науково-технічний журнал «Техногенно-екологічна безпека». – Харків: НУЦЗУ, 2017. – № 2. – С. 100 – 109.

А.5.3. **Вамболь С.О.** Результати комплексного критеріального паливно-екологічного оцінювання дизельного двигуна 2Ч10,5/12 для аварійно-рятувальних енергетичних установок [Текст] / **С.О. Вамболь, О.М. Кондратенко** // Науково-технічний журнал «Техногенно-екологічна безпека». – Харків: НУЦЗУ, 2017. – № 1. – С. 99 – 109.

ISBN 978-83-62683-42-0

Sergij O. Vambol,
Viola V. Vambol,
Yana O. Suchikova,
Igor V. Mishchenko,
Olexandr M. Kondratenko

SCIENTIFIC AND PRACTICAL PROBLEMS OF APPLICATION OF ECOLOGICAL SAFETY MANAGEMENT SYSTEMS IN TECHNICS AND TECHNOLOGIES

Monograph

300 copies

Publishing House:
Wyższa Szkoła Zarządzania i Administracji w Opolu
45-085 Polska, Opole, ul. Niedziałkowskiego 18
tel. 77 402-19-00/01
info@poczta.wszia.opole.pl

Opole 2017

ISBN 978-83-62683-42-0