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Қазақстан Республикасы Ұлттық ғылым академиясы "ҚР ҰҒА Хабарлары. Химия және технология сериясы" ғылыми журналының Web of Science-тің жаңаланған нұсқасы Emerging Sources Citation Index-те индекстелуге қабылданғанын хабарлайды. Бұл индекстелу барысында Clarivate Analytics компаниясы журналды одан әрі the Science Citation Index Expanded, the Social Sciences Citation Index және the Arts & Humanities Citation Index-ке қабылдау мәселесін қарастыруда. Web of Science зерттеушілер, авторлар, баспашылар мен мекемелерге контент тереңдігі мен сапасын ұсынады. ҚР ҰҒА Хабарлары. Химия және технология сериясы Emerging Sources Citation Index-ке енуі біздің қоғамдастық үшін ең өзекті және беделді химиялық ғылымдар бойынша контентке адалдығымызды білдіреді.

НАН РК сообщает, что научный журнал «Известия НАН РК. Серия химии и технологий» был принят для индексирования в Emerging Sources Citation Index, обновленной версии Web of Science. Содержание в этом индексировании находится в стадии рассмотрения компанией Clarivate Analytics для дальнейшего принятия журнала в the Science Citation Index Expanded, the Social Sciences Citation Index и the Arts & Humanities Citation Index. Web of Science предлагает качество и глубину контента для исследователей, авторов, издателей и учреждений. Включение Известия НАН РК в Emerging Sources Citation Index демонстрирует нашу приверженность к наиболее актуальному и влиятельному контенту по химическим наукам для нашего сообщества.

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**ANALYSIS OF INFLUENCE OF EMISSIONS OF HARMFUL
SUBSTANCES WITH EXHAUST GASES OF MARINE DUAL FUEL
INTERNAL COMBUSTION ENGINE ON THE ENVIRONMENT AND
HUMAN HEALTH**

Abstract. Due to the low cost of gas and the expediency of its use for power generation, especially in the areas of its production, as well as on ships-gas carriers, a number of engine companies began to upgrade their engines to adapt them to work on gas fuel. Modernization goes on in two directions: on transfer of the diesel to work on Otto cycle with use of carburetors and spark plugs similar to the carburettor gasoline engine and preservation of the diesel cycle with injection of a small amount of diesel fuel for ignition of a mixture of gas and fuel. In the case of necessity is not excluded by the operation of the engine only on diesel fuels – dual fuel engines. The purpose of the work is to study the use of two-fuel internal combustion engines on ships and formed suspended particles during its combustion. The relevance of the topic lies in the fact that most ships use as fuel oil, gasoline and diesel fuel, which adversely affects human health and the environment, especially marine. Therefore, the solution to this situation was the introduction of two-fuel internal combustion engines, which at times reduce emissions from ships to the marine and air environment.

Key words: emissions of harmful substances, exhaust gases of marine internal combustion engines, environment, public health, liquefied natural gas, atmospheric diffusion calculation models.

Introduction

The level of air pollution largely depends on the conditions of dispersion of impurities in atmosphere. Under certain meteorological conditions, the concentration of impurities in air increases, and can reach dangerous values. Prevention of such cases on the basis of their advance forecast is essential for improving state of the air basin.

The main and auxiliary engines of power plants are the main source of marine pollution of environmental pollution. The most common are diesel engines. Diesel engines have the highest fuel economy (their efficiency exceeds 50%); Stable operate on various types of gaseous and liquid fuels, including heavy with a viscosity of 700 cSt (the value of viscosity measurement) and sulfur content of 5%; best suited to automation, ensuring unobstructed management and maintenance. They have a significant resource and always ready for operation.

The exhaust gases (EG) of marine diesel engines are complex gas mixture. Their composition has more than 200 components and largely depends on the type of used fuel, type of mixture formation, nature of the combustion process, parameters of operating cycle. The components of complete combustion (carbon dioxide CO₂ and water H₂O), residual oxygen O₂ and nitrogen of air N₂ constitute 99-99.9% of the volume of exhaust gases, are non-toxic. The remaining 0.1-1% of gases constitute harmful components,

which determine the ecological level of internal combustion engine (ICE), i.e. its negative impact on the environment and public health. The most toxic of these are nitrogen oxides NO_x , carbon oxide CO, total hydrocarbons CH_x and sulfur oxides SO_x (Table 1) [1-5].

Table 1 - The average composition of exhaust gases of marine diesel engines [1]

Component EG	Concentration in exhaust gas		
	%	g/m^3	$\text{g}/(\text{kW}\cdot\text{h})$
Nitrogen (N_2)	74.0–78.0	–	–
Oxygen (O_2)	2.0–18.0	–	–
Water vapor (H_2O)	0.5–9.0	15–100	–
Carbon dioxide (CO_2)	1.0–12	40–240	–
Nitric oxide (NO)	0.004–0.5	1.0–4.5	6–18
Nitrogen dioxide (NO_2)	0.00013–0.0130	0.1–0.8	0.5–2.0
Carbon oxide (CO)	0.005–0.4	0.25–2.5	1.5–12.0
Hydrocarbons (CH_x)	0.009–0.3	0.25–2.0	1.5–8.0
Sulphur dioxide (SO_2)	0.0018–0.02	1.0–0.5	0.4–2.5
Carbon black (Soot)(C)	–	0.05–0.5	0.25–0.5

In the Gothenburg Protocol until 2020 contain commitments to reduce emissions of finely dispersed suspended particles ($\text{PM}_{2.5}$). In the new edition, black carbon or soot appears as an important component of $\text{PM}_{2.5}$. Black carbon is a pollutant that has a negative impact on human health and contributes to climate change [2,4].

Currently considered, that negative impact on human health is due to the action of many PM components associated with black carbon. So polycyclic aromatic hydrocarbons (PAHs) have their carcinogenic and direct toxic effects on cells. The International Agency for Research on Cancer has classified exhaust gases from diesel engines consisting of solid particles, as carcinogenic to humans. According to the American expert M. Jacobson, 15-30% of global warming is due to the emission of soot particles. In the air, soot absorbs solar energy and emits infrared (thermal) radiation, contributing to its additional warming up of the Earth [3-5].

When burning raw materials in power-generating installations, tens of millions of tons of harmful toxic components are formed, that are ejected annually into the environment.

Emissions of exhaust gases become the main global problems of ecology, i.e. lead to the formation of "greenhouse effect", the degradation of ozone layer and formation of acid rain.

Emissions of harmful substances that included in the composition of exhaust gases of internal combustion engines, the criteria for their normalization and hazard class are presented in Table 2.

As can be seen from the presented table, many harmful substances belong to the 1st class of danger. So benzopyrene has a good penetrating ability in cells of living organisms. A person gets it through skin, airways and with food. In the body, benzopyrene is oxidized to phenolic and quinone type having mutagenic activity, and partially excreted from body in an unchanged form.

The average annual concentration of benzopyrene in atmospheric air is $0.001 \mu\text{g}/\text{m}^3$ (according to the World Health Organization (WHO)), above which adverse on human health are observed, causing cancer.

The degree of danger of air pollution is determined by maximum permissible concentration of pollutants (MPC).

The MPC does not take into account regional climatic conditions, does not reflect the toxicological load on the ecosystem as whole, since it does not take into account the processes of substance accumulation in biological objects [4-7].

To determine criteria for real hazard of harmful substances, standard GOST 12.1.007-76 "Classification and general safety requirements" is set, taking into account the following characteristics of the hazard class definition (Table 3).

Table 2 - Harmful substances emitted into atmosphere from internal combustion engines and criteria for their normalization

Code	Ingredient name	Hazard Class	$MPC_{m.p.}$	$MPC_{e.c.}$
0110	di-vanadium pentoxide (Vanadium pentoxide)	1	—	0,0020
0183	Mercury (Mercury metal)	1	—	0,0003
0184	Lead and its inorganic compounds (in recount of lead)	1	—	0,0003
0185	Lead sulfite (Sulfur lead (in recount of lead))	1	—	0,0017
0192	Tetraethyl lead	1	0,0001	0,00004
0203	Chromium hexavalent (in recount of chromium trioxide)	1	—	0,0015
0301	Nitrogen dioxide	3	0,20	0,04
0304	Nitrogen oxide	3	0,40	0,06
0326	Ozone	1	0,16	0,03
0328	Carbon (Soot)	3	0,15	0,05
0329	Selenium dioxide (in recount of selenium)	1	0,0001	0,00005
0330	Sulfur dioxide (Sulphurous anhydride)	3	0,50	0,05
0332	di sulfur dichloride (Sulfur chloride)	—	—	—
0333	Dihydrogen sulfide (Hydrogen sulfide)	2	0,008	—
0334	Carbon disulphide	2	0,03	0,005
0337	Carbon oxide	4	5,0	3,0
0602	Benzene	2	0,3	0,1
0616	Dimethylbenzene (Xylene)	3	0,2	—
0621	Methylbenzene (Toluene)	3	0,6	—
0703	Benz (a) pyrene (3,4-Benzopyrene)	1	—	0,000001
1071	Hydroxybenzene (Phenol)	2	0,01	0,006
1325	Formaldehyde	2	0,05	0,01

Table 3 - Classification of the risk of air pollution [1]

Air pollution hazard category	Signs of human exposure
Extremely dangerous	Acute death defeats. Increase in specific mortality
Highly dangerous	Toxic lesions of the respiratory system and other organs. Chronic
Dangerous	Physiological changes outside the norm. Signs of the disease
Moderately dangerous	Changes within the physiological norm
Safe (allowable)	No change

Safe and permissible pollution is considered, which for any duration of exposure, have not directly or indirectly affected the human body. Moderately hazardous are one-time concentrations exceeding 2-2.5 times the MPC, are able to subjectively deteriorate person's state due to odor and cause short-term changes in the body within physiological norms without complications and diseases. Air pollution at the level of more than 10 MPC has a more pronounced effect on the body. At such contamination, increase in the number of visits to the doctor and general morbidity is observed. The main symptoms of the disease are irritation of mucous membranes of eyes, nosepharynx, respiratory failure, reduction of working ability. This level of pollution belongs to hazardous category. A higher level of air pollution, depending on type and concentration of toxic agents, can increase mortality and morbidity of population. Such an effect on humans refers to cases of extremely dangerous air pollution.

At determining the criteria for real danger of pollution, one of the main tasks is the establishment of dependencies of adverse effects from amount of harmful substances. Based on these dependencies, the level of environmental safety of ships is normalized.

The International Marine Organization (IMO) develops requirements for the environmental safety of ships. These requirements in the form of IMO standards, applications and protocols of the MARPOL 73/78 convention regulate the technical, organizational and legal issues of environmental protection at sea. The technical requirements determine the means and necessary equipment for cleaning harmful emissions, specify the maximum levels of waste toxicity. Organizational requirements provide for periodic certification of ships for their compliance with the provisions of the Convention MARPOL.

In Russia, standards for the regulation of harmful emissions from exhaust gases of diesel engines were introduced in 1980-1981. The introduction of these standards allowed to streamline the ecological control over produced diesel engines. For 30 years, these standards have been repeatedly revised and significantly changed. As rule, changes concerned list of controlled parameters, their values, test methods and calculations. At present, the main national documents limiting harmful emissions of ship internal combustion engines are:

–GOST R 51250-99. Diesel ships, diesel and industrial. Smoke of exhaust gases. Norms and methods of measurement;

–GOST R 51249-99. Reciprocating internal combustion engines. Emissions of harmful substances with exhaust gases. Norms and methods of measurement;

–GOST R 52408-2014. Reciprocating internal combustion engines. Emissions of harmful substances with exhaust gases. Measurement in operating conditions.

The toxicity and smoke emissions of exhaust gases are largely regulated by the requirements of Russian and international standards.

The toxicity and smokiness of the exhaust gases are assessed by analyzing sample of gas taken from the exhaust manifold. In order to gas sample was representative, the gas sampler must be located in exhaust gas flow. For cleaner experiment, samples are sometimes taken directly from the diesel cylinder using stroboscopic umbrella. The following requirements are imposed on the gas sampling system:

–the identity of the gas composition in sample selection and in the combustion chamber of the diesel engine;

–unchanged gas composition of gas sample during sampling and during storage until analysis;

–the sampling tube should be short to maintain the temperature of sample gas at 150-200 ° C and thereby eliminate condensation of water vapor.

In order to fulfill the first requirement and obtain gas sample corresponding to this operating mode of the engine, recommended taking gas after special mixer. Such mixer allows averaging the values of the sample, since the harmful substances in composition of the exhaust gases of multi-cylinder diesel are distributed unevenly. This is due to the uneven cyclic fuel flow through the cylinders and, as consequence, the exhaust gases from each cylinder have different chemical composition.

Another feature of measurements is that gaseous toxic components have chemical selectivity, i.e. the direction of action on one or other component, in this connection measurement results depend on the selected chemical analysis. For this reason, in existing normative documents strictly specify the components and methods for measuring them.

The aim of this work is to study the use of bi-fuel internal combustion engines on ships and formed suspended particles during its combustion.

Objects and methods of research

In this paper, the following methods and techniques were taken into account in the calculation of the characteristics of dual-fuel internal combustion engines:

1) Method for selecting the flow characteristic of the injector;

2) Method for selecting the static and dynamic fuel consumption of an electromagnetic injector;

3) Method for specifying the flow characteristic of an electromagnetic injector in the electronic control unit of a two-fuel internal combustion engine;

4) Method for calculating the electromagnetic nozzle for a spark-ignited internal-combustion gas engine;

5) The method of using the energy of the gas differential pressure at the injector to improve the filling of the cylinders with the gas-air mixture;

6) Procedure for processing the parameters of electromagnetic nozzles after testing at a non-motorized stand;

7) Method for controlling the start-up and warm-up of a dual-fuel gas-fueled internal combustion engine;

8) The method of controlling the gas feed at stationary conditions;

9) The method of control of gas supply in transient modes;

10) The method of controlling the ignition timing for operation on one and two types of fuel;

11) Control methods for ignition misfires;

- 12) Correction method for cyclic feed depending on pressure pulsations in the gas train of injectors;
- 13) Method of adaptation to various gas fuel compositions;
- 14) Methods of diagnostics of elements of gas-cylinder equipment during the operation of the vehicle;
- 15) Methods of diagnostics of measuring devices of gas-cylinder equipment;
- 16) Methods of diagnostics of executive devices of gas-cylinder equipment;
- 17) Methods for controlling the operation of a dual-fuel internal combustion engine on standby modes in the event of failure of gas-cylinder equipment;
- 18) Methods of adapting the control system of a gas internal combustion engine;
- 19) Methods for reducing fuel consumption when working on gas fuel [6-10].

Results and discussion

The study of the mechanism of formation of normalized harmful components in combustion chamber of diesel engine allows to purposefully look for ways and means to reduce them. This approach makes it possible to justify the principles of influence on the processes of fuel mixture formation and combustion in order to reduce the formation of toxic substances and soot. These methods do not lead to an increase in fuel consumption.

In the combustion chamber of an internal combustion engine, the chemical reaction of oxidizing the fuel by air oxygen occurs at variable rate depending on the physical processes of mixing the fuel by air, formation of a fuel-air mixture, its heating, ignition and combustion. The main provisions of these processes, formulated in 1927, by N.N. Semenov, made up the theory of chain oxidative reactions. According to this theory, active molecules determine beginning of chain reaction. As they collide, thermal energy is released, which is expended on heating the reacting substances and the formation of new active molecules. Depending on the conditions in the combustion chamber, the reaction can be unbranched (linear) or branched. In the first case, instead of one active molecule, one new molecule is formed, and reaction proceeds until chain breaks. In the second case, several new molecules form from one active molecule, as result of which the oxidation reaction self-disperses, accumulation of active molecules takes place, in result a fuel ignition source appears. At branched chain reaction, the reaction rate can increase to infinity, but this does not occur for two reasons. First, part of the branches in the reaction terminates, reaching relatively cold walls of the combustion chamber, and, secondly, number of active molecules decreases as reactants. Having reached the maximum value, the reaction rate will begin to decrease.

The considered theory of ignition and combustion due to chain reactions is valid for homogeneous combustible mixtures, i.e. such mixtures, in which reactants of the reaction are in the same aggregate state and pre-mixed together [1,5-9].

A special place in a row of marine engines is occupied by L32DF (Dual-Fuel) engine, which represents the two-fuel version of the Wärtsilä L32 engine (Figure 1), which operates on a diesel cycle using both diesel fuel and gaseous fuel with an effective efficiency of 44%. The transfer of engine from one type of fuel to another is automatic and, practically, instantaneously, regardless of the mode in which it operates.

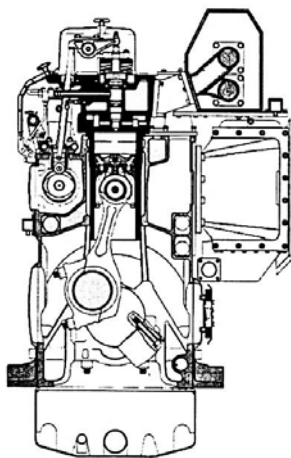


Fig. 1 - Cross section of the engine of Wärtsilä L32

An important feature of the engine (Figure 2) is that it operates on poor gas mixtures, air in the cylinder is roughly twice as large as required for complete combustion. Therefore, a large amount of heat is expended on heating air, and this, contributes to significant reduction in the peak values of combustion temperatures and sharp decrease in formation of NO_x .

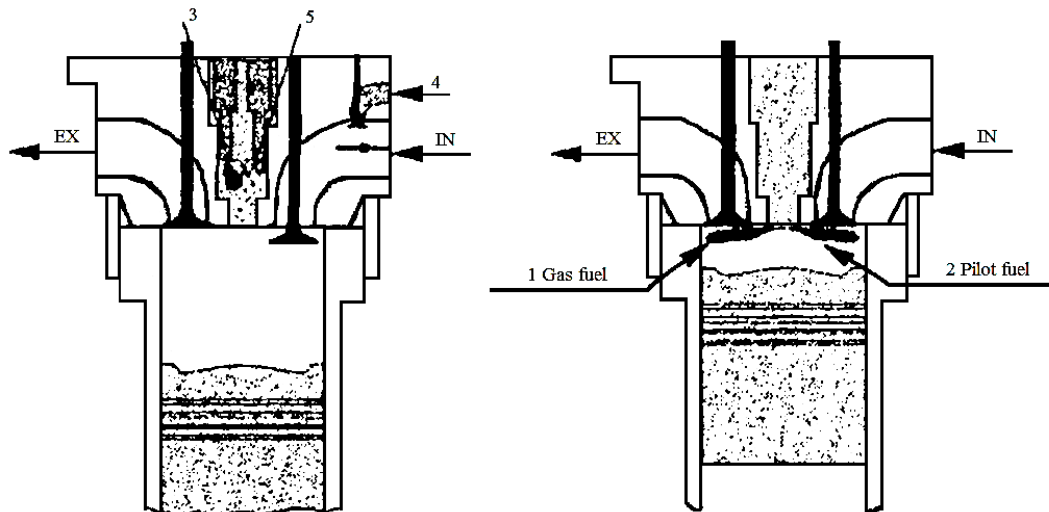


Fig.2 - Supply of gas and fuels

The excessively large values of detonation (explosive combustion) lead to characteristic for gas engines skip flares in cylinders. Therefore, for all loads and speed conditions, excess air ratio should lie in relatively narrow range. Adjustment of “air-gas” ratio (Figure 3) is carried out automatically in all modes by changing the turbocharger output, by bypassing exhaust gases, some of them are directed past the gas turbine plant.

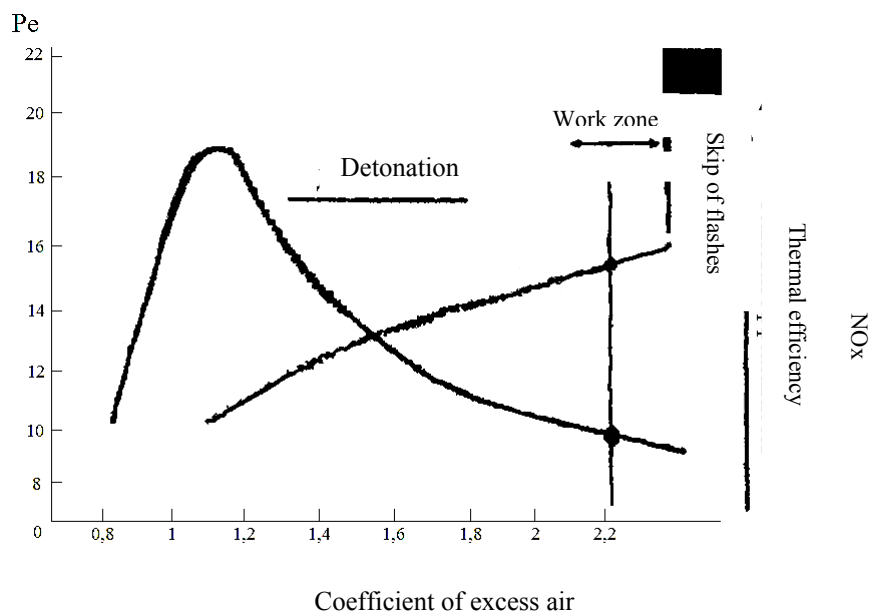


Fig. 3 - Operating range of air-gas ratio

Before engine, the gas is filtered, compressed depending on the engine load to pressures (3.5 bar at full load). The magnitude of the pressure depends on the engine condition. Then gas is directed to main inlet valve, which installed on cover of each cylinder. Control impulses to valves are fed from the

electronic control unit, which receives information from the load-sensing sensors, pressure and charge air temperature and combustion control sensor in each cylinder.

The main gas valve opens and closes at specified times. Delivers the required amount of gas to the inlet of the cylinder cover.

The gas enters cylinder during its filling by air. Feeding is carried out through main hydraulically controlled valve, installed in inlet pipe of cylinder. The valve is opened by oil, compressed to 370 bar. The opening and closing phases of the valve are determined by electronic control unit, which drops the current to solenoid valve.

The ignition of lean air-gas mixture is initiated by flame that occurs at small amount fuel into the combustion chamber is ignited at self-ignition. The supply of diesel fuel to the engine is carried out in two ways. The fuel for pre-injection is compressed by a separate scaled pump to 1000 bar and sent to battery in which constant pressure is maintained. From the accumulator fuel arrives to atomizers. Each nozzle has two nozzles and two needles. A small needle is designed for preliminary fuel injection, and large - for the main supply during engine operation marine diesel (MDO). The time for opening a small needle is determined by opening and closing the solenoid-operated valve in nozzle. The current to the solenoid comes from common electronic control unit. The large needle is controlled hydrodynamically, advance angle and amount of fuel supplied are set by high-pressure fuel pump (HPFP) in its usual version for diesel engines. The consumption of diesel fuel for pre-injection does not exceed 1 g/kW per hour.

The main advantage of dual-fuel engines is that they operate on cheap gas fuels and use them rationally on gas carrier ships and onshore power plants in gas fields. In the event of interruptions in the supply of gas, engine can continue to operate on marine diesel fuel (MDO) [5-8,11-15].

To model the processes of air pollution and build concentration fields at small and medium distances from the source of emissions, there are two approaches - based on Gaussian dispersion, which involves estimating the distribution of pollutant concentrations along the coordinate axes and based on the mass transfer theory (the so-called "gradient" models or K-models, based on solution of turbulent diffusion equations).

Various versions of Gaussian models are widely used abroad. Such models include the American models HIWAY-2, CALINE-4 (California Line Source Model), GM (General Motors), GFLSM (General Finite Line Source Model), the Finnish model - CAR-FMI (Contaminants in the Air from a road, By the Finnish Meteorological Institute). In the HIWAY-2 and CALINE-4 models, concentrations are calculated for a finite linear source with an arbitrary wind direction; in calculation process the source is divided into series of elements from which concentrations are calculated, which are then summed. The GFLSM model is based on formulas for an infinite linear source.

The basis for modeling distribution of pollutants on basis of statistical description of processes of turbulence was laid down by works of Setton, Pasquill, Gifford. The models are constructed on assumption that trail of suspended solids has a Gaussian distribution and concentration at given point along wind direction can be calculated using the generalized Gauss equation. Such models are widely used due to the simplicity and the obtaining of results consistent with experiment. Gaussian models are officially recommended by European Economic Commission, meteorological services of several countries.

The basic model for the case of constant wind speed and absence of chemical transformation is represented by formula:

$$C = \frac{M}{2\pi u \delta_y \delta_z} \exp\left(-\frac{y^2}{2\delta_y^2}\right) \left(\exp\left(-\frac{(z-H)^2}{\delta_z^2}\right) + k \exp\left(-\frac{(z+H)^2}{\delta_z^2}\right) \right), \quad (1)$$

where: C - concentration of suspended substances, g/m³; M - emission power, g/s; u - wind speed at height H, m/s; δ_y , δ_z - parameters of horizontal and vertical dispersion, m; y - distance from the center line of plume, m; z - height above ground, m; k - reflection coefficient ($0 \leq k \leq 1$); H - final height of plume, m.

Equation (1) is valid for concentrations averaged over time for several minutes, that for time interval for which values of scattering parameters and wind speed are representative. The merits of model, thanks

to which it found greatest application in calculating atmospheric pollution in most countries of the world, is as follows:

–the field of concentration from one or several emission sources is described by algebraic relationships, so the machine implementations of this model are characterized by high speed and do not require large amounts of memory;

–the Gaussian scattering approximation allows to take into account a multitude of factors that influence on levels of impurity concentrations in the near-Earth atmosphere. Among these factors are meteorological conditions (wind speed and atmospheric stability), reflection of the impurity from the underlying surface and raised inversions, removal of impurities from atmosphere by precipitation, due to dry deposition and chemical transformation;

– the results of calculations for the model and numerous experimental observations carried out by research teams, showed a good correspondence between themselves: the errors in calculations for the model are estimated at several tens of percent. In some cases, the differences can reach 2-3 times. Estimates of atmospheric pollution within these errors satisfy most practical problems.

The main causes leading to differences in the comparison of measured and calculated concentrations are associated with inaccurate determination of emission of harmful substances from sources of pollution, uncertainty in the choice of the category of atmospheric stability, measurement errors of meteorological parameters.

The main disadvantage of the Gaussian model is that it treats the initial state of the atmosphere as unperturbed, and the distribution of temperature, pressure, inversion, air humidity and other physical parameters along the height leads to the correspondence with the model of the International Standard Atmosphere, which in real conditions is never observed. As known from numerous studies, meteorological conditions are one of the most important factors affecting the dispersion and distribution of concentrations of harmful substances in the atmosphere. The model allows to predict the spatiotemporal picture of atmospheric pollution without taking into account specifically to terrain and meteorological conditions of the territory.

The Gaussian approach is empirical, which hinders the generalization of its results in number of practically important cases. It does not take into account the dependence of diffusion coefficients on height of source, therefore it allows to describe the surface field of impurity concentrations from source of only fixed height.

Models based on the K-theory are based on equations of turbulent diffusion and are the most elaborated theoretically. Russia occupies leading place in the world in these models. In Russia was widespread model M.E. Berland.

In accordance with this approach, the degree of air pollution by emissions of harmful substances from continuously operating sources is determined by the largest calculated value of the single surface concentration (C_M), which is set at certain distance (x_M) from the emission site under unfavorable meteorological conditions, when wind speed reaches dangerous value (u_M) and an intense turbulent exchange occurs in surface layer.

According to this method, the process of transport of harmful substances is described by equations of turbulent diffusion in atmosphere. Then applying averaging techniques from diffusion equations for instantaneous concentrations go to equation of turbulent diffusion for mean values of the concentrations.

The approach of M.E. Berland is applicable only under the condition that dimension of the emission cloud is greater than size of dominant turbulence. In general, all models constructed on the solution of the turbulent diffusion equation are most applicable to describing vertical diffusion near the earth's surface for distance of no more than 10 km from the source.

Models based on the equations of turbulent diffusion possible to solve a variety of practical problems on unified basis and at the same time: take into account development, terrain, averaging time (one-time, annual), photochemical reactions, meteorological conditions (normally unfavorable and anomalously unfavorable). It is also possible to consider various types of sources: point, linear, area.

It can be concluded that the transfer process according to the model of M.E. Berland is applicable to insufficiently powerful sources, since it is not designed for strong overheating of gases in source zone and presence of powerful turbulent mixing as result of overheating. Theoretical patterns of distribution and spatial-temporal distribution of contaminants in the atmosphere are determined by solving the equation of

atmospheric diffusion. This partial differential equation (2), in fact, represents mathematical formalization of fundamental physical law of the conservation of flow of matter and in this sense gives universal description of the regularities of distribution of atmospheric impurities:

$$\frac{\partial q}{\partial t} + \sum_{i=1}^3 u_i \frac{\partial q}{\partial x_i} = \sum_{i=1}^3 \frac{\partial}{\partial x_i} K_i \frac{\partial q}{\partial x_i} - \bar{\alpha} q, \quad (2)$$

where: q - calculated impurity; x_i - impurity coordinates, hereinafter denoted by x, y, z ; u_i ; K_i - components of the average velocity of impurity transfer and coefficient of exchange related to directions of axis x_i ($i = 1, 2, 3$); α - coefficient determining change of concentration due to atmospheric metabolism (impurity transformation).

The use of this fundamental approach to mathematical modeling of turbulent diffusion, which often called K-theory, together with justified simplifications and empirical refinements, has found expression in the mathematical model (3) for emissions. This expression calculates the values of largest total concentration of harmful impurity C_M (mg/m^3), which is set at certain distance (x_M) from the place of ejection from vessels as from sources close to each other in separate sections:

$$C_M = \frac{AMFm'_3}{H^{7/3}}. \quad (3)$$

where A - coefficient that depends on the temperature stratification of atmosphere; M - mass of suspended substances emitted into atmosphere per unit time (g/s); F - dimensionless coefficient, taking into account rate of gravitational settling of solid particles (dust) in atmospheric air on underlying surface, recommended to take the values of parameter $F = 1$ when calculating the scattering in the atmosphere of soot during the operation of ship engines; m'_3 - dimensionless coefficient equal to 0.9; η - dimensionless coefficient taking into account the influence of terrain, in case of flat or slightly intersected terrain with height difference not exceeding 50 m per 1 km, $\eta = 1$; H - height, determined by the terrain.

Vessels of arbitrary geometric configuration and distribution of traffic intensity of ships are represented as set of point, linear and area sources of harmful substances, by summation of which the total air pollution is determined.

The use of such design scheme possible to take into account number of factors important for assessing the impact of ships:

- degree of unfavorability of local climatic conditions for the stable dispersion of impurities in the air, in particular, the inversion (stagnant) states of the atmosphere;
- influence of the terrain, the quality of underlying surface;
- photochemical metabolism of substances;
- possibility of operating with the database MPC, that is, in fact, have an extreme situational picture of air pollution.

To obtain reliable results of computed monitoring of atmospheric air pollution, real, that is, very specific (in terms of vessel's application) and, at the same time, complete (on the structure of vessels) information on the emission capacity and its distribution across the terrain is required. Direct instrumental monitoring of traffic intensities and structural distribution of vessels by characteristic groups and ecological classes solve this task.

The use of numerical methods for calculating impact of vessels on the environment and public health using direct observations of intensity and structure of flows will allow more balanced decision - making and urgent measures to improve environmental situation [16-22].

Difficulties in reducing the toxicity of exhaust gases are due to the selectivity of effect on particular harmful component. Therefore, to solve this problem, important to establish targeted priorities. The choice of these priorities is limited to regulatory standards and regulatory documents, but ways to achieve them can be very diverse. These difficulties are connected with search for rational solution that allows to meet the requirements of the standard at minimum costs and without significantly degrading operating cycle parameters of internal combustion engine.

Measures to reduce the impact of air pollution on the environment and public health are regulatory and legislative regulation (stricter air quality standards, maximum permissible emissions from various sources); structural changes (for example, reduced energy consumption, especially energy produced by burning fuel, changing modes of movement, land-use planning); and also changes in behavior at the individual level, which are expressed, for example, in use of ecology clean ways of transportation or household energy sources.

Conclusions

Thus, the main feature of the use of dual-fuel internal combustion engines on ships is that it operates on poor gas mixtures in which air is approximately twice as large as required for complete combustion. Consequently, a large amount of heat is expended on heating the air, and this contributes to a significant reduction in high values of combustion temperatures and a sharp decrease in the formation of nitrogen oxides, sulfur, and solid particles.

The use of bi-fuel internal combustion engines on ships carrying liquefied natural gas (LNG), possible to reduce cost of operating vessel by approximately 50% in comparison with option of equipping vessel with steam turbine power plant, completely eliminate SO_x emissions, drastically reduce NO_x emissions by 90% and significantly reduce CO_x emissions by 30%.

The main advantage of dual-fuel internal combustion engines is that they operate on cheap gas fuel and are rationally used on gas-carrier ships and onshore power plants in gas fields. In case of power outage, the engine can continue to run on liquid fuel.

The main incentives for expanding scope of application of dual-fuel internal combustion engines will be further tightening of environmental standards and rising prices for traditional types of marine fuel, caused by gradual reduction of world oil reserves. As result, it will be economically more profitable for shipowners to invest in construction of more expensive vessels when they are built, but cheaper to operate.

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ЕКІ ОТЫНДЫ ПЖ КЕМЕЛЕРДІҢ ПАЙДАЛАНЫЛҒАН ГАЗДАРЫМЕН ЗИЯНДЫ ЗАТТАРДЫҢ ШЫҒАРЫЛУЫНЫҢ ҚОРШАҒАН ОРТАҒА ЖӘНЕ ТҮРҒЫНДАР ДЕНСАУЛЫҒЫНА ӘСЕРІН ТАЛДАУ

Аннотация. Газдың төмен құндылығы және әсіресе оны өндіру аймақтарында электр энергиясын өндіру үшін, сонымен қатар газ тасымалдаушы кемелерде қолданудың пайдалылығына байланысты бірқатар қозғалтқыш жасаушы фирмалар өздері шығаратын қозғалтқыштарды газ отынымен жұмыс жасауға бейімдеп жетілдіре бастады. Жетілдіру екі бағытта жүреді: карбюраторлық бензин қозғалтқыштарына ұқсас карбюраторларды және тұтандыру білтесін қолданумен Отто циклы бойынша дизельді жұмысқа көшіру және газ және отын қоспасын тұтандыру үшін дизельдік отынның аз мөлшерін шашыратумен дизельдік циклды сақтау. Бұл кезде қажеттігіне қарай қозғалтқыштың тек қана дизельдік отында – екі отынды қозғалтқышпен

жұмыс жасауы да мүмкін. Жұмыстың мақсаты іштен жанатын екі отынды қозғалтқыштардың кемеді қолданылуын және ол жанған кезде қалқымалы бөлшектердің түзілуін зерттеу. Тақырыптың өзектілігі көптеген кемелердің отын ретінде мазут, бензин және дизельдік отындарды қолдануымен байланысты, бұл тұрғындардың денсаулығына және қоршаған орта жағдайына, әсіресе теңізге кері әсер етеді. Сондықтан мұндай жағдайдан шығу үшін екі отынды қозғалтқыштарды ендіру қолданылған, бұл кемелерден теңіз және ауа ортасына лактыруларды бірнеше есеге дейін азайтады.

Түйін сөздер: зиянды заттар лактырындылары, кемелердің іштен жану қозғалтқыштарынан шыққан газдар, қоршаған орта, тұрғындар денсаулығы, сығылған табиғи газ, атмосфералық диффузияны есептеу үлгісі.

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АНАЛИЗ ВЛИЯНИЯ ВЫБРОСОВ ВРЕДНЫХ ВЕЩЕСТВ С ОТРАБОТАВШИМИ ГАЗАМИ СУДОВЫХ ДВУХТОПЛИВНЫХ ДВС НА ОКРУЖАЮЩУЮ СРЕДУ И ЗДОРОВЬЕ НАСЕЛЕНИЯ

Аннотация. В связи с низкой стоимостью газа и целесообразностью его использования для выработки электроэнергии, особенно в зонах его добычи, а также на судах-газовозах, ряд двигателестроительных фирм стали модернизировать выпускаемые ими двигатели для приспособления их к работе на газовом топливе. Модернизация идет по двум направлениям: по переводу дизеля на работу по циклу Отто с использованием карбюраторов и свечей зажигания подобно карбюраторным бензиновым двигателем и сохранению дизельного цикла с впрыском небольшого количества дизельного топлива для воспламенения смеси газа и топлива. При этом в случае необходимости не исключается работа двигателя только на дизельном топливе – двухтопливные двигатели. Цель работы заключается в исследовании применения двухтопливных двигателей внутреннего сгорания на судах и образуемых взвешенных частицах при его сгорании. Актуальность темы заключается в том, что большинство судов используют в качестве топлива мазут, бензин и дизельное топливо, что негативно сказывается на здоровье населения и состоянии окружающей среды, особенно, морской. Поэтому выходом из такого положения послужило внедрение двухтопливных двигателей внутреннего сгорания, которые в разы уменьшают выбросы от судов в морскую и воздушную среду.

Ключевые слова: выбросы вредных веществ, отработавшие газы судовых двигателей внутреннего сгорания, окружающая среда, здоровье населения, сжиженный природный газ, модели расчета атмосферной диффузии.

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