сколькими новыми видами специалистов. К сожалению, вокруг мало информации о внедрении H_2 во флот, однако, большая часть компаний расположения именно на территории Норвегии[8]. Безусловно, водородное топливо является очень дорогой и опасной технологией. К тому же, судоходным и судостроительным компаниям приложить немало сил, чтобы слезть с убивающей нашу планету нефтяной иглы. На данный момент водород является самым экологичным видом топлива, который способен продлить наше время на день другой.

Литература

1. Распоряжения Правительства Российской Федерации от 5 августа 2021 г. № 2162-р «Концепция развития водородной энергетики в Российской Федерации».
2. Группа «Деловой профиль». Аналитическое исследование: «Развитие водородной энергетики в России».
3. ООО «ЭкоГазСистем»: «Генераторы водорода PEM-типа».
4. Водородная энергетика: Себестоимость производства водорода.
5. ООО «ЭкоГазСистем»: «Водородные электролизёры. Принципиальная схема электролизной установки получения водорода».
6. Интеллектуальная система управления судовой энергетической установкой с использованием адаптивного многорежимного нейросетевого регулятора применительно к морским автономным судам / А. И. Епихин, Е. В. Хекерт, А. А. Иванченко, Г. А. Зеленков // Эксплуатация морского транспорта. – 2021. – № 4(101). – С. 112-119. – DOI 10.34046/aumsuomtl01/15. – EDN PGYDCO.
7. Каракаев А.Б. Разработка методологии, методов и моделей анализа влияния различных вариантов построения структуры и режимов поддержания и восстановления работоспособности судовых электроэнергетических систем (Часть 1) [Текст] / А.Б. Каракаев, А.В. Луканин, Е.В.Хекерт//Эксплуатация морского транспорта. 2016. № 3 (80). С. 54-60.
8. Modina M.A., Kheckert E.V., Epikhin A.I., Voskanyan A.A., Shkoda V.V., Pismenskaya Yu.V. 2021. Ways to reduce harmful emissions from the operation of power plants in special environmental control areas *IOP Conference Series: Earth and Environmental Science* **867** 012104.

References

1. Rasporyazheniya Pravitel'stva Rossijskoj Federacii ot 5 avgusta 2021 g. № 2162-r «Koncepciya razvitiya vodorodnoj energetiki v Rossijskoj Federacii».
2. Gruppa «Delovoj profil'». Analiticheskoe issledovanie: «Razvitie vodorodnoj energetiki v Rossii».
3. OOO «EkoGazSistem»: «Generatory vodoroda PEM-tipa».
4. Vodorodnaya energetika: Sebestoimost' proizvodstva vodoroda.
5. OOO «EkoGazSistem»: «Vodorodnye elektrolizyory. Principial'naya skhema elektroliznoj ustanovki polucheniya vodoroda».
6. Intellektual'naya sistema upravleniya sudovoj energeticheskoj ustanovkoj s ispol'zovaniem adaptivnogo mnogorezhimnogo nejrosetevogo regulyatora primenitel'no k morskim avtonomnym sudam / A. I. Epihin, E. V. Hekert, A. A. Ivanchenko, G. A. Zelenkov // Ekspluataciya morskogo transporta. – 2021. – № 4(101). – S. 112-119. – DOI 10.34046/aumsuomtl01/15. – EDN PGYDCO.
7. Karakaev A.B. Razrabotka metodologii, metodov i modelej analiza vliyaniya razlichnyh variantov postroeniya struktury i rezhimov podderzhaniya i vosstanovleniya rabotosposobnosti sudovyh elektroenergeticheskih sistem (CHast' 1) [Tekst] / A.B. Karakaev, A.V. Lukanin, E.V.Hekert//Ekspluataciya morskogo transporta. 2016. № 3 (80). S. 54-60.
8. Modina M.A., Kheckert E.V., Epikhin A.I., Voskanyan A.A., Shkoda V.V., Pismenskaya Yu.V. 2021. Ways to reduce harmful emissions from the operation of power plants in special environmental control areas IOP Conference Series: Earth and Environmental Science 867 012104.

УДК 621
DOI: 10.34046/aumsuomt105/38

CLOSED-LOOP MARINE ENGINE OPERATION WITH ZERO EMISSIONS OF HARMFUL COMBUSTION PRODUCTS

Mihail-Vlad VASILESCU, Octavian Narcis VOLINTIRU, A I Epikhin, T G Toria

In the modern world, the problem of environmental pollution with various toxic emissions is growing more and more. Exhaust or exhaust gases of internal combustion engines are one of those man-made factors. All countries impose restrictions on the concentration of hazardous substances, for example: Euro - for cars, Tier and Stage - for heavy equipment and MARPOL-73/78, which regulates emissions from maritime transport. The situation is extremely acute for marine vessels, since engines of impressive power that operate for a long period are difficult to adapt to stringent environmental requirements. The purpose of the article, based on open sources, is to evaluate the prospects for the development of internal combustion engines with an exhaust gas recirculation system to minimize the amount of toxic emissions into the atmosphere. The development of technologies that

allow for the recirculation of exhaust gases in ship conditions is quite promising. The installation of such equipment will significantly reduce emissions into the environment.
Keywords: environment, exhaust gases, toxic emissions, internal combustion engines

РАБОТА СУДОВОГО ДВИГАТЕЛЯ ПО ЗАМКНУТОМУ ЦИКЛУ С НУЛЕВЫМ ВЫБРОСОМ ВРЕДНЫХ ПРОДУКТОВ СГОРАНИЯ

Mihail-Vlad VASILESCU, (Romania)
Octavian Narcis VOLINTIRU (Romania)
А.И., Епихин, кандщидат технических наук, доцент
Т.Г. Тория, преподаватель

В современном мире все больше обостряется проблема загрязнения окружающей среды различными токсичными выбросами. Выхлопные газы двигателей внутреннего сгорания являются одним из таких техногенных факторов. Все страны вводят ограничения по концентрации вредных веществ, например: Euro — для легковых автомобилей, Tier и Stage — для тяжелой техники и MARPOL-73/78, регулирующий выбросы от морского транспорта. Для морских судов ситуация крайне острая, так как двигатели внушительной мощности, работающие длительный период, сложно адаптировать к жестким экологическим требованиям. Цель статьи на основе открытых источников оценить перспективы развития двигателей внутреннего сгорания с системой рециркуляции отработавших газов для минимизации количества токсичных выбросов в атмосферу. Перспективна разработка технологий, позволяющих осуществлять рециркуляцию выхлопных газов в корабельных условиях. Установка такого оборудования позволит значительно сократить выбросы в окружающую среду.
Ключевые слова: окружающая среда, выхлопные газы, токсичные выбросы, двигатели внутреннего сгорания.

Method of closed circulation

One of the most successful technologies for increasing the environmental friendliness of diesel engines is the reduction of gas exchange between the engine and the environment, since an engine running on the same working fluid does not pollute the air at all. Modern diesel submarines are equipped with air-independent diesel engines. In such engines, the exhaust gases (EG), after sufficient processing, are fed back into the cylinders. Although it is very difficult to implement such a process, because The gas at the inlet to the engine must be close in composition to atmospheric air, which differs significantly from the composition of the engine exhaust gas. However, on civilian ships there is no need for complete exhaust gas recirculation - it is only necessary to make part of the air charge artificial. In practice, a very good result is the return of 30-40% of the exhaust gas to the engine. This measure alone reduces toxic emissions by a third at once, and together with the use of the most effective filtration system, the result will be much more significant. In addition, the air entering the cylinders is diluted with chemically inert gases from the composition of the exhaust gas. The maximum result during recirculation is brought by gases with an increased specific heat capacity, which include, for example, CO_2, which is one of the main parts of the exhaust gas. Thus, the exhaust gas recirculation ensures that the air charge is diluted with carbon dioxide, which retards the combustion process and lowers the combustion temperature, thereby reducing the emission of NOx and aldehydes. The cooling of the exhaust gases before mixing also has a positive effect. Cooling improves filling of cylinders with fresh charge and further reduces cycle temperatures. However, the exhaust gas has a very low oxygen content, which will lead to only partial combustion of the fuel if the recirculation rate is high. Without additional enrichment of the bypassed exhaust gas with oxygen, recirculation values of only 3-5% can be achieved, which is extremely insufficient. However, such systems with a small recirculation share are widely used in modern diesel engines in the automotive industry. A diagram of such a design is shown in Fig. 1.

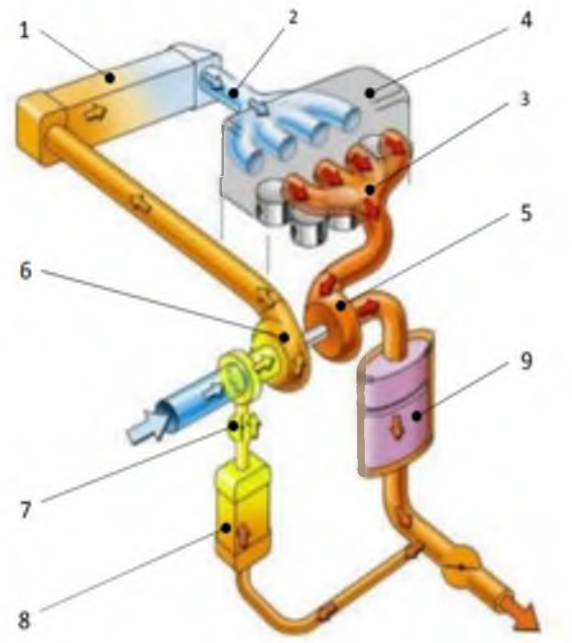

Figure 1. Scheme of the operation of the diesel engine recirculation system
1 – intercooler; 2 – intake manifold; 3 – exhaust manifold; 4 - engine; 5 – gas turbine; 6 – air compressor; 7 – recirculation valve; 8 – CFU; 9 – exhaust gas boiler

Another difficulty is the high corrosive wear of engine components, determined by the action of condensate and sulfuric acid vapors formed from sulfur compounds of the exhaust gas. Soot particles in the exhaust gas, which reduce the efficiency of the engine oil, also contribute to an increase in the wear of the elements.

Problems in the design of installations

The recirculation method is quite effective, although for its implementation it is necessary to clean them from soot and sulfur compounds before supplying the exhaust gas to the engine inlet, cool them and bring them closer in composition to atmospheric air. In table. 1 shows the differences in the composition of air from the atmosphere and engine exhaust gas by key components.

Table 1 - Comparison of the composition of atmospheric air and exhaust gases by main components.

Substance	Air	Exhaust gases
N_2	78.1	76-78
O_2	20.9	2-8
CO_2	0.03	5-10
H_2	$0.05*10^{-3}$	$0.05*10^{-3}$

As can be seen from Table. 1, in order to supply part of the exhaust gas back to the cylinder, it is necessary in every possible way to bring their composition closer to atmospheric air, i.e. it is enough to get rid of harmful components, cool and enrich with oxygen to a content of approximately 21%. Thus, an artificial air charge, consisting of air and prepared exhaust gases, will enter the engine inlet. For cleaning from mechanical impurities, it is appropriate to use a cyclone-foam unit (CFU), this type of units allows you to remove soot efficiently, regardless of the engine operating modes, has relatively small weight and size characteristics, is elementary in manufacture and does not need expensive maintenance. In addition, the CFU solves the issue of exhaust gas cooling to the fresh charge temperature at the engine inlet. The principle of operation of the CFU is that the exhaust gases, leaving the exhaust manifold, enter a special "snail" (or otherwise, the annular zone). The gas swirls and enters a chamber filled with liquid, and under the action of a tangential force consisting of centrifugal force and inertial forces (during gas-liquid friction), a dynamic foam is formed that traps particles and cools the passing gas. Due to its advantages (reliability, simplicity and compactness), the CFU is advisable to be used for cooling gases, dust collection, as well as for the absorption and desorption of only gases that are highly soluble in a liquid.

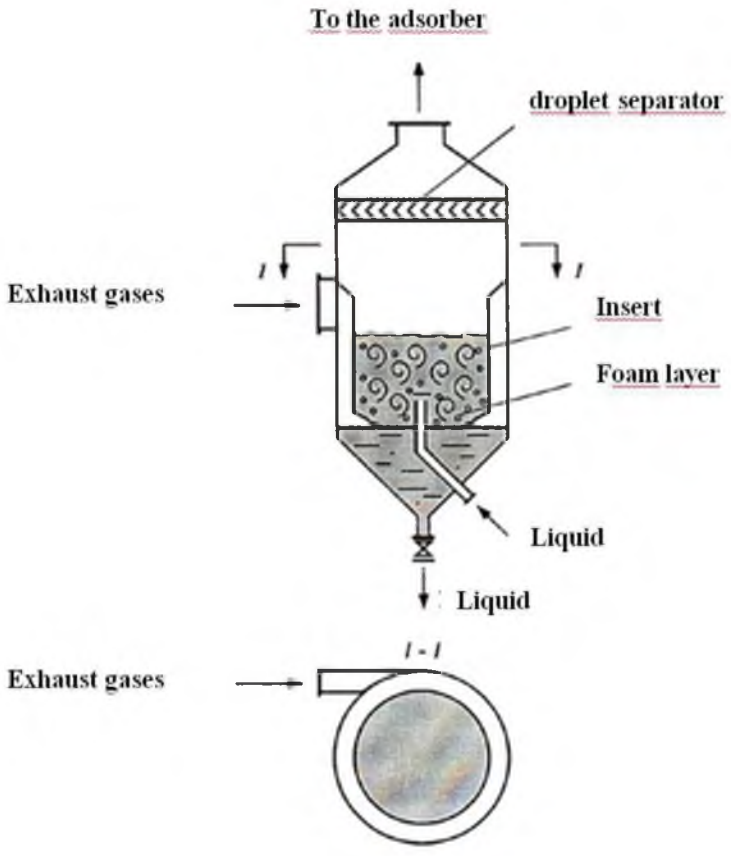

Figure 2. Scheme of operation of the Cyclone-foam unit

After cleaning the exhaust gas, it is necessary to increase the concentration of oxygen in their composition. To do this, they are mixed with oxygen or air with a high oxygen content (up to 70-80%).

To increase the oxygen content, it is necessary to use an oxygen generator, which will be used to enrich the exhaust gas with oxygen. One of the most promising options for such a generator is an adsorption plant for oxygen generation. They use a solid adsorbent. Installations of this type have a number of advantages: reliability, simplicity of design, high purity of oxygen. The disadvantages include the gradual destruction of the adsorbent, but its service life is quite long, and there are no specific requirements for storage.

The principle of its operation is that air is pumped by compressor 1 into the chamber with adsorber 2, where part of the mixture components is absorbed, and the rest pass to the outlet of the installation and receiver 3. Oxygen in the receiver serves to regenerate the adsorbent by the return flow, which creates a vacuum pump 5.

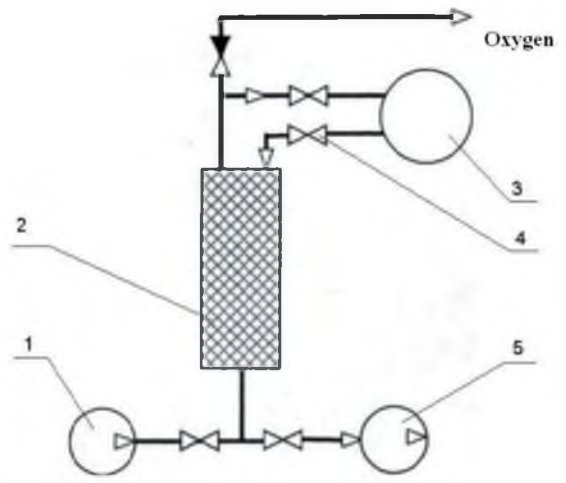

Figure 3. Scheme of a single-adsorber oxygen generation plant
1 – compressor unit; 2 – adsorber; 3 – receiver; 4 - control valve; 5 – vacuum pump

Scheme of the installation for creating an artificial charge

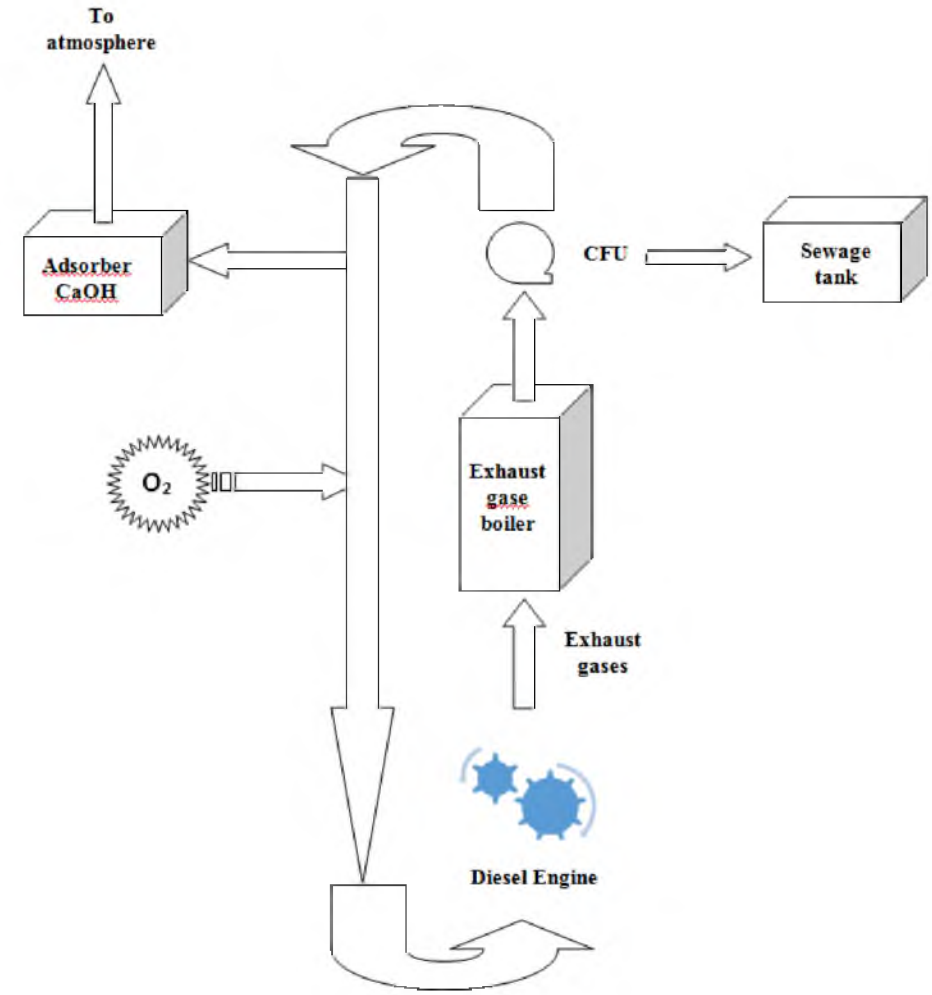

Figure 4. Functional diagram of the installation.

When the system is operating according to the presented scheme (Fig. 3), the exhaust gas from the engine passes through a waste heat boiler, in which heat is removed and, accordingly, it is cooled. Then it

enters the liquid apparatus, which is a CFU, where filtration and the second stage of cooling take place. This is followed by a slide valve, which regulates the amount of exhaust gas taken. Further, the gas is enriched with oxygen from the oxygen generator to a concentration close to atmospheric, mixed with air from the atmosphere at point 1 and fed back to the engine. Based on this, an air charge with the amount of oxygen necessary for high-quality fuel combustion enters the engine.

Conclusion

According to the data studied, it can be concluded that the development of technologies that allow exhaust gas recirculation in ship conditions is quite promising. The installation of such equipment will significantly reduce emissions into the environment. At the moment, there remains a problem with the creation of a device that will create an artificial air charge that enriches the exhaust gases with oxygen.

Bibliography:

1. Результаты экспериментального исследования установки по созданию искусственного воздушного заряда для судового двигателя / Н. Н. Арефьев, А. С. Курников, В. С. Наумов, Н. Ф. Попов // Морские интеллектуальные технологии. – 2018. – № 4-2(42). – С. 30-35. – EDN LULZUK.
2. Research and data to make progress against the world's largest problems URL: http://ourworldindata.org
3. Su, Penghao Emissions of intermediate volatility organic compound from waste cooking oil biodiesel and marine gas oil on a ship auxiliary engine 2020// *Journal of environmental sciences*. **Volume 9**, May; pp 262-270.
4. Our Carbon Footprint / Carol Sutters, William Fong. Bloomington, Indiana: AuthorHouse UK, 2021. 34 p.
5. Ivar Ihle, Jon Alme, Frode Bloch. Approaches to agreener DP vessel. Marine Technology Society DYNAMIC POSITIONING CONFERENCE 2016 Houston October 11-12,
6. IMO (2010) "Module 2 - Ship Energy Efficiency Regulations and Related Guidelines", IMO Train the Trainer Course on Energy Efficient Ship Operation.
7. Туркин А В, Туркин В А, Самойленко А Ю Моделирование рабочих процессов малооборотного судового двигателя для снижения эмиссии оксидов азота Морские интеллектуальные технологии.– 2018.– № 1-1(39).– С. 106-110.
8. Modina, M.A., Kheckert, E.V., Epikhin, A.I., Voskanyan, A.A., Shkoda, V.V., Pismenskaya, Yu.V. Ways to reduce harmful emissions from the operation of power plants in special environmental control areas (2021) IOP Conference Series: Earth and Environmental Science, 867 (1), статья № 012104.
9. Turkin V A, Sarychev I A, Ignatenko G V 2021 Monitoring pollution from ship power plants with laser technologies IOP Conference Series: Earth and Environmental Science **867** (1) 012177 doi=10.1088/1755-1315/867/1/012177