10.31653/smf343.2021.5-17

Zablotskyi Yu.V[1], Sagin A.S[2]
National University "Odessa Maritime Academy"
yurzpost@gmail.com[1], saginarseniy@gmail.com[2]

APPLYING OF FUEL ADDITIVES IN MARINE DIESEL ENGINES

Abstract. A *method for improving the operational characteristics of a marine diesel engine by applying fuel additives has been proposed. A marine medium-speed four-stroke cycle diesel 6L20 by Wartsila-Sulzer was used for this research. It was shown that the use of fuel additives improves fuel efficiency of a marine diesel, in particular reduces specific fuel oil consumption by 3.5 to 5.8 % subject to diesel load and additive concentration in the fuel. Improved environmental performance of the diesel – decrease by 1.4 ... 4.3 % in the concentration of nitrogen oxides in exhaust gases, was also found. It was shown that the concentration of the additive has an optimal value, can be determined experimentally and depends on the characteristics of the fuel and the load on the diesel engine.*

Анотація. *Запропоновано спосіб поліпшення експлуатаційних характеристик суднового дизеля за рахунок використання присадок до палива. Дослідження виконувались на судновому середньообертовому чотиритактному дизелі 6L20 Wartsila-Sulzer. Показано, що використання паливних присадок підвищує паливну економічність суднового дизеля, зокрема знижує питому витрату палива на 3,5 ... 5,8% в залежності від навантаження дизеля і концентрації присадки в паливі. Також встановлено поліпшення екологічних характеристик дизеля – зниження на 1,4 ... 4,3 % концентрації оксидів азоту в випускних газах. Було показано, що концентрація присадки має оптимальне значення, може бути визначена експериментально і залежить від характеристик палива і навантаження на дизель.*

Statement of the problem in general. Effective and efficient operation of transport ships is affected directly by fuel cost, with the share of such cost in total financial operation costs being the largest [1, 2]. Optimized fuel consumption and improved utilization efficiency due to activation of output performance of such fuel facilitates better performance of the whole propulsion unit [3, 4].

Marine internal combustion engines are the most popular heat engines used in ships. As compared with power plants of any other types (steam turbine and gas turbine), which are used to power a marine propulsion unit, marine diesels are known for their minimum fuel consumption per unit of power (kg/kW·h) and per unit of ship mileage (kg/mile).

According to ISO DIS DP-8217, distillate fuels of two grades are used in marine combustion engines: DBM clean diesel fuel and DMC blended fuel, and also RM refined fuel. Viscosity of the DMB and DMC fuels ranges 5 to 10 sSt at 100° C and density of such fuels is 820 … 850 kg/m^3 at 15° C. Therefore, such fuel grades are called light. Viscosity of the RM (RMG, RMH, RMK) fuels is 35 … 55 sSt at 100° C and density of such fuels is 990 … 1010 kg/m^3 at 15° C, which makes them heavy fuels. Heavy grades are cheaper, as compared with light grades, which determines their usage in marine diesels to cut fuel costs. One should also mention that fuel of heavy grades is used for operation of marine diesels in all conditions, including startup and reversal. Operation of diesels under the conditions can not be reliable, unless a fuel preparation process is applied. Complex fuel preparation for marine diesels is done, starting from felling ships and finishing with fuel feeding to the engine cylinder [5, 6].

Analysis of recent researches and publications. For now, design and technology of marine internal combustion engines reached perfection, ensuring lowest fuel consumption rates by heat engines of these types, as compared to other engines (steam generators and gas turbines). Thus and so, application of fuel additives is considered a way of enhancing fuel efficiency of diesels [7].

Numerous works [8-10] were dedicated to an effect of fuel additives on heat engine performance, while application of additives even in such energy intensive and demanding power settings as nuclear power engineering was considered [11-13].

Fuel additives are designed to improve fuel performance, starting from pumpability and ending with flash point, while dispersing, enhanced lubricating power, and combustion process activation are primary functions of fuel additives. Place of introduction of additives into the fuel system (Fig. 1) depends on overall system configuration, diesel specification and tasks such additives are designed for.

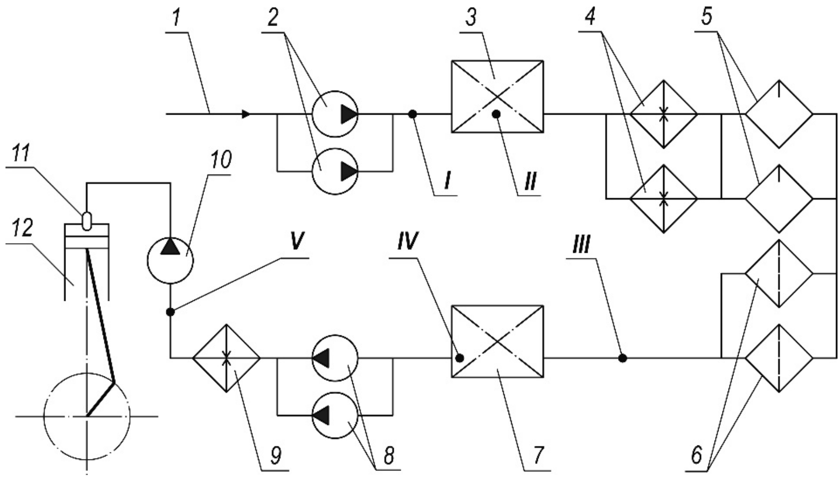

Fig. 1. Possible points of introduction of additives into a marine diesel fuel system:

1 – feeder feed line; 2 – fuel pumps; 3 – slop tank; 4 – fuel heaters 5 – fuel separators; 6 – fuel filters; 7 – service tank; 8 – buster pumps; 9 – fuel heater; 10 –fuel pump; 11 – nozzle; 12 – diesel;*I*, *II*, *III*, *IV*, *V* – recommended points of introduction of additives

Formulation of the problem. Marine fuel additives are now rather popular on ships; however, their performance is not evaluated the same way. This is due to a variety of reasons, primarily marine diesel and diesel power unit specification and ensuring right application technology of additives. Therefore, determination of an effect of fuel additives on power, economic and environmental properties of a marine internal combustion engine was the objective of this research [14, 15].

When additives are used to prevent microbiological contamination of the fuel, additive components must ensure eradication of any organisms present in the fuel. And a slop tank (item *II* in Fig. 1) is their primary place of introduction into the fuel system. When fuel additives are used as friction modifiers, contributing to reduction of hydraulic resistance in piping and other elements of the fuel unit, soft metals are freed from the additive and create a micron intermediate layer on friction surfaces, and facilitate generation of molecules of oriented structure close to the metal surface. For this purpose, additives may be introduced along the whole passage of fuel in the system (items *I*, *III*, *IV* in Fig. 1). When fuel additives are applied to reduced formation of heavy fraction deposit, they are introduced to a service tank (item *IV* in Fig. 1).

Application of additives is of special relevance to auxiliary engines that serve as electric generator drives. These engines are known for their high (as compared to main engines) crankshaft speed and continuous operation as a part of the marine power station (in cruising and harbor modes). The first parameter (high speed) reduces the time of fuel injection, and the second parameter (operation in the harbor mode in seaport waters) poses additional environmental requirements to diesels [16].

Presentation of the main research material. Studies under the conditions of a marine ship with its deadweight carrying capacity of 32,150 tons were done in a fuel system of a 6L20 diesel by Wartsila-Sulzer with the following specifications:

- type – vertical, water-cooled, 4-cycle diesel engine;
- cylinder bore – 200 mm;
- stroke – 260 mm;
- rated speed of revolution – 1000 min^{-1} (rpm);
- number of cylinder – 6;
- power – 1200 kW.

Marine power unit comprised three such diesels that served as diesel generators. This allowed for two diesels to be used for the experiments and one diesel left as the control one. Diesel fuel system schematic is given in Fig. 2. For the purpose of this experiment, the fuel system was also equipped with a flow meter 3 and additive dispenser 4. Such way of feeding the additive into the fuel system ensured the required dispersion and even dissolution in the fuel [17, 18].

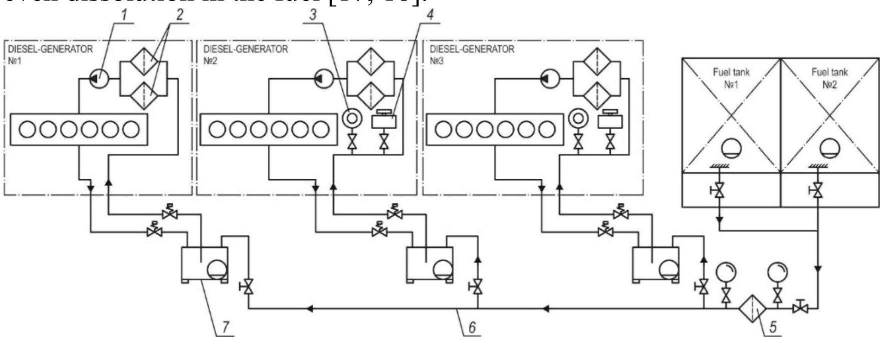

Fig. 2. Marine fuel system (a fragment):
1 – fuel pump; 2 – fine mesh fuel filters; 3 – flow meter; 4 – additive dispenser; 5 – coarse mesh fuel filter; 6 – fuel line; 7 – service tank

Operation of the engines in experiments was concurrent, which allowed for maintaining equal load on the experimental diesels and on the control diesel. Load was N_e=550 … 1100 kW.

To calculate specific fuel oil consumption (SFOC) value according to the level meter, which is located on each service tank (item 7 in Fig. 2), current fuel consumption was determined.

For the purpose of experiment equivalence, preliminary preparation was done for all diesels before testing. Operating conditions allowed for complete engine purge of the diesels one by one within 40 hours, thus preparing them for the experiment. At the same time, piston group (pistons and piston rings) and basic elements of the system (precision pairs of the fuel pump plunger-bushing and needle-nozzle) were replaced in all diesels. Moreover, power unit control and adjustment was done for both engines before the experiments. At the same time, fuel pumps were adjusted for the same fuel injection advance angle and engine nozzles were set for the same needle lifting pressure. Operation time and working load on diesels was monitored for the whole duration of the experiment. Diesels were switched to stand-by one by one to ensure equal operation time of the diesels. Power discrepancy of diesel generators under study did not exceed 10 kW by way of re-connecting power consumers, which may be considered a non-significant discrepancy and working conditions may be considered identical for such energy intensive items. Engines run on the fuel of the same grade. At the same time, automatic controls maintained continuous fuel viscosity for the duration of the experiment. The grade of circulation oil was also maintained identical, which ensured lubricating conditions and performance. These measures allowed for an assumption that the experiment was done under the same conditions [19-21].

The following parameters were primarily subjected to control and determination: specific fuel oil consumption, exit gas temperature, NO_X content in exit gases, and technical condition of power unit and diesel cylinder-piston group elements. For the experiments, diesels run on the DMB25 fuel.

Comprehensive research of the effect that additives have on power, economic and environmental properties of diesel fuel has produced the following results.

Dosing rates for the additives vary greatly and depend on the intended use of the additive and fuel system specification. Additives that are introduced into fuel tanks or individual sectors of fuel lines for biological effect on the fuel or reduction of hydraulic losses are used in the ratio of

1:8000 … 1:12500. Additives that improve the fuel combustion process are introduced in the ratio of 1:1000 … 1:8000. Dosing may vary in both cases, subject to engine configuration, operating state of the fuel system, fuel contamination rate in tanks, ultimate fuel composition (traces of vanadium, sodium and sulphur) [22-24]. Optimum additive dosing range is determined experimentally; therefore, the following additive and basic fuel ratios were selected: 1:2000, 1:3500, 1:5000, 1:6500 и 1:8000. In addition to the above, the lowest SFOC value was obtained for concentrations of 1:3500 and 1:5000, which were selected for further research. Characteristic SFOC curves for the 6L20 Wartsila-Sulzer diesel for relative power N_e/N_{enom} for various additive concentrations in the fuel are given in Fig. 3.

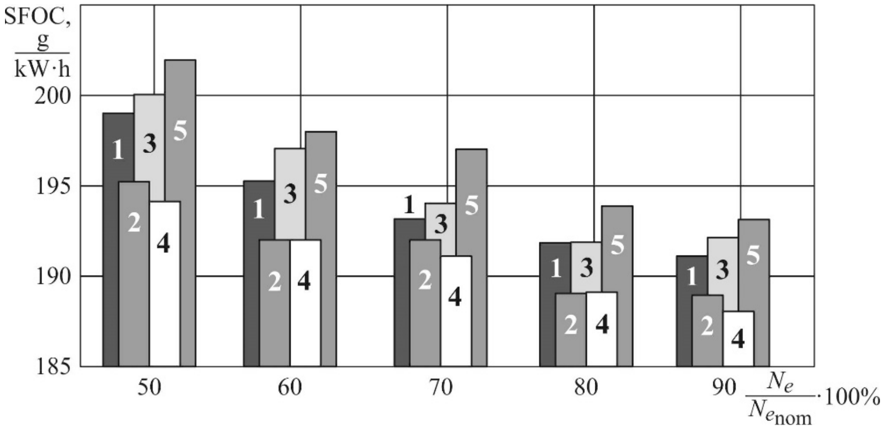

Fig. 3. SFOC and relative power Ne/Nenom ratios for a 6L20 Wartsila-Sulzer diesel for various additive concentrations in a fuel:

1 – 1:2000; 2 – 1:3500; 3 – 1:6500; 4 – 1:5000; 5 – 1:8000

These data are indicative of better carburation and combustion, and more complete use of additive-containing fuel heat content.

Determination of optimum additive concentration ranges for the fuel allowed us to conduct the next stage of our research, using the following alternative: a control diesel, an experimental diesel, running on additive concentration of 1:3500 and experimental diesel, running on additive concentration of 1:5000. At the same time, temperature of gases downstream a gas turboblower tgas, and NOX concentrations in exit gases were determined [25-26].

Gas temperature at the engine output is a parameter that determines quality of the working cycle in the diesel cylinder and degree of thermal factor of its parts. This temperature is most often measured in the output line downstream the gas turboblower. Ratios of temperature of gases at the diesel output that has been averaged for all cylinders tgas and relative diesel power Ne/Nenom are given in Fig. 4. Measurements were made for the control diesel and experimental diesels, which run on the fuel containing the additive in the optimum concentration (1:3500 and 1:5000). According to Fig. 4, application of additives to the fuel facilitates a reduction in temperature of gases at the diesel output, which is indicative of full fuel combustion and maximum use of heat energy of gases in the cylinder. One should also mark out a smaller deviation of gas temperature across cylinders from the averaged value Δtmid, when the additive is used in the fuel. Thus, for the control diesel (at relative diesel power of Ne/Nenom=78 %) at Δtmid=397 °C this value is $\Delta t^{+}_{\text{mid}}$ =13 °C, $\Delta t^{-}_{\text{mid}}$ =10 °C, and for an experimental diesel at Δtmid=380 °C – $\Delta t^{+}_{\text{mid}}$ =8 °C, $\Delta t^{-}_{\text{mid}}$ =6 °C (Fig. 5).

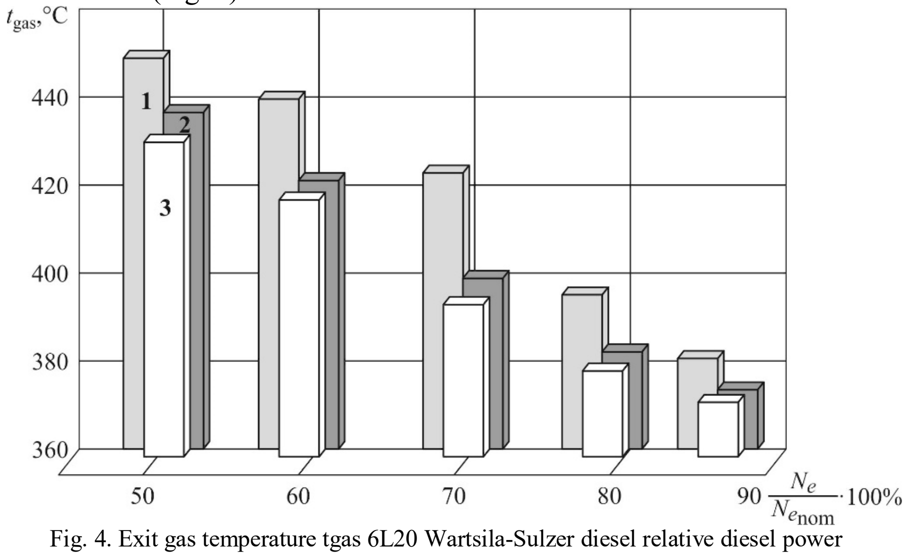

Fig. 4. Exit gas temperature tgas 6L20 Wartsila-Sulzer diesel relative diesel power Ne/Nenom:1 – control diesel; 2 – experimental diesel (fuel with additive concentration of 1:3500); 3 – experimental diesel (fuel with additive concentration of 1:5000)

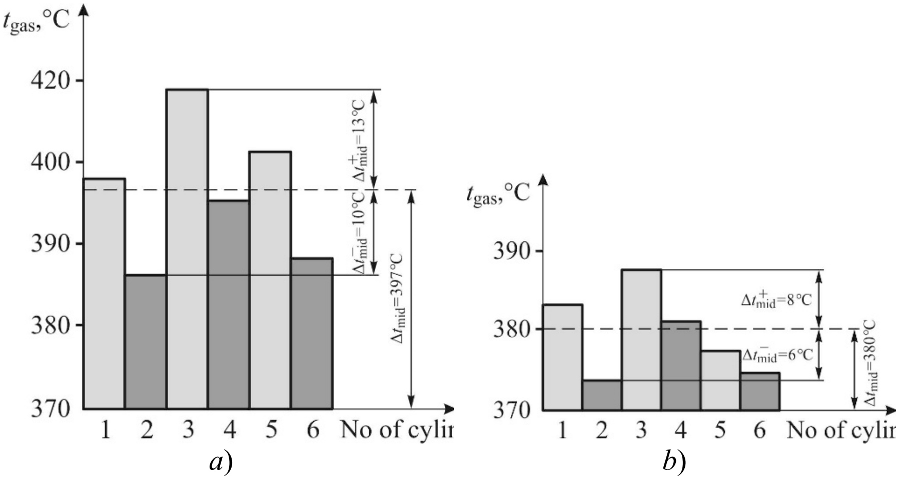

Fig. 5. Exit gas temperature discrepancy across 6L20 Wartsila-Sulzer diesel cylinders at different experiment conditions:*a*) control diesel (no fuel additive used); *b*) experimental diesel (fuel additive used)

The results given in Fig. 6 are indicative of improved environmental performance of the diesel; at the same time, the best reduction in harmful emissions between experimental and control diesels is observed in the load range of 65 to 80 %, which is most typical for operation of auxiliary marine engines [27-28].

Improved technical condition of the diesel and power units was visually determined in our experiments, when fuel additives were used. Thus, it was observed in the process of diesel engine purge that cylinder-piston group elements of the diesel that runs on the fuel additive demonstrated less carbon deposits on the heating surfaces (in particular, on the piston cap, cylinder lid and more flexible piston rings), as compared to the diesel that runs on the additive-free fuel. Moreover, almost no carbon deposits were observed around nozzle openings and injection nozzles were less worn out in the diesel that used the fuel additive. This is again indicative of intensified carburation and combustion, when the additive-containing fuel was used [29-30].

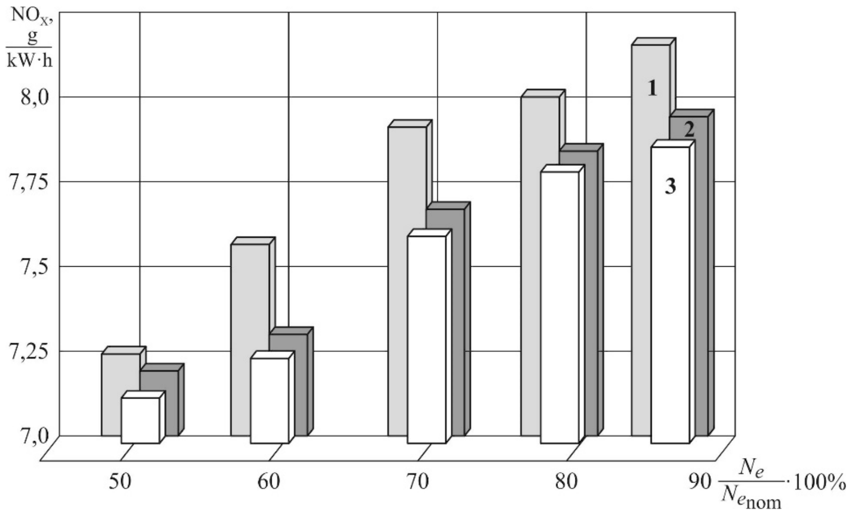

Fig. 6. NO_X concentration change in exit gases of a 6L20 Wartsila-Sulzer diesel and relative capacity of the diesel $N_e/N_{e\text{nom}}$:

1 – control diesel; 2 – experimental diesel (fuel with additive concentration of 1:3500); 3 – experimental diesel (fuel with additive concentration of 1:5000)

Conclusions and prospects for further researches. Experimental results that prove SFOC reduction, when fuel additives are used, is indicative of intensified carburation and combustion process. At the same time, different SFOC reduction is observed for different additive concentration in the basic fuel. We contribute it to the fact that some free additive radicals remain unengaged in disruption of intramolecular bonds of the fuel and combustible ingredient activation.

Reduced exit gas temperature is also the result of improved fuel combustion process and this process offset to the isochoric heat input line. This is due to fuel additives facilitating the combustion process in the diesel cylinder along the stationary-state combustion line, instead of chain reaction line resulting in detonation.

SFOC decrease and associated full use of fuel heat content reduces the amount of fuel that is burned out in process of expansion and in the outlet collector, which is indicated by visual control of gas outlet surface state. Similar results were also observed in other studies.

Decreased gas temperature, when using an additive-containing fuel, improves environmental diesel performance. In particular, this leads to reduced NO_X concentration in exit gases.

Therefore, the following conclusions are possible, based on the results presented:

1) the use of fuel additives, which may be added to the fuel system in various points: a slop tank, a feed tank, fuel line or immediately before feed to a diesel cylinder, is a method of improving fuel performance properties;

2) the use of fuel additives leads to an improved fuel efficiency of a marine diesel. Thus, SFOC reduction by 3.5 to 5.8 % may be achieved, when using fuel additives for various four-stroke diesel conditions. At the same time, maximum increase in fuel efficiency of 50 to 60 % of the diesel load, i.e. in conditions of the longest operation and high thermal factor, is gained. By using fuel additives, not only total fuel consumption is reduced, but also exit gas temperature drop by 3.3 to 7.2 % and lesser temperature shift across diesel cylinders are facilitated, thus equalizing heat load on individual cylinders;

3) environmental diesel performance is greatly improved, when fuel additives are used. Thus, the use of additives facilitates exit gas NO_X concentration decrease by 1.4 to 4.3 %. The above facts are of special importance with view to the requirements of Annex IV MARPOL73/78 and particularly for four-stroke diesels that operate for along time in off-shore strips and seaport waters;

4) additive concentration is optimum; it is determined experimentally and depends on diesel and fuel specification.

REFERENCES

1. Kuropyatnyk O.A. The use of bypass exhaust gases to ensure the environmental performance of marine diesel engines // Суднові енергетичні установки: наук.-техн. зб. – 2018. – Вип. 38. – С. 217 - 228.

2. Sagin S., Madey V., Stoliaryk T. Analysis of mechanical energy losses in marine diesels // Technology Audit and Production Reserves. – 2021. – № 5 (2 (61)). – P. 26 - 32.

3. Sagin S.V., Kuropyatnik A.A. Application of the system of recirculation of exhaust gases for the reduction of the concentration of nitric oxides in the exhaust gases of the ship diesels // American Scientific Journal. – 2017. – № 15. – Iss. 2. – P. 67 - 71.

4. Звєрьков Д.О., Сагін С.В. Зниження механічних втрат у суднових дизелях // // Суднові енергетичні установки: наук.-техн. зб. – 2020. – Вип. 40. – Одеса : НУ «ОМА». – С. 20 - 25.

5. Побережний Р.В., Сагін С.В. Забезпечення екологічних показників дизелів суден річкового та морського транспорту // Суднові енергетичні установки: наук.-техн. зб. – 2020. – Вип. 41. – Одеса : НУ «ОМА».– С. 5 - 9.

6. Поповский А.Ю., Сагин С.В. Комплексная оценка эксплуатационных характеристик смазочных углеводородных жидкостей // Автоматизация судовых технических средств: науч.-техн. сборник. – 2014. – Вып. 20. – С. 74 - 83.

7. Заблоцкий Ю.В., Куропятник А.А. Повышение топливной экономичности и экологических параметров работы судовых дизелей при использовании присадок к топливу // Austria-science. – 2017. – № 2. – С. 83 - 88.

8. Madey V. V. Usage of biodiesel in marine diesel engines // Austrian Journal of Technical and Natural Sciences. – 2021. – № 7 - 8. – P. 18 - 21.

9. Sagin S.V., Solodovnikov V.G. Cavitation Treatment of High-Viscosity Marine Fuels for Medium-Speed Diesel Engines // Modern Applied Science. – 2015. – Vol. 9. – №. 5. – P. 269 - 278.

10. Марченко О.О., Сагін С.В. Вдосконалення процесу очищення суднових важких палив // Суднові енергетичні установки: наук.-техн. зб. – 2020. – Вип. 41. – Одеса: НУ «ОМА». – С. 10 - 14. DOI : 10.31653/smf341.2020.10-14.

11. Zablotsky Yu.V., Sagin S.V. Maintaining Boundary and Hydrodynamic Lubrication Modes in Operating High-pressure Fuel Injection Pumps of Marine Diesel Engines // Indian Journal of Science and Technology. – 2016. – Vol. 9. – Iss. 20. – P. 208 - 216.

12. Заблоцкий Ю.В. Исследование влияния органических покрытий на работу элементов топливной аппаратуры высокого давления судовых дизелей // Судовые энергетические установки: науч.-техн. сб. – 2015. – № 35. – Одесса: НУ «ОМА». – С. 83 - 92.

13. Мацкевич Д.В., Заблоцкий Ю.В. Определение смазочной способности дизельных топлив // Судовые энергетические установки: науч.-техн. сб. – 2011. – № 28. – Одесса: ОНМА. – С.145 - 153.

14. Zablotsky Yu. V., Sagin S.V. Enhancing Fuel Efficiency and Environmental Specifications of a Marine Diesel When using Fuel Additives // Indian Journal of Science and Technology. – 2016. – Vol. 9. – Iss. 46. – P. 353 - 362.

15. Sagin S.V., Semenov O.V. Marine Slow-Speed Diesel Engine Diagnosis with View to Cylinder Oil Specification // American Journal of Applied Sciences. – 2016. – Vol. 13. – Iss. 5. – P. 618 - 627.

16. Куропятник А.А., Сагин С.В. Управление выпускными газами судовых дизелей для обеспечения экологических показателей // Автоматизация судовых технических средств: науч.-техн. сб. – 2018. – Вып. 24. – С. 72 - 80.

17. Сагин С.В., Заблоцкий Ю.В., Перунов Р.В. Технология использования и результаты испытаний присадок к топливам для судовых дизелей // Проблеми техніки: наук.-виробн. журнал. – 2012 . – № 3. – Одесса : ОНМУ. – С. 84 - 103.

18. Sagin S.V., Semenov O.V. Motor Oil Viscosity Stratification in Friction Units of Marine Diesel Motors // American Journal of Applied Sciences. – 2016. – Vol. 13. – № 2. – P. 200 - 208. DOI: 10.3844/ajassp.2016.200.208.

19. Мацкевич Д.В., Сагин С.В., Ханмамедов С.А. Изменение реологических характеристик смазочных материалов в циркуляционной масляной системе в процессе эксплуатации среднеоборотного двигателя // Судовые энергетические установки: науч.-техн. сб. – 2010. – Вып. 25. – Одесса : ОНМА. – С.109 - 118.

20. Поповский Ю.М., Сагин С.В., Ханмамедов С.А., Гребенюк М.Н., Терегеря В.В. Влияние анизотропных жидкостей на работу узлов трения // Вестник машиностроения. – 1996. – № 6. – С. 7 - 11.

21. Сагин С.В. Определение диапазона стратификации вязкости смазочного материала в трибологических системах судовых дизелей // Вісник Одеськ. нац. мор. ун-ту. Зб. наук. праць. – 2019. – Вип. 1(58). – С. 89 - 100.

22. Сагин С.В. Оптимизация расхода высокощелочного цилиндрового масла судовых малооборотных дизелей // Universum: технические науки : электрон. научн. журн. – 2016. – № 7 (28) . URL: http://7universum.com/ru/tech/archive/item/3385.

23. Сагин С.В. Реология моторных масел при режимах пуска и реверса судовых малооборотных дизелей // Universum: Технические науки. – 2018. – Вып. 3(48). – С. 67 - 71.

24. Солодовников В. Г. Ультразвуковая обработка топлива для снижения сернистой коррозии в судовых среднеоборотных дизелях // Автоматизация судовых технических средств: наук.-техн. сб. – 2015. – Вып. 20. – С. 84 - 91.

25. Сагин С.В., Заблоцкий Ю.В. Влияние анизотропных жидкостей на работу узлов трения судовых дизелей // Проблеми техніки : наук.-виробн. журнал. – 2012 . – № 4. – Одесса : ОНМУ. – С. 68 - 81.

26. Сагин С.В., Заблоцкий Ю.В. Определение триботехнических характеристик поверхностей по степени упорядоченности пристенных слоев углеводородных жидкостей // Проблеми техніки : наук.-виробн. журнал. – 2011. – № 3. – Одесса : ОНМУ. – С. 78 - 88.

27. Сагин С.В., Куропятник А.А. Оптимизация режимов работы системы перепуска выпускных газов судовых среднеоборотных дизелей // Автоматизация судовых технических средств: науч. -техн. сб. – 2019. – Вып. 25. – Одесса : НУ «ОМА». – С. 79 - 89.

28. Сагін С.В. Зниження енергетичних втрат в прецизійних парах паливної апаратури суднових дизелів // Суднові енергетичні установки: наук.-техн. зб.. – 2018. – Вип. 38. – Одеса : НУ «ОМА». – С. 132 - 142.

29. Мацкевич Д. В., Заблоцкий Ю.В. Определение смазочной способности дизельных топлив // Судовые энергетические установки: науч.-техн. сб. – 2011. – № 28. – Одесса : ОНМА. – С.145 - 153.

30. Заблоцкий Ю.В., Солодовников В.Г. Снижение энергетических потерь в топливной аппаратуре судовых дизелей // Проблеми техніки: наук.-виробн. журнал. – 2013. – № 3. – Одесса : ОНМУ. – С. 46 - 56.