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Environmental indicators of the operation of a diesel generator running on a mixture of biofuels

Abstract: The article examines the environmental performance of a diesel generator that runs on a biofuel mixture. Biofuels are considered to be more environmentally friendly than traditional petroleum products and have become popular alternatives in the field of electricity production. To reduce dependence on petroleum fuels and decrease harmful exhaust-gas emissions from diesel generators, it is suggested to use biodiesel fuel and its mixture with diesel fuel. Various environmental indicators were measured and analyzed in this study, including the emissions of harmful substances, carbon dioxide, nitrogen oxides and particulates. By using biofuels, pollutant emissions are expected to be reduced because biofuels are made from renewable sources such as vegetable oils or biomass. The results of the study show that the use of a biofuel mixture in a diesel generator leads to a signi-

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ficant reduction in the emission of harmful substances compared to the use of traditional petroleum products. A reduction in the emissions of carbon dioxide and nitrogen oxides was found, which contributes to a reduction of the impact on climate change and air pollution. In addition, a decrease in particle emissions was noted, which contributes to the improvement of air quality and people's health.

The goal was achieved by researching the impact of a mixture of diesel and biodiesel fuel on the technical, economic and environmental indicators of an autonomous diesel generator. The regulation of the composition of the fuel mixture ensured the preservation of the power of the generator in all its modes of operation, while reducing the cost of purchasing fuel by 10% and reducing the smokiness of exhaust gas by up to 57%, depending on the mode of operation of the diesel engine.

Keywords: emissions, greenhouse effect, ecology, energy generation

Introduction

In recent years, the global demand for petroleum fuels has continued to outstrip domestic production in many countries, including Ukraine. This reliance on foreign energy resources poses a significant challenge to the country's energy security (Rutkevych et al. 2022; Kupchuk et al. 2022). To address this issue and reduce dependency on conventional fossil fuels, extensive research and development of alternative energy sources has become imperative. These alternative sources need to encompass a wide range of applications, from electricity generation to the production of alternative fuels.

One promising avenue in the quest for sustainable energy solutions is the use of biofuels in diesel engines, including those equipped with common rail power systems. Numerous studies have explored the possibilities and prospects of integrating biofuels into traditional diesel engines . The findings of these investigations have highlighted that successful integration requires a thorough understanding of how biofuels differ in their physical and chemical properties compared to traditional petroleum-based fuels. Consequently, adjustments to the diesel engine's settings and structure are necessary to effectively optimize the use of biofuels.

One of the key advantages of utilizing biofuels lies in their potential to mitigate harmful exhaust gas emissions and reduce overall fuel costs. As the proportion of biofuels in the fuel mixture increases, several properties also change, such as increased density, viscosity, and cetane number, along with its low heat of combustion. However, the introduction of higher levels of biofuels in the mixture may lead to certain challenges, such as reduced engine power and increased fuel consumption, as noted by experts in the field.

In light of the pressing need for energy security and sustainable solutions, this study aims to delve deeper into the analysis of research findings concerning the application of biofuels in diesel generators. By investigating the influence of biofuels on the working processes of diesel engines, this research seeks to identify specific areas that require attention, such as optimizing

engine settings and making structural modifications. Additionally, this study will explore the trade-offs involved in increasing the content of biofuels in the fuel mixture, balancing reduced harmful emissions with potential reductions in engine performance.

The ultimate goal of this research is to provide valuable insights and recommendations that can inform policymakers, industry stakeholders, and researchers on the viability and challenges associated with using biofuels in diesel generators. By doing so, we can contribute to the wider adoption of sustainable energy practices and enhance energy security, thereby reducing dependence on imported petroleum fuels and fostering a more environmentally friendly energy landscape in Ukraine and beyond.

1. Formulation of the problem

The article considers the problem of the impact of the use of biofuel in diesel generators on environmental indicators. Despite the general trend to reduce the consumption of petroleum products and increase the use of renewable energy sources, the use of biofuels still faces problems and challenges.

One of the central problems is the environmental efficiency of diesel generators operating on a mixture of biofuels. Biofuels are known to be produced from organic materials such as plant and animal fats and have the potential to reduce greenhouse-gas emissions and dependence on petroleum products (Kaletnik et al. 2020b; Honcharuk et al. 2022, Yaropud et al. 2022; Lohosha et al. 2023). However, different types of biofuels can have different levels of ecological efficiency and a different impact on the environment.

The study of the environmental indicators of the operation of a diesel generator on a mixture of biofuels includes the assessment of such parameters as emissions of harmful substances, air pollution, energy efficiency and economic benefit (Vasilevskyi et al. 2023). It is necessary to establish to what extent the use of biofuel in diesel generators can really contribute to reducing emissions and improving the state of the environment compared to traditional petroleum products.

2. Analysis of the latest research

The latest studies to consider the environmental performance of a diesel generator on a mixture of biofuels have made a significant contribution to the understanding of this issue. One such example is a study conducted by Aliev E.B. in which the effect of using a biodiesel mixture on

the environmental performance of a diesel generator was investigated. The researchers compared the emissions of harmful substances such as nitrogen oxides (NO_x), particulate matter (BF) and hydrocarbons (HC) when using a mixture of biodiesel with different concentrations. The results showed that the use of a biodiesel mixture reduces NO_x and BF emissions, but there is a clear increase in HC emissions.

Other studies by Bulgakov V. focused on the energy efficiency of bioethanol diesel generators. The researchers performed a comparative analysis of fuel consumption and CO_2 emissions when using different concentrations of bioethanol. It was found that the addition of bioethanol to fuel helps to reduce the consumption of petroleum products and CO_2 emissions while not significantly affecting the energy performance of the generator.

The work of Pryshliak V.M. is devoted to the economic indicators of the use of biodiesel mixture in diesel generators. The researchers analyzed the cost of biodiesel production, its impact on the cost of fuel and the benefits associated with reducing the use of petroleum products. They noted that while biodiesel may be more expensive to produce, the use of the blend in diesel generators may bring economic benefits as a result of reduced dependence on petroleum products and the ability to use biorenewable fuel sources.

3. Materials and methods

Analysis of the results of research on the use of biofuel for diesel generators reveals both benefits and challenges caused by it which should be taken into account when considering the possibilities of implementing this technology. There are some key aspects that emerge from the research. One of the main advantages of using biofuel in diesel generators is its ability to reduce the amount of harmful emissions, particularly nitrogen oxides and soot. Biofuel, as a rule, contains less sulfur and aromatic compounds, which helps to improve the quality of exhaust gases. Some studies indicate a decrease in the energy efficiency of diesel generators when using large concentrations of biofuel in the fuel mixture. This is due to the low calorific value of biofuel compared to traditional oil fuel. However, there are studies that show that with correct engine settings and optimization of the fuel mixture, this negative effect can be reduced. The use of biofuels can cause some mechanical problems in diesel engines, including corrosion and higher wear. Biofuels have the property of absorbing moisture, which can cause the oxidation of metal parts. Additionally, some biofuels can be more aggressive to some materials in fuel systems.

Another important aspect is the reliability and stability of biofuel supply. In some regions, particularly in Ukraine, the infrastructure for the production, storage and supply of biofuels may be limited, which may create difficulties for its large-scale use.

The use of biofuels can have an economic impact through changes in fuel prices and production costs. The cost of biofuels can be higher compared to conventional fuels, especially in regions where it is not widely available.

Biofuel production can take up significant land resources, which can compete with the cultivation of food crops. This could have a negative impact on agriculture and food prices.

Numerous studies have established that the best substitute for traditional diesel fuels is fuel of plant origin, particularly, fuel oBFained from rapeseed. Currently, rapeseed occupies a strong position in world agriculture as one of the main oil crops (Burlaka et al. 2022a; Kupchuk et al. 2023).

The use of rapeseed oil is connected with three main directions for improving Ukraine's energy security:

1) increasing the amount of decentralized energy production (that is, by means of small power generation);

2) increasing the amount of energy use of biomass;

3) differentiation of the domestic fuel market with the replacement of petroleum products and natural gas with biofuel.

It should be recognized that many issues of the optimal use of alternative biofuels and, in particular, rapeseed oil, have not been well studied in our country (Burlaka et. al. 2022b).

Experiments on drying rapeseed in the installation with microwave energy supply are shown in Table 1.

Table 1. The maximum permissible content of harmful substances in exhaust gases per 1 kW of produced power

Tabela 1. Maksymalna dopuszczalna zawartość substancji szkodliwych w spalinach na 1 kW wyprodukowanej mocy

%	CO	CH	Soot	CO_2
Euro III	>0,0015	>0,04	>0,1	>0,0005
Euro IV	0,0015	0,04	0,04	0,0005
	0,0007	0,02	0,02	0,0002
Euro V	0,0007<	0,02<	0,02<	0,0002<

Figure 1 presents a graph of the dependence of fuel consumption on power consumption which shows that the consumption of DF is the lowest, but at the same time, no changes were made to the fuel supply system which could reduce the consumption when using bio-additives, such as replacing the nozzle or heating the mixture. Furthermore, the fuel consumption is the lowest, but the consumption at 10, 15 and 20% BF content in the fuel does not exceed 15% of the fuel consumption.

The increase in the content of harmful exhaust gas impurities increases with the increase in power consumption. Figure presents a graph of the dependence of the CO content on 1 kW produced engine power, while DF has the worst performance.

From Figure 2, we can see that over the entire range, the ratio of CO release per 1 kW of BF15DF85 is lower than pure DF. It is possible to make a comparative assessment of the content of harmful substances in exhaust gases using the table provided by the manufacturer of auto testers.

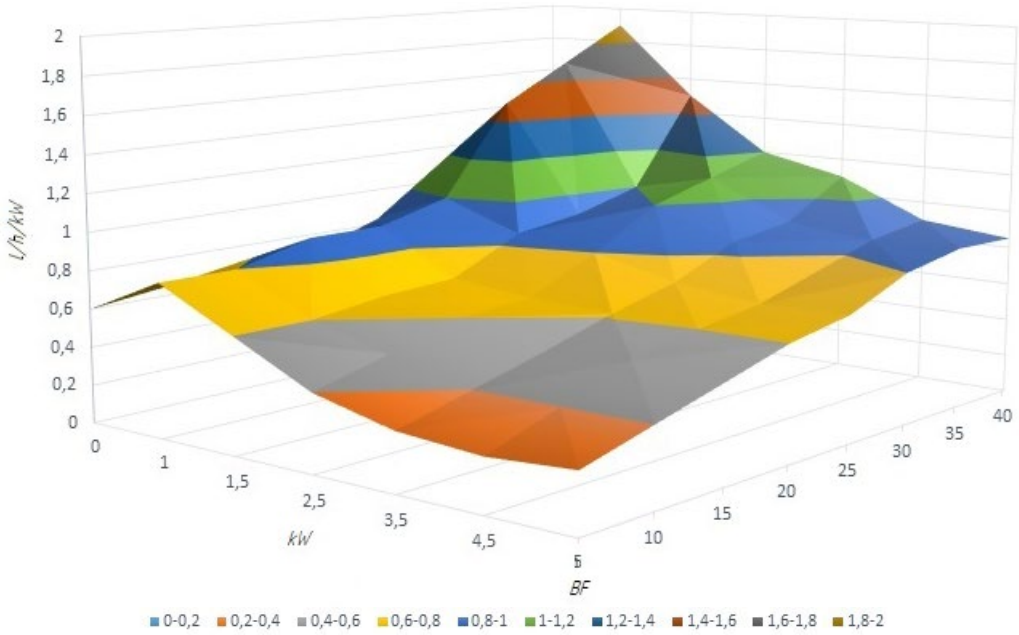

Fig. 1. Fuel consumption per 1 kW of produced power

Rys. 1. Zużycie paliwa na 1 kW wytworzonej mocy

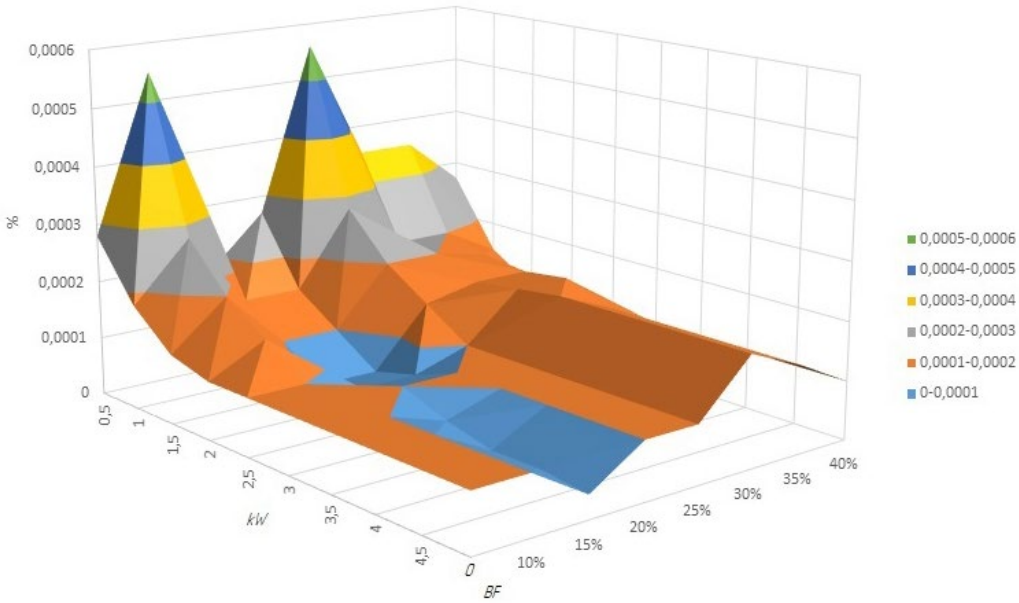

Fig. 2. Dependence of CO % content per 1 kW of produced power

Rys. 2. Zależność procentowej zawartości CO na 1 kW wytwarzanej mocy

This presents the values of the limits of environmental standards for EURO III, EURO IV and EURO V. The table provides an opportunity to determine the minimum load on the diesel generator, at which the emissions of harmful exhaust gases do not exceed the maximum permissible values. Having determined the minimum load values for each type of fuel, choosing the maximum value for exhaust (CO, CO, CH, soot), it is possible to determine the composition of the mixed fuel depending on the environmental restrictions (CO, CH, CO, soot), as shown in Figure 3.

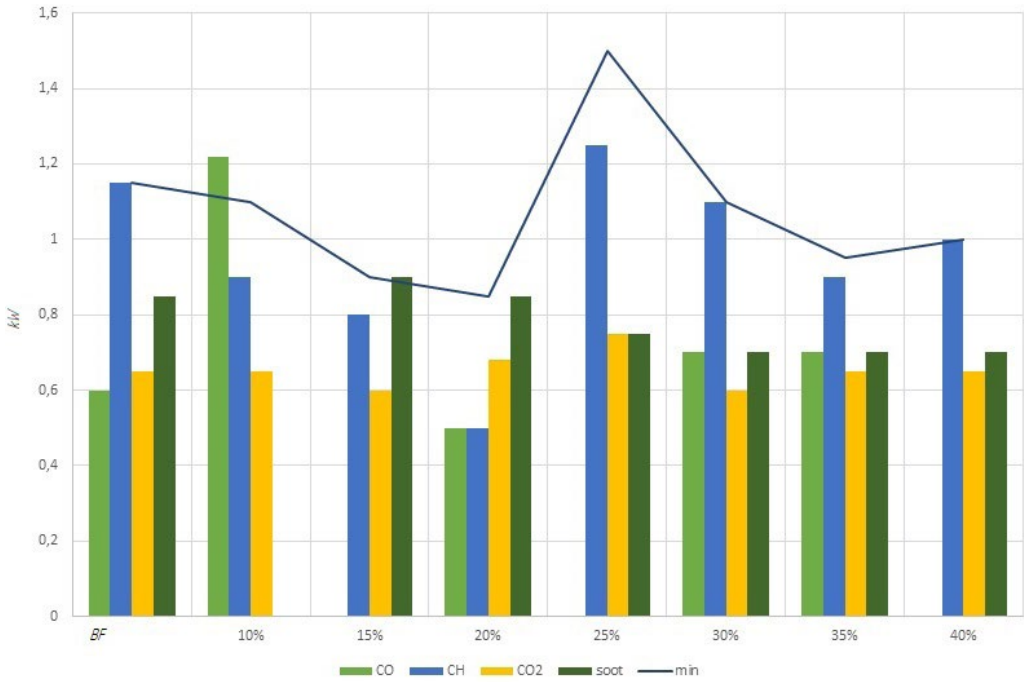

Fig. 3. The minimum power consumption of a diesel generator depending on the percentage ratio of biofuel to diesel according to the Euro III standard

Rys. 3. Minimalny pobór mocy generatora diesla w zależności od procentowego stosunku biopaliwa do oleju napędowego zgodnie z normą Euro III

Figure 4 presents a graph of the dependence of soot concentration on the time of day during the operation of a diesel generator with a given load using a mixture of fuels of different percentages and with dynamic regulation of the BF content in the mixture.

It can be seen from the graph that with increased loading of the crankshaft of a diesel engine, the smokiness of the exhaust gases increases. The use of a fuel mixture leads to a reduction in the smoke level of diesel exhaust gases. When working in the idling mode on mixtures with BF contents of 25, 50, 75 and 100%, reduction levels are 37.95, 56.86, 56.72, 37.55%, respectively, and when working with a load of 60 kW, the reduction levels are 2.08, 3.29, 3.62 and 3.08%, respectively.

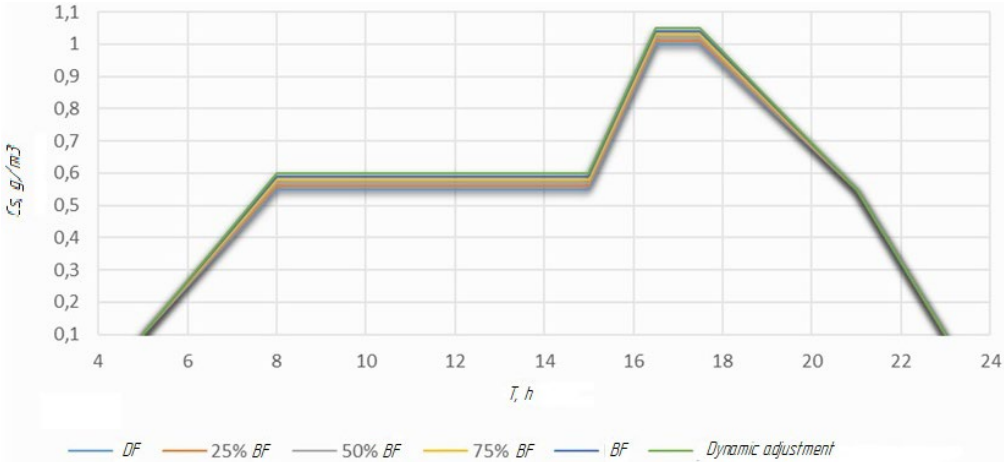

Fig. 4. Dependence of the concentration of soot Cs on the hour of the day T during operation of the diesel generator

Rys. 4. Zależność stężenia sadzy Cs od pory dnia T podczas pracy generatora diesla

Due to the energy value of VT being less than DF, it is necessary to increase the cyclic supply of VT in order to ensure the same effective torque (Hraniak et al. 2022; Paziuk et al. 2022; Bulgakov et al. 2019). However, when the diesel engine is operating at maximum power (with maximum cyclic feed), the power system of the SMD-15 diesel engine does not provide an opportunity to compensate for the lower energy value of the BF by increasing its cyclic feed (Fig. 5); this leads to a decrease in the effective torque, and an increase in the acceleration time of the diesel crankshaft during the use of BF (Fig. 6).

With increases in the BF content in the fuel mixture, the acceleration time of the diesel crankshaft increases (dynamics deteriorate).

When using mixtures with BF contents of 25, 50, 75 and 100%, the acceleration time of the diesel crankshaft increases by 3.9, 7.5, 10.8 and 13.95%, respectively. Considering the fact that the diesel generator constantly works at a stable frequency of rotation of the crankshaft, changing the acceleration dynamics of the diesel engine will not affect its operation in any way (Wallner and Miers 2012; Honcharuk et al. 2023; Pryshliak et al. 2022).

Figure 6 presents the consumption diagram of fuel mixtures of different percentages during acceleration of the diesel crankshaft from idling to the speed limited by the regulator. When using mixtures with BF contents of 25, 50, 75 and 100%, the hourly consumption of the fuel mixture increases by 3.8, 9.9, 13.6 and 20%, respectively, compared to the hourly consumption of DF.

Mobile power plants equipped with diesel engines are mostly of higher power than the generators themselves, and this leads to the fact that when the diesel generator is operating at maximum load, the engine operates at partial load at a crankshaft rotation frequency close to the nominal rate (Pryshliak et al. 2021; Bondarenko et al. 2023; Pronko et al. 2020). In accordance with this, the diesel engine operates in modes in which it is advisable to use fuel mixtures with

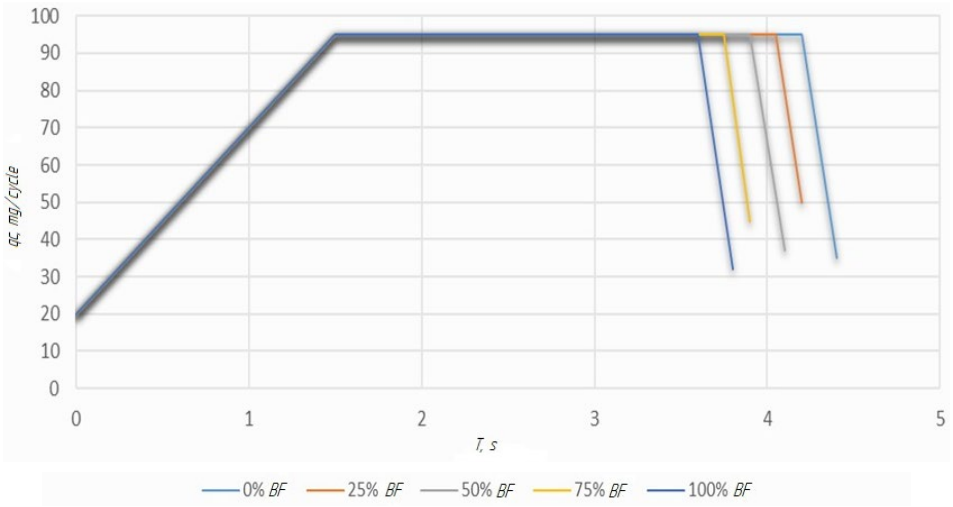

Fig. 5. Dependence of the cyclic supply of the fuel mixture qts with different percentage composition on time T during acceleration of the diesel engine crankshaft

Rys. 5. Zależność cyklicznego zasilania mieszanką paliwową qts o różnym składzie procentowym od czasu T podczas przyspieszania wału korbowego silnika wysokoprężnego

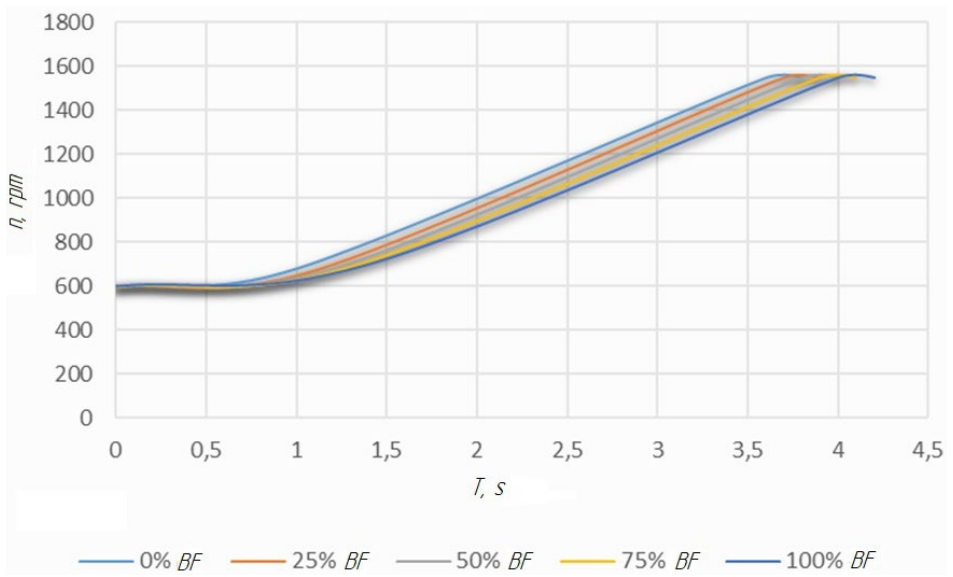

Fig. 6. Dependence of crankshaft rotation frequency nd on time T during acceleration of its mixture of fuels with different percentage composition

Rys. 6. Zależność częstotliwości obrotów wału korbowego nd od czasu T podczas rozpędzania jego mieszanki paliw o różnym składzie procentowym

a high BF content. The diesel fuel system with dynamic adjustment of the percentage composition of the fuel mixture ensures efficient operation of the power plant in all its operating modes, easy start-up at low temperatures even at low temperatures, and helps to eliminate the negative effects of using BF with an unheated engine.

Conclusion

Based on the analysis of the latest research on the environmental indicators of the operation of a diesel generator on a mixture of biofuels, the following conclusions can be drawn:

The use of biofuels in diesel generators has the potential to reduce emissions of harmful substances, in particular nitrogen oxides (NO_x) and particulate matter (BF), compared to traditional petroleum products. However, some biofuels may lead to increased hydrocarbon (HC) emissions, which requires attention and further research.

Biofuel diesel generators can be energy efficient, reducing petroleum consumption and greenhouse-gas emissions, particularly carbon dioxide (CO_2). Research shows that adding bioethanol to fuel can be a promising solution for increasing the energy efficiency of diesel generators.

The economic aspects of using biofuel in diesel generators require additional study. With regard to the costs of biodiesel production, the possibility of reducing the use of petroleum products and the possibility of using biologically renewable fuel sources, the use of biofuels can have economic advantages in the long term.

Optimizing the environmental indicators of the operation of a diesel generator on a biofuel mixture is possible through the selection of the optimal type of biofuel, the development of effective exhaust gas purification systems, and the improvement of biofuel production technologies.

As a result of the use of the dynamic regulation of the percentage composition of the fuel mixture for a diesel generator, the generator power of which is close to the power of a diesel engine, the excess consumption of the fuel mixture in relation to the use of DF is 5.9%. Furthermore, fuel purchase costs are reduced by 10% and the smoke level of exhaust gases is also reduced (up to 57%, depending on the mode of operation of the diesel engine).

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Środowiskowe wskaźniki pracy generatora diesla na mieszance biopaliw

Streszczenie

W artykule przeanalizowano wydajność środowiskową generatora diesla zasilanego mieszanką biopaliw. Biopaliwa są uważane za bardziej przyjazne dla środowiska niż tradycyjne produkty ropopochodne i stały się popularną alternatywą w dziedzinie produkcji energii elektrycznej. Aby zmniejszyć zależność od paliw ropopochodnych i obniżyć emisję szkodliwych gazów spalinowych z generatorów diesla, sugeruje się stosowanie paliwa biodiesel i jego mieszaniny z olejem napędowym. W niniejszym artykule zmierzono i przeanalizowano różne wskaźniki środowiskowe, w tym emisję szkodliwych substancji, dwutlenku wę-

gla, tlenków azotu i cząstek stałych. Oczekuje się, że dzięki zastosowaniu biopaliw emisja zanieczyszczeń zostanie zmniejszona, ponieważ biopaliwa są wytwarzane ze źródeł odnawialnych, takich jak oleje roślinne lub biomasa. Wyniki analizy pokazują, że zastosowanie mieszanki biopaliw w generatorze diesla prowadzi do znacznego zmniejszenia emisji szkodliwych substancji w porównaniu z wykorzystaniem tradycyjnych produktów ropopochodnych. Stwierdzono zmniejszenie emisji dwutlenku węgla i tlenków azotu, co przyczynia się do redukcji wpływu na zmiany klimatyczne i zanieczyszczenie powietrza. Ponadto odnotowano spadek emisji cząstek stałych, co przyczynia się do poprawy jakości powietrza i zdrowia ludzi.

Cel został osiągnięty poprzez zbadanie wpływu mieszanki oleju napędowego i biodiesla na wskaźniki techniczne, ekonomiczne i środowiskowe autonomicznego generatora diesla. Regulacja składu mieszanki paliwowej zapewniła zachowanie mocy generatora we wszystkich trybach jego pracy, przy jednoczesnym obniżeniu kosztów zakupu paliwa o 10% i zmniejszeniu zadymienia spalin nawet o 57%, w zależności od trybu pracy silnika wysokoprężnego.

Słowa kluczowe: emisje, efekt cieplarniany, ekologia, wytwarzanie energii