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ANALYSIS OF METHODS OF USING AMMONIA AS A FUEL FOR A MARINE INTERNAL COMBUSTION ENGINE

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The article considers ammonia as an alternative to modern fuels. A theoretical layout of an engine running on ammonia is presented. The article compares ammonia with other alternative fuels, compares ammonia prices with diesel and heavy fuels, analyzes emissions of harmful substances at different stages of ammonia use - production, transportation and combustion on a ship.
The novelty of this article is that ammonia is often not considered as an alternative to traditional fuels, competing with hydrogen and natural gas. However, it has a number of advantages, both environmental and technical and economic. The article also discusses 3 methods for converting marine engines to ammonia, 2 of which are applicable to ships already in operation. Comparison of prices for ammonia with other fuels has been made.
The use of ammonia makes it possible to reduce the emission of harmful substances into the atmosphere, which is economically justified. The methods of switching to it and increasing the efficiency of the engine are considered. There are no CO2 and SOx emissions and NOx is greatly reduced. Ammonia is cheaper than HFO and DO, as well as H2 and LNG. Transferring a marine engine to ammonia is possible by increasing the compression ratio, using forced ignition, and also using it in conjunction with the additives listed in the article.
Keywords: CO2, SOx, NOx, efficiency, production, transportation and storage, corrosion, combustion, engine layout.

АНАЛИЗ МЕТОДОВ ИСПОЛЬЗОВАНИЯ АММИАКА В КАЧЕСТВЕ ТОПЛИВА ДЛЯ МОРСКОГО ДВИГАТЕЛЯ ВНУТРЕННЕГО СГОРАНИЯ

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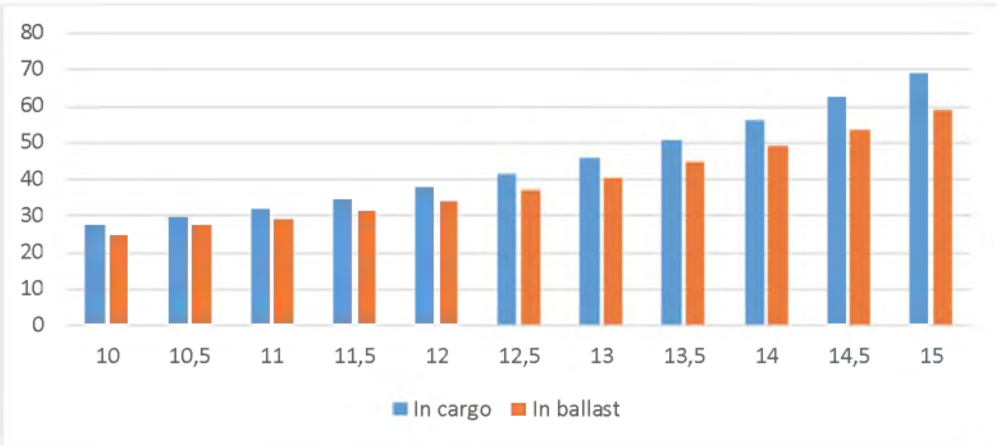
В статье рассматривается аммиак как альтернатива современным видам топлива. Представлена теоретическая компоновка двигателя, работающего на аммиаке. В статье сравнивают аммиак с другими аль-

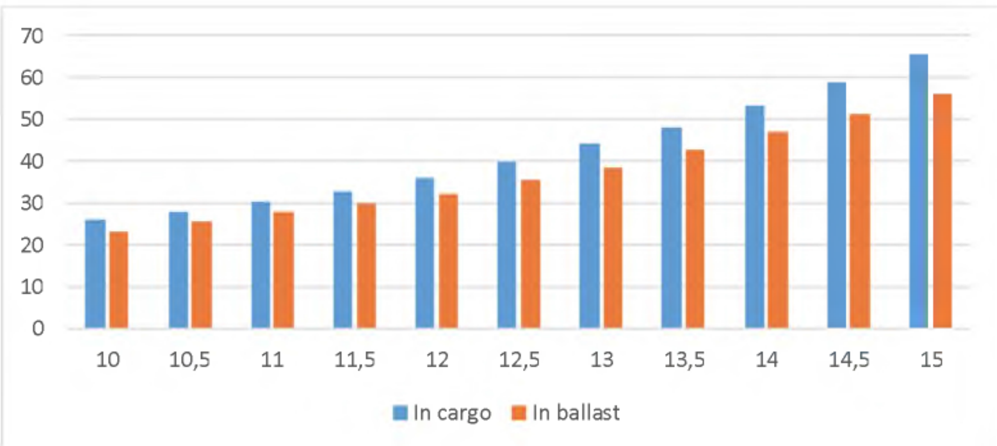
тернативными видами топлива, сравниваются цены на аммиак с дизельным и тяжелым топливом, анализируются выбросы вредных веществ на различных стадиях использования аммиака - производстве, транспортировке и сжигании на судне.
Новизна этой статьи заключается в том, что аммиак часто не рассматривается в качестве альтернативы традиционным видам топлива, конкурируя с водородом и природным газом. Однако она имеет ряд преимуществ, как познавательных, так и технических, и экономических. В статье также рассматриваются 3 способа преобразования морских двигателей в аммиак, 2 из которых применимы к уже эксплуатируемым судам. Проведено сопоставление цен на аммиак с другими видами топлива.
Использование аммиака дает возможность снизить выброс вредных веществ в атмосферу, что экономически оправдано. Рассмотрены методы перехода на него и повышения КПД двигателя. Отсутствуют выбросы CO2 и SOx, а NOx значительно сокращается. Аммиак дешевле, чем HFO и DO, а также H2 и LNG. Перевод судового двигателя на аммиак возможен за счет увеличения степени сжатия, использования принудительного зажигания, а также использования его в сочетании с присадками, перечисленными в статье.
Ключевые слова: CO2, SOx, NOx, эффективность, производство, транспортировка и хранение, коррозия, сгорание, компоновка двигателя.

To reduce CO_2 emissions from marine internal combustion engines

Today, the solution of the issue of ecology occupies one of the most important places along with issues of safety and efficiency. The shipping industry emits huge amounts of CO2 every year by burning huge amounts of fuel. SCF imposes on its vessels the following daily requirements for fuel consumption per day, depending on the speed [1, 9, 10, 11].



Graph 1 – Fuel consumption (MT) versus speed (knot) for HFO



Graph 2 – Fuel consumption (MT) versus speed (knot) for MDO

Based on the "Paris Agreement" adopted in 2015, it can be concluded that in the near future the world community will strive to reduce emissions to a minimum level [2]. As you might guess, this will lead to changes in the design of modern diesel engines.

Suggestion: Use ammonia as a fuel

Our proposal for solving this problem is the use of ammonia as an alternative type of fuel. This solution is both economical and environmentally friendly, and therefore has great prospects.

Why ammonia?

1) does not have CO2 in the composition of its combustion products

Compared to other types of fuel, ammonia has a number of advantages. So, for example, during the combustion of NH3, CO2 cannot be obtained.

2) Does not require major changes in the design of modern ships

The process of combustion of ammonia in two-stroke engines with a high compression ratio is similar to the combustion of modern types of fuels. This suggests that there will be no major changes in the design during the production of engines on ammonia.

3) Easy to transport compared to alternative substitutes

Compared to hydrogen and natural gas, ammonia liquefies at lower pressures and temperatures. This makes it easier to store and transport

Table 1 – Pressures and temperatures of liquefaction of different types of fuel

Type of fuel	Pressure (bar)	Temperature (°C)
LNG	250	-160
Hydrogen	700	-253
Ammonia	8.5	-36

4) Already has industrial production

Ammonia is already produced commercially in the fertilizer industry. From this it follows that in most ports there will be no problems with bunkering. In addition, mankind has already developed tanks that can store this gas in liquefied form.

Question research:

The prospect of using ammonia as one of the alternative fuels is due to: availability, cost-effectiveness and an extensive resource base.

Availability is due to ease of manufacture. Today, ammonia is produced on a large scale by the chemical industry from hydrogen and nitrogen. Hydrogen is taken from water, nitrogen from air.

This fuel is economical, at least because its price at the time of 2021 is lower than that of other common types of marine fuels [3, 12, 13, 14]. These data are shown in Table 2.

Table 2 – Price of different types of fuel.

Type of fuel	cost per mt
VLSFO	535 $
ULSFO	600 $
MDO	648 $
LNG	518 $
NH3	450 $

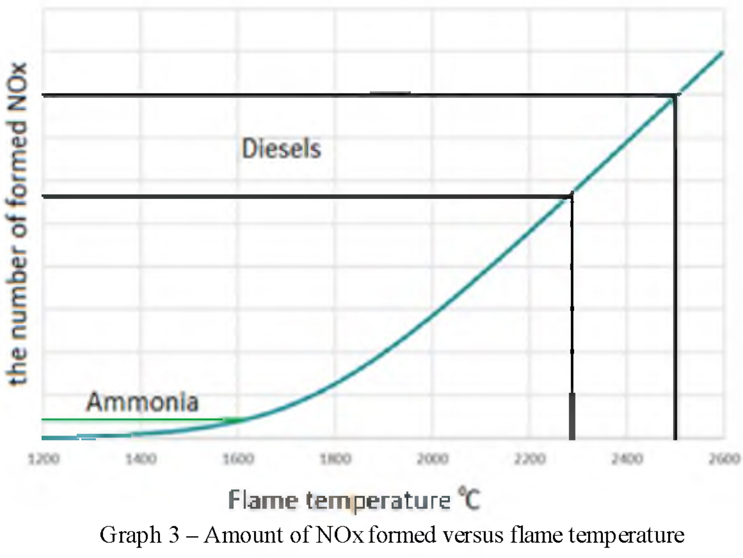
The vast resource base is characterized by the fact that in theory it is unlimited. The materials from which ammonia is produced are products of its combustion. Thus, ammonia is an inexhaustible type of fuel.

Emissions: NOx SOx CO2

Consider the combustion products of ammonia. Let's write the formula:

$$4NH_3 + 3O2 = 2N_2 + 6H_2O$$

As can be seen, the reaction is completely free of CO2, which already satisfies the Paris Agreement. Sulfur is also absent, which means that the formation of SOx is zero. The only harmful substances are nitrogen oxides NOx. However, the combustion temperature of ammonia is much lower than that of HFO and MDO. Consider the graph of the formation of nitrogen oxides on the temperature of the flame (graph 3):



Graph 3 – Amount of NOx formed versus flame temperature

The "Diesel" region corresponds to the volume that is valid for modern SHWs [4, 15, 16, 17]. The temperature of the Ammonia flame is about 1650 C°. It follows that NOx emissions are significantly lower than those of modern fuel types.

Production

As noted above, for the production of ammonia, it is necessary to combine hydrogen, which is obtained by the hydrolysis of water, and nitrogen contained in the air. This method is called chemical.

But there is another way. Ammonia is used in the agricultural industry, for the manufacture of substitutes for natural fertilizers. Natural fertilizers, in turn, also contain ammonia. Therefore, it is possible to extract this fuel directly from them.

The second method is very advantageous for ships carrying livestock. For obvious reasons, they have no problems with natural fertilizers.

Transportation storage

The most optimal storage of ammonia is possible in tanks located on the main deck of the vessel, which has already been well implemented by SCF in the new line of "green" tankers. This solution is the best, since its implementation does not require large investments and major changes in the design of the tanker.

Figure 1 – LNG placement method

Schematic diagram and equipment for the operation of a ship power plant on ammonia fuel [5].

1) Preparation of fuel gas for combustion is carried out in the gas line (Fig. 2).

2) Then the fuel gas enters the mixer (Fig. 3), where it is mixed in the required proportions with air, while its pressure is equal to atmospheric

3) With the help of a throttle valve (Fig. 4) with an electric drive, the gas-air mixture entering the engine is dosed.

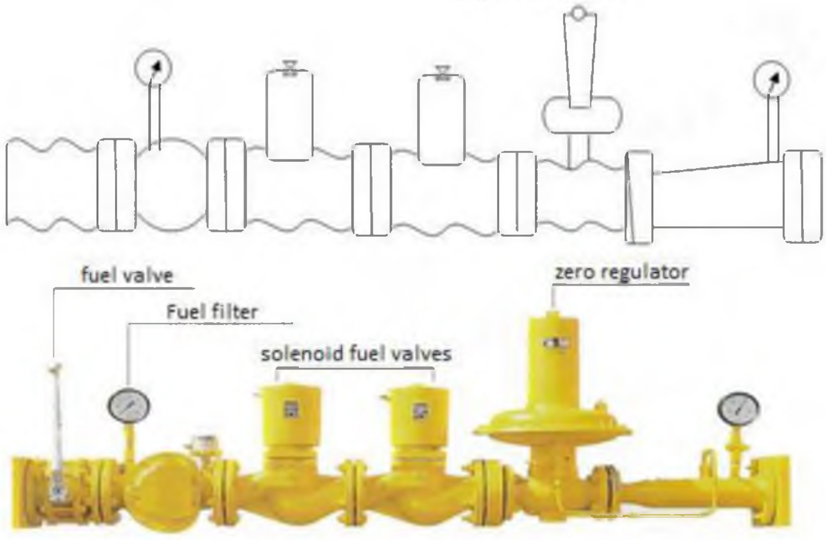


Figure 2 – Gas ruler

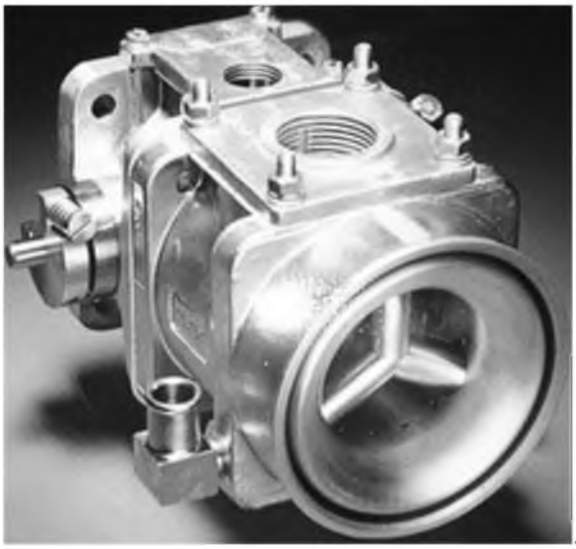


Figure 3 – Mixer

Figure 4 – Throttle

Speed and spark control is performed by the gas engine management system. This system performs the functions of an engine alarm, opens and closes the fuel solenoid valve at the right time when starting and stopping the engine.

How to deal with corrosion: in storage, in pumping, in the engine

Ammonia, unlike modern fuels, has alkaline properties. For this reason, many non-ferrous metals suffer from severe corrosion. However, steel, cast iron and aluminum are less susceptible to this type of wear. But this is not a problem for marine engines, since they are made from these materials.

In addition, due to the absence of sulfur in ammonia, there can be no sulfur corrosion in the cylinder-piston group. Accordingly, there is no need for expensive cylinder oils. So in two-stroke engines, you can use ordinary oil from the circulating lubrication system.

Combustion process

Liquefied ammonia has a moderate energy intensity. Its heat of combustion is 17.13 MJ/kg or $11.64*10^3$ MJ/m^3. This makes it less energy intensive than gasoline, methanol and hydrogen by 2.5, 1.1 and 7 times, respectively. However, its density is higher than that of hydrogen, which makes it easier to transport. In addition, it has a higher octane rating than hydrogen, so it is more resistant to detonation. Its octane number is approximately equal to 111 units. This allows us to use higher compression ratios, greatly improving the overall efficiency of the engine without the detrimental effects of detonation.

The first way is to increase the compression ratio

Despite a number of advantages, ammonia in a modern marine engine will not burn. The auto-ignition temperature of ammonia is 650°C. This is much higher than HFO, MDO and LNG. Accordingly, we need to solve the issue of supplying additional activation energy to the working fluid at the moment of ignition.

So, for the use of ammonia on a marine diesel engine, we offer 3 ways. The first is to increase the compression ratio.

This method will provide stable combustion of ammonia at compression ratios up to 35 units. This will increase the thermal efficiency of the engine.

$$\eta_t = 1 - \frac{1}{\varepsilon^{k-1}}$$

However, this method is not beneficial in relation to modern ships, when they are modernized.

Their degree of compression is already determined by the design, the change of which is quite expensive.

The second way is to use forced ignition

Changing the compression ratio is not required, however, it is necessary to add a spark plug to the engine design. This candle should create a spark with a high temperature. This method is already more profitable in terms of modernization, since installing candles is easier and more feasible than changing the compression ratio.

The third way is to add additives to ammonia. If, together with ammonia, hydrogen or acetylene is also injected. This will allow the ammonia to spontaneously ignite at the current compression ratio. However, in addition to ammonia, these additional components will also need to be transported, albeit in smaller quantities, because. stable combustion of ammonia requires only 6–10% hydrogen and 15–20% acetylene [6]. Also, this method can be implemented using diesel fuel. At the same time, the issue of bunkering will be completely resolved, however, it will not be possible to completely get rid of CO2 emissions, but we will significantly reduce them.

The third method is used on dual-fuel engines running on LNG using MDO as a filler fuel.

Scheme of an engine running on ammonia.

MAN B&W offers the following fuel system arrangement [7]:

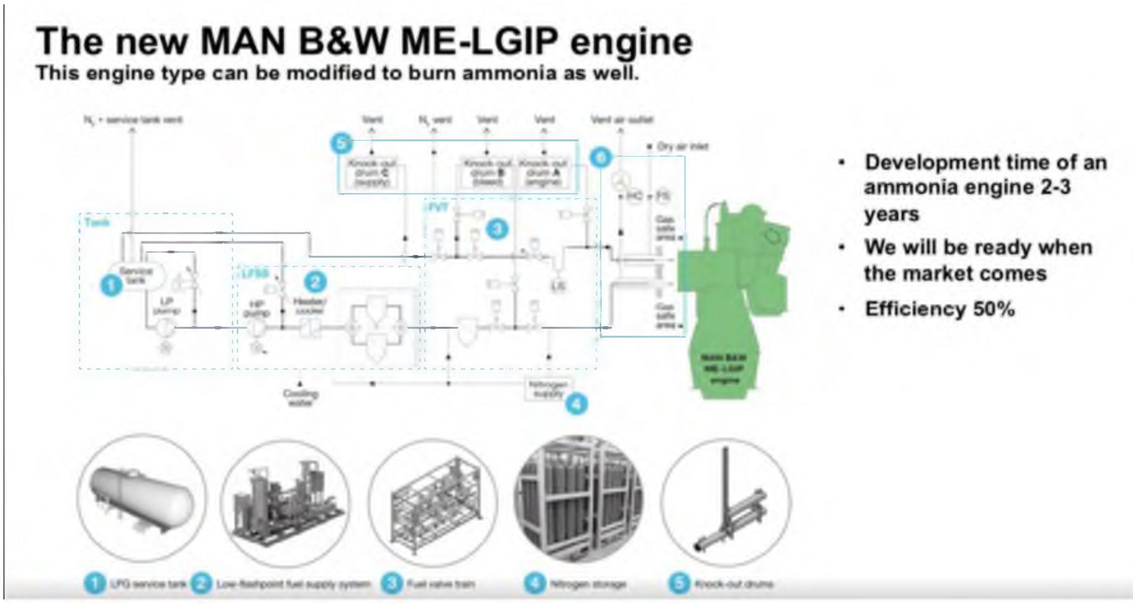


Figure 5 – Schematic of the B&W fuel system

Inert gas system

The use of Ammonia reduces CO2 emissions. This means that carbon dioxide will not be produced in sufficient quantities to fill the cargo tanks. But at the same time, we can use nitrogen, which is a combustion product of NO3, but it will need to be separated from the water using a dehumidifier.

Conclusion: what can be done

Ammonia is very promising as an alternative fuel. Its advantages include environmental friendliness due to the reduction of NOx emissions and the complete absence of SOx and CO2 emissions.

The transition to it is possible using the three methods described above, 2 of which can be applied to old ships by upgrading their power plants. This will allow them to continue to be used without being written off due to the upcoming tightening of CO2 emissions requirements.

Ammonia increases the efficiency of the engine due to the possibility of increasing the compression ratio, due to the high octane number.

Ammonia is cheap compared to modern fuels used on ships today.

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