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FEATURES OF LNG VAPOR TREATMENT ON A GAS CARRIER

The article considers the use of liquefied natural gas (LNG) as a fuel for low-speed marine engines. The environmental aspect of the transition to LNG use is crucial when choosing a specific way to comply with the requirements of MARPOL 73/78. The result of the operation of an internal combustion engine on natural gas is low emissions of exhaust gases into the environment due to the absence of pollutants in the fuel. Methane, the main component of natural gas, is a highly efficient hydrocarbon fuel. In addition to environmental aspects in this case are very important and economic. The number of gas vessels in the world will reach about 200 units, and the consumption of LNG as fuel in ship power plants will increase rapidly. The transition to gas fuel on ships reduces operating costs due to low gas costs, lower maintenance costs. To date, two technologies for the use of PGI have been implemented. Gas supply at high pressure is carried out at the position of the piston near the top dead centre (BMT) and is implemented in MAN B & W engines of the ME-GI series. That low-pressure gas supply technology is based on the combustion of depleted gas-air mixtures and is implemented in Winterthur Gas & Diesel Ltd (WinGD) DF and RT-flexDF engines. Existing technologies for the use of natural gas in marine low-speed engines are fundamentally different. In terms of dynamic and powerful indicators has obvious advantages of high-pressure gas supply technology. However, environmentally friendly performance, capital investment and operating costs are much better in engines with low gas supply pressure. The technology of combustion of gas fuel in the DG does not affect the choice of LNG storage tanks but fundamentally determines the fuel preparation system. Various designs are used to store liquefied gases tanks. For engines with low gas supply pressure enough centrifugal cryogenic pump, and low-pressure evaporator, whereas for the engine with high pressure requires a high-pressure pump (HPP) plunger type and suitable evaporator. It is necessary to find the most efficient and economical options treatment of excess LNG generated when the vessel is parked, which cannot be used as fuel in marine boilers and engines internal combustion.

Key words: *liquefied, natural gas, ecological aspect, membrane tanks, exhaust gases, ship systems, naturally evaporated gas (NEG). Gas combustion unit (GCU).*

Introduction. The use of liquefied natural gas (LNG) as a fuel for the main ship's engines, as well as for the production of electricity to meet the needs of ships during berthing in ports can curb the growth of pollution and comply with strict environmental restrictions. The environmental aspect of the transition to LNG use is crucial when choosing a specific way to comply with the requirements of MARPOL 73/78. The economic advantages of liquefied gas allow to recoup in a reasonable time the cost of adapting the vessel to work on LNG, technological equipment and the cost of bunkering.

According to the latest data, by 2019 the number of gas vessels in the world will reach about 200 units, and the consumption of LNG as fuel in ship power plants will reach 1 million tons by 2020 and will increase rapidly to 8.5 million tons of 2025.

The result of the operation of an internal combustion engine on natural gas is low emissions of exhaust gases into the environment due to the absence of pollutants in the fuel. Methane, the main component of natural gas, is a highly efficient hydrocarbon fuel. Thus, in the mode of operation of the engine on gas CO_2 emissions are reduced by 20% in comparison with the operation of the engine on residual grades of fuel. Accordingly, NO_x emissions are reduced by 85–90%, while SO_x emissions are virtually eliminated. Moreover, there is no visible smoke, sludge, lead emissions, benzene emissions are reduced by 97%.

In addition to environmental aspects in this case are very important and economic. The transition to gas fuel on ships provides a reduction in operating costs due to low gas costs, lower maintenance costs, etc.

The power plant of a dual-fuel container ship

Today, two gas combustion technologies have been implemented fuels in marine low-speed engines, which are conveniently classified by gas supply pressure to the cylinder [1].

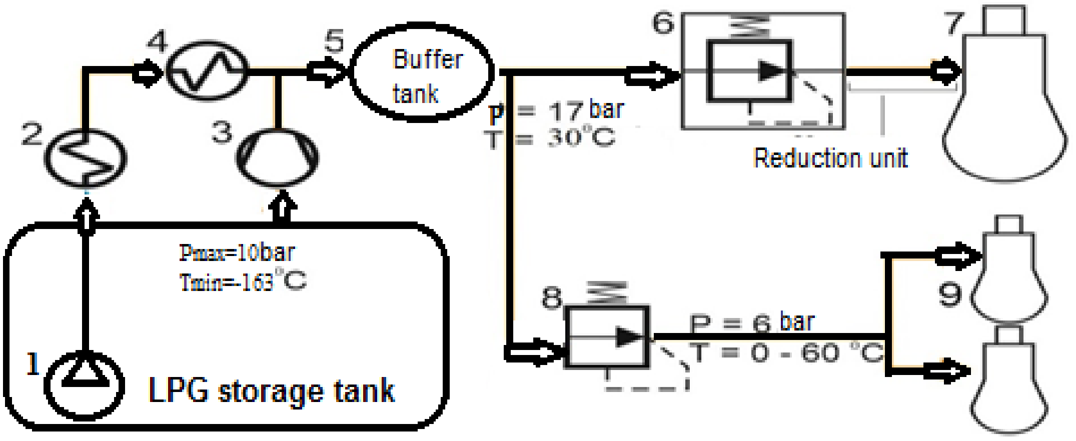

Fig. 1. Schematic gas supply diagram to the WinGD-DF engine

1 – pump; 2 – evaporator; 3 – compressor; 4 – heater; 5 – buffer tank; 6 –Gas valve unit (GVU); 7 – main engine; 8 – pressure reduction valve; 9 – auxiliary engines

Gas supply at high pressure is carried out at the position of the piston near the top dead centre (TDC) and implemented in MAN B&W ME-GI series. Low-pressure gas supply technology is based on combustion of depleted gas-air mixtures and implemented in engines Winterthur Gas & Diesel Ltd (WinGD) DF and RT-flexDF.

An important feature of WinGD engines is that they run on depleted gas mixtures, the air in the cylinder is oriented twice as much than required for complete combustion, so a lot of heat is spent to heat the air, which contributes to a significant reduction in peak values combustion temperatures and a sharp decrease in NO_x formation. Efficiency increases engine and power, at the same time the detonation disappears. The excess ratio of the air is maintained in the range of 2.0–2.2.

Before the engine the gas is filtered, the pressure in the pipeline is regulated in depending on the engine load (8 kg/cm^2 at full load). Next, the gas is directed to the main inlet valve installed in the cylinder head. Control pulses to the valves are supplied electronically the control unit, which in turn receives information from the sensors speed, load, pressure and temperature of the charge air and the sensor combustion control in each cylinder [1].

From the LNG storage tank with a multistage centrifugal pump regulated LNG capacity is fed to the evaporator, where it completely evaporates. After the evaporator, the gas enters the heater, in which the temperature rises to 30° C. From the heater, the gas enters the buffer tank. Stabilization of gas pressure in the LNG tank occurs with the help selection of “warm” vapors by the compressor. From the buffer tank that plays a role battery, gas at a temperature of 30° C and a pressure of 18 bar is supplied to the GVU main engine. Gas enters the fuel system of auxiliary engines through a pressure reduction valve, which reduces the pressure to 6 bar. GVU regulates the gas pressure in gas-fuel ramp depending on engine load [1]. The combustion process in a low-pressure gas engine is characterized uniform temperature distribution in the short circuit, resulting in the number produced NOx does not exceed 4 g / (kW * year), which completely meets the requirements of the third stage of the Program VI of the MARPOL 73/78 Convention [1].

In MAN B&W ME-GI series, a gas supplied to the cylinders under high pressure. This engine uses the idea of achievement required pressure due to LNG compression and then gasification [3] (Fig. 2). Compression of LNG to the required pressure occurs in the three-plunger high-pressure pumps (HPP). Liquefied natural gas is supplied to the HPP by the feed pump. In this case, the LNG from the gas tank is fed into the evaporator low-capacity high-pressure compressor. Flow and pressure in the system regulated by the speed of the pump from the drive motor that allows reaching necessary pressure at variable loading of GD. Although the flow rate changes, the pressure in the system is maintained constant by the means of a rather difficult system of regulation [8].

Gas supply to the engine is carried out through two separate gas injectors, located in the cylinder head. To achieve a critical pressure drop on the gas nozzle and in the combustion chamber, the pressure in the gas pipeline should be 150–300 kgf/cm^2 (depending on the load). The temperature of the end of the cycle compression is 500–600° C, which is insufficient for reliable inflammation methane, given its high auto-ignition temperature (600° C), therefore a small dose

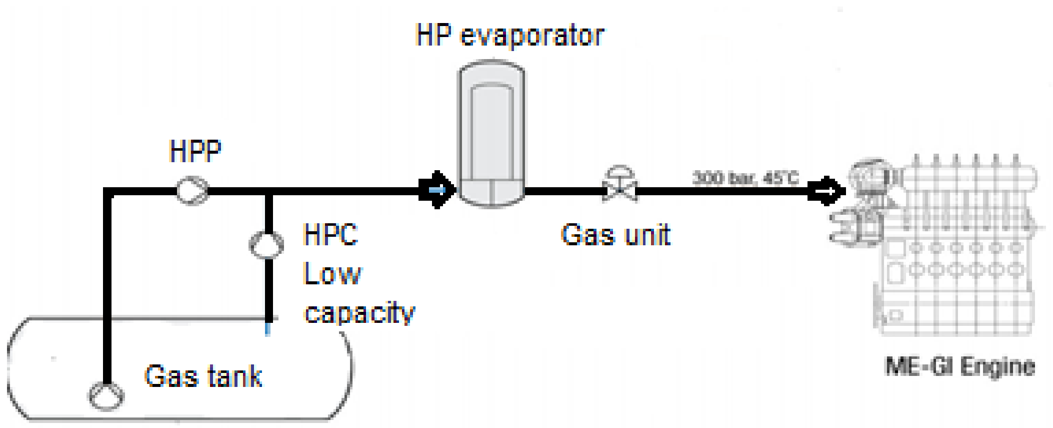

Fig. 2. General schematic gas preparation and supply diagram for MAN B&W ME-GI

of flammable fuel is supplied before the gas fuel is supplied [3].

The intake of engines with high gas supply pressure is comparable to diesels running on liquid fuel, given more widely allowable range of excess air ratio.

The technology of combustion of gas fuel in the DG does not affect the choice of LNG storage tanks but fundamentally determines the fuel preparation system. For engines with low gas supply pressure enough centrifugal cryogenic pump, and low-pressure evaporator, whereas for the engine with high pressure requires a high-pressure pump (HPP) plunger type and suitable evaporator [1].

The advantage of a low-pressure gas supply system, in this case, is at lower energy costs for LNG vapor compression, while for engines with high gas supply pressure require a multistage high-pressure pump [1].

In the process of combustion of gas in the engine with high supply pressure in the short circuit, there are local high-temperature zones where the reaction takes place NO_x formation. NO_x emissions correspond to stage II only Program VI MARPOL, and for compliance with the III stage requires further exhaust gas purification by selective catalytic neutralization [1].

Analysis of possible options for the selection of LNG storage tanks. Though the use of LNG as a fuel in marine power plants has many advantages and disadvantages. LNG storage tanks take 3-4 ship space than conventional fuel tanks. So free cargo space is becoming one of the main issues to discuss. Increasing the duration of the planned flight necessitates an increase of volume of LNG tanks [10]. Therefore, one of the main goals in the design ships – to optimize the size of stock tanks depending on the free space [9].

Various designs are used to store liquefied gases tanks. This takes into account such parameters as:

–maximum working pressure;

–maximum LNG temperature;

–tank configuration;

–material used in tank construction [9].

Today, there are several possible options for installing tanks stock of LNG carriers [9]. The use of such tanks is permissible in accordance with IMO requirements. Such tanks include independent tanks of type A, B and C, as well as membrane tanks [8].

Membrane tanks are not self-supporting, consist of a thin membrane, laid on insulation. The insulation is located directly on the hull so that the pressure in the tank is directly transmitted to the structure housing. The hull is the main supporting element of such tanks. Membrane tank is designed so that thermal and other types of expansion or compression was compensated without its excessive stress [8]. Calculated the vapor pressure P in such tanks should not exceed 0.07 MPa [6]. For this type of tank requires a secondary barrier.

Independent tanks – self-supporting, are not part of the hull and do not participate in ensuring the overall strength of the case. Such tanks are attached to the hull only through special calipers, allowing them to compress and expand independently of the hull. LNG is stored in storage tanks in the form of cryogenic tanks without any means of external cooling. So, a significant part of the LNG volume evaporates during the flight [4]. This evaporated gas commonly referred to as naturally evaporated gas (NEG). Formed NEG can be used as fuel.

Although when installing type C tanks much more used useful space on ships, this option remains the most attractive in terms of financial savings that it is necessary to spend on the utilization of NEG from more compact membrane tanks.

For example, in a cylindrical tank type C with a volume of 200 m^3 with working pressure from 0.6 bar to 4 bar and with elastic polyurethane foam in quality of insulation with a thickness of 200 mm – the maximum allowable pressure in the tank will be achieved after about 25 days [9].

Thus, for ships with a small deadweight – optimal option is to install type C tanks, which are available on the market in different volumes with a maximum allowable operating pressure of up to 10 bar [9]. They are the most attractive for use on ships with low gas consumption, or on those that frequently call at ports where it is possible to bunker the vessel. Type C tanks are already used on many ferries and offshore vessels [9].

However, for large vessels, it is advisable to use membrane tanks due to the fact that the installation of such tanks is more profitable in terms of optimal use of free space.

An example of such vessels can be built on Chinese shipyards 9 container vessels, SMA SGM with a capacity of 22,000 containers. It is reported that these vehicles will go between Europe and the Far East with bunkering in European countries. It is planned that the capacity of cargo tanks will reach 18,600 m^3. Capacity such stock tanks can be correlated with a small capacity gas carrier. Thus, it is obvious that it is advisable to use only tanks membrane type.

Recent orders for large ships using as LNG fuels show a significant increase in demand and demand for more advanced and efficient technological solutions for LNG processing that formed by the inevitable transfer of heat through cryogenic insulation the tank [11].

NEG processing methods

LNG is stored in storage tanks at a pressure close to atmospheric and a temperature of -163 – -159° C [2]. The most acceptable option for large container vessels with a dual-fuel installation is the use of membrane tanks. So, for example, on the mentioned container vessels on 22 000 containers, GTT designs membrane LNG fuel tanks, type Mark III, which will allow the most efficient use of cargo space on these vessels. Such tanks are designed for a working overpressure of 7 kPa. At 25 kPa the safety valve works [2]. The company CMA CGM states that on the mentioned construction 12-cylinder, two-stroke internal combustion engines will be installed in container vessels WinGD 12X92DF with a piston D=92 cm and low-pressure gas supply system. Maximum power will be reached 63,840 kW at 80 rpm. The volume of LNG tanks will be 18,600 m^3. It is planned that the container ship will operate on the line Europe – the Far East with one-time bunkering in Europe. Obviously, the running of operating modes of the vessel formed by the LNG will be completely ignited in cylinders of the main engine. However, suppose LNG tanks fully filled and the vessel is at anchor or drifting. In this case, the power consumption of the vessel will be much lower and the entire LNG will be impossible to dispose of in diesel generators or boilers. To estimate the quantity excess LNG can calculate the imbalance between the required heat combustion and heat of NEG.

The required amount of heat is proportional to the power and specific consumption gas fuel at a certain engine load

$$Q_{необ} = N_e \cdot g_e \cdot 24$$

Power varies depending on the mode of operation of the vessel. Power, consuming a container ship in the parking lot depends on the number of consumers, necessary to secure the vessel. Suppose for a future flight the ship was not scheduled to carry refrigerated containers. Then the power consumption of such a container ship is approximately 500 kW.

$$Q_{необ} = \frac{500kwt \cdot 7091 \frac{kJ}{kwt/h} \cdot 24}{1000} = 85092 \frac{MJ}{day}$$

The amount of heat of NEG is characterized as the daily volume of evaporated cargo and its calorific value. The amount of NEG heat is possible to calculate by the formula:

$$Q_{ПВГ} = e \cdot V \cdot l \cdot \rho \cdot H$$

Where: e – is the daily evaporation coefficient of LNG; V – a volume of cargo tanks; l – tank filling factor; ρ – is the density of LNG; H – is the mass lower heat gas combustion. Manufacturers of cargo systems claim that the daily cargo evaporation coefficient for membrane tanks of cargo systems Mark III is equal to 0.0015. Also, assume that the cargo pair will contain only methane. Then the mass lower heat of combustion will be 50,041 MJ / kg [1].

So:

$$Q_{ПВГ} = 0{,}0015 day^{-1} \blacksquare 18600 м^3 \blacksquare 0{,}98 \blacksquare 459{,}4 \frac{kg}{м^3} \blacksquare$$

$$\blacksquare 50{,}041 \frac{MJ}{kg} = 628560{,}73$$

The imbalance of evaporated and the required amount of heat will be equal to their differences

$$\Delta Q = Q_{ПВГ} - Q_{необ}$$

$$\mathit{\Delta} Q = 628560 - 85092 = 543468 \frac{MJ}{day}$$

Necessary to re-liquefy LNG in different re-liquefaction plants.

To date, several types are used for processing NEG gas re-liquefaction plants. The most common are installations running on the Brighton cycle, produced by several manufacturers in a different layout.

However, the use of installations that operate on a cycle Brighton is impractical with a small daily volume of LNG.

Cyclic natural gas liquefaction systems Brighton have a dual-circuit system with a common heat exchanger. How working fluid they use N_2 (nitrogen).

The gas is compressed isothermally in a three-stage compressor with an intermediate cooling (Fig. 3). Then the gas passes through the heat exchanger at constant pressure in which energy is exchanged with the waste stream low pressure. From point 3 to point 4 is an isoentropic expansion in the expander. From point 4 to point 1, the cold gas is heated to initial temperature, removing energy at constant pressure from high-pressure inlet flow [5].

Mini LNG can be an alternative to such settings installations operating on the principle of mixed cooling. Such installations were developed and tested in laboratories scientifically – Sintef Research Institute in Trondheim. At the moment they are being installed on small vessels – gas carriers, such as the company's gas carrier I.M. Skaugen SE with a capacity of LNG of 20 tons/day. In installations of this type of LNG compressed in the compressor to 18 bar, cooled by seawater and propylene to a temperature of -35° C in the pre-cooling circuit in special heat exchangers. The gas is then liquefied and supercooled in the mixed cooling circuit. Then the supercooled liquid throttles to the required pressure [13].

Installations of this type are produced by many companies productivity from 5 to 50 tons of LNG per day. Average energy consumption in such installations is equal to 0.47 kW / kg of LNG. Another alternative to the liquefaction setting may be the installation of StirLNG that operates on the reverse Stirling cycle based on compression and expansion of helium in a closed cycle.

For a clear explanation, the process can be divided into 4 main ones the position of the piston shown in Fig. 3. In position 1, helium is in space D at ambient temperature. In position 2 this the gas is compressed by the piston B with a subsequent increase in temperature to 80° C. When the plunger C moves down from position 2 to position 3, the gas is displaced from space D into space E, passing through the cooler H with further heat transfer of cooling water and lowering the temperature gas up to 15° C. Next, helium passes through the regenerator G into the space EV the regenerator gas is cooled almost to the liquefaction temperature. During the last and main action of the gas expands with the movement of the plunger and piston provision 4.

In the process of expanding the necessary refrigeration capacity is created, liquefied methane in heat exchanger J. To start a new cycle, the plunger moves to position 1, returning helium to space D.

For the first time on ships, the StirLNG installation will be used on bunkering vessel with a volume of cargo tanks of 2200 m^3 in the company's project Tote. This vessel will be equipped with 6 StirLNGs with a capacity of 900 kg/day and power consumption of 38 kW each.

Conclusions. Taking into account modern environmental requirements and constant growth prices for residual fuels, Propulsive complex with two-stroke gas diesel is another evolutionary solution.

Existing technologies for the use of natural gas in marine low-speed engines are fundamentally different. In terms of dynamic and powerful indicators has obvious advantages of high-pressure gas supply

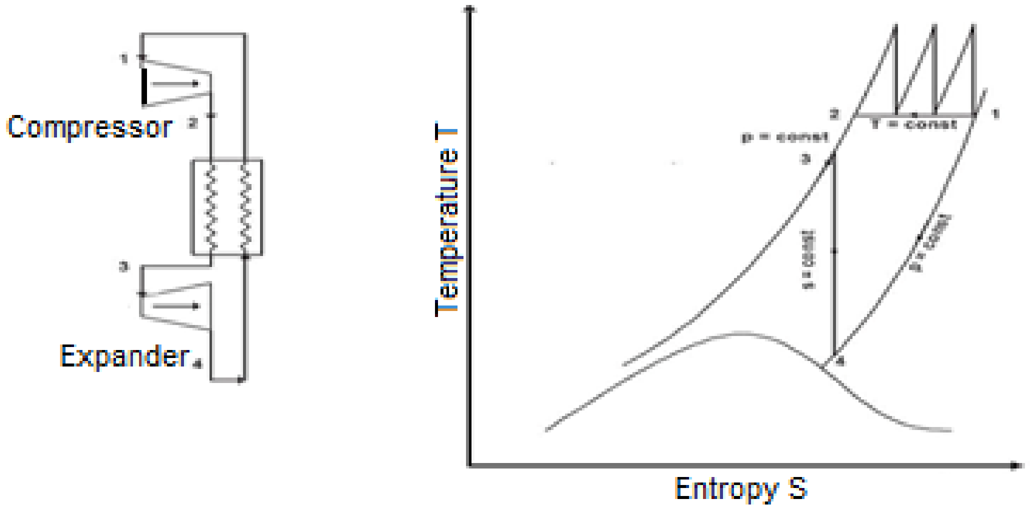

Fig. 3. Brighton reverse cycle

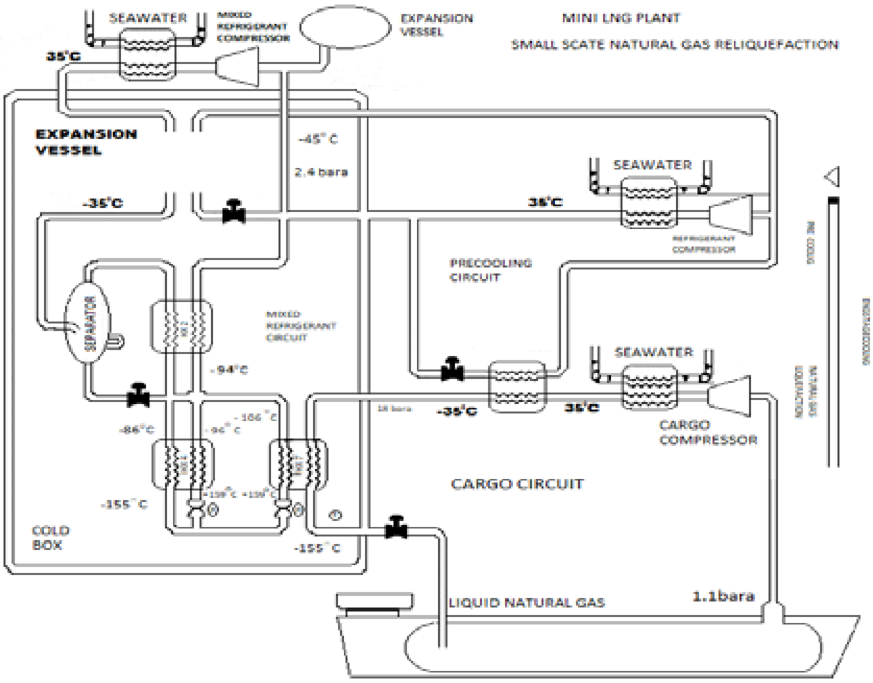

Fig. 4. Plant Sintef`s institute

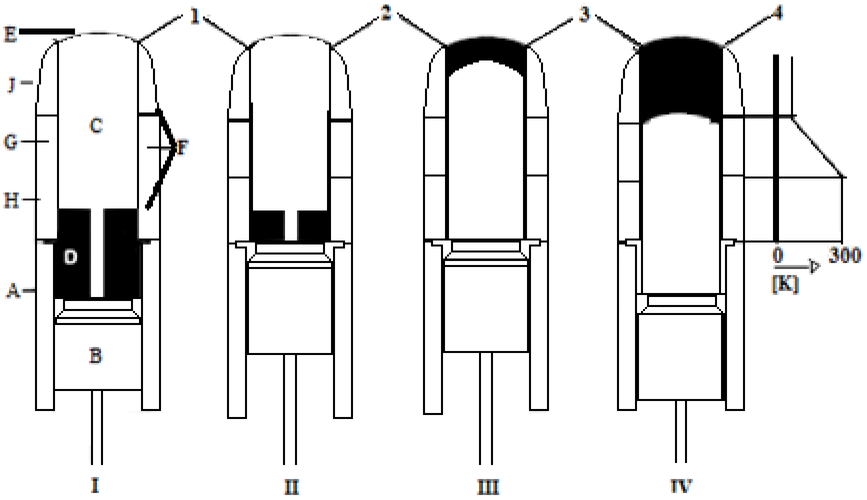

Fig. 5. StirLNG plant

technology. However, environmentally friendly performance, capital investment and operating costs are much better in engines with low gas supply pressure.

For small ships – the best option is to install tanks type C, which does not require additional installations for the processing of LNG. While, as for large ships, the most attractive option would be to install tanks stock membrane type, allowing the most efficient use of the cargo space of the vessel.

It is necessary to find the most efficient and economical options treatment of excess LNG generated when the vessel is parked, which cannot be used as fuel in marine boilers and engines internal combustion.

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Козьміних М.А., Задорожний В.А. ОСОБЛИВОСТІ ВИКОРИСТАННЯ ЗРІДЖЕНОГО ПРИРОДНОГО ГАЗУ НА ГАЗОВОЗІ

У статті розглядається використання зрідженого природного газу (ЗПГ) як палива в судових малообертових двигунах. Екологічний аспект переходу на використання ЗПГ є визначальним при виборі конкретного шляху виконання вимог конвенції МАРПОЛ 73/78. Результатом роботи двигуна внутрішнього згорання на природному газі є низькі викиди вихлопних газів у навколишнє середовище через відсутність у паливі забруднювачів. Метан, головний компонент природного газу, є високоефективним вуглеводневим паливом. Крім екологічних аспектів, у цьому випадку дуже важливі і економічні. За останніми даними, до 2019 року кількість судів газоходів у світі досягне приблизно 200 одиниць, а споживання ЗПГ як палива в суднових енергетичних установках досягне 1 мільйона тонн до 2020 року і стрімко зростає. Перехід на газове паливо на суднах забезпечує зниження експлуатаційних витрат за рахунок низької вартості газу, менших витрат на технічне обслуговування.

Нині реалізовані дві технології використання ЗПГ. Подача газу при високому тиску здійснюється при положенні поршня поблизу верхньої мертвої точки (ВМТ) і реалізована у двигунах MAN B & W серії ME-GI. Та технологія подачі газу при низькому тиску заснована на спалюванні збіднених газоповітряних сумішей і реалізована в двигунах Winterthur Gas & Diesel Ltd (WinGD) DF і RT-flexDF. Сучасні технології використання природного газу в суднових малообертових двигунах принципово різні. З позиції динамічних і потужних показників очевидними перевагами володіє технологія подачі газу під високим тиском. Однак екологічні характеристики, капіталовкладення та експлуатаційні витрати значно кращі у двигунів із низьким тиском подачі газу. Технологія спалювання газового палива в ГД не впливає на вибір танків запасу ЗПГ, проте принципово визначає систему паливопідготовки.

Можливі різноманітні варіанти вибору конструкції танків запасу ЗПГ залежно від типу та характеристик судна. Для двигунів із низьким тиском подачі газу досить відцентрового кріогенного насоса і випарника низького тиску, тоді як для двигуна з високим тиском необхідний насос високого тиску (НВТ) плунжерного типу і відповідний випарник. Необхідний пошук найбільш ефективних і економічних варіантів обробки надлишкового ПВГ, що утворюється в процесі стоянки судна, який неможливо використовувати як палива в суднових котлах і двигунах внутрішнього згоряння.

Ключові слова: *зріджений природній газ, екологічний аспект, мембранні танки, вихлопні гази, суднові системи, природньо випаруваний газ (ПВГ), газовий топочний агрегат (ГТА).*