Building the Method for Calculation of Heating System Applied to High-Kinematic Viscosity Fuels

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Abstract—Environmental pollution in transportation is very serious. Finding alternative fuels is becoming increasingly urgent in order to minimize environmental pollution and diversify fuel sources for marine engines. In alternative fuels, bio-oils are considered as a potential fuel. The paper presents theoretical findings on application of exhaust energy for heating up biodiesel/bio-oil used in ship engines in order to raise the fuel's viscosity and to improve the volatizing and mixing abilities with ambient air. This fuel heating system is designed basing on the energy balance between the required energy to raise the fuel temperature to the target one and the energy either directly obtained from the exhaust gas or gained from intermediate medium. Results of this study are potentials to direct the design and fabrication of this bio-fuels heating system for ship engines which can meet the operating conditions and safety issues of this kind of engines.

Index Terms—Oil Spill; Oil Slick; Policy; Vietnam Maritime

I. INTRODUCTION

In the strategy of marine economic development, the maritime sector plays an important role, in which seaports are the nucleus of development, the focal point for receiving and transporting import and export goods and circulating to all regions of the country [1],[2]. Shipping now accounts for 90% of the volume of imports and exports and part of the goods to regions, the main artery in the system of transportation and distribution of goods of the economy. Therefore, the development of new technologies applied in the maritime field [3]-[6], marine environment protection [7]-[9] and shipbuilding (material technology in shipbuilding) [10]-[16] is one of the key determinants of survival in the maritime industry. In addition, the reduction of marine pollution is also a major contributor to maritime development. The International Maritime Organization (IMO) has decided to implement the requirement to limit sulfur in marine fuels to 0.50% from 1 January 2020. In order to comply with IMO's decision, ships They must equip themselves with exhaust gas cleaning systems (called air purifiers) or compatible fuel tanks. Shipping companies are concerned that they will not be able to collect additional costs from shippers. According to US government statistics, ships accounted for two-thirds of SO2 emissions in the transport sector in 2002, the lack of control measures would cause the rate to rise 98% by 2020. In addition, the US and Canadian governments also set new emission standards for large vessels. Accordingly, new ships must reduce 96% of SO2 emissions by 2015 from now. Similarly, ships built after 2016 will have to cut 80% of their NO emissions. The EU also confirmed the need for the establishment of the first low-emissions areas, minimizing pollution from thousands of cargo ships traveling through the seas each year [17]-[20]. The EU will accept governments to support maritime companies to meet strict SO2 standards. In order to effectively control the emissions of ships in maritime activities, Vietnam should have policies, legal documents, regulations and state regulations for fishing vessels and transport ships and reduce emissions, especially greenhouse gas emissions, ship science and technology, ship engines, waste gas collectors [21]. In addition, Vietnam needs to train human resources, raise awareness on reducing emissions from ships and climate change for objects related to shipping, marine and marine economy. Renovation of new marine technology, reduction of engine emissions - ship engines, waste incinerators. To promulgate policies on taxation and collection of charges for ship gases; Collaborate and exchange experience with international maritime-environment organizations in the field of marine emissions [22].

The United Nations Intergovernmental Panel on Climate Change (IPCC) has estimated marine emissions to reach a maximum of 400 million tons of CO2 per year. However, a recent report by an international team of scientists based on data collected from oil and maritime industries by the International Maritime Organization (IMO) shows that emissions are causing a change. The climate change of maritime operations is practically three times higher than previously known: reaching 1.12 billion tons of CO2 per year, accounting for nearly 4.5 percent of all greenhouse gas emissions mostly global. The report argues that emissions from the maritime sector - which are not included in the European cut-off to curb climate change - will become one of the new sources of CO2 emissions after the transition. road, life, agriculture and industry [23],[24]. Aviation is currently under heavy pressure to reduce greenhouse gases. However, the industry's 650 million tons of CO2 emissions each year are equivalent to more than half of emissions from shipping.

Historical figures for the carbon emissions of the maritime industry are often based on the amount of primary fuel purchased by boat owners. However, the latest UN data is considered to be more accurate because it is based on the size of the engine of the ships in the world, the time spent on the sea and the amount of primary fuel sold shipowners. This new figure not only shows much worse emissions than fears, but also warns that CO2 emissions are about to increase by 30% by 2020. The European Commission and some countries have insisted climate impact of the ship. They claim that it is less than 2% of global emissions and
erroneously bypassing this indicator in national estimates for CO2 emissions. Meanwhile, scientists expect that increasing pressure on shipowners will force them to switch to better fuels and also make the EU take into account the marine industry in its trade planning their emissions.

The UN report also shows that other pollutants from maritime activity are growing even faster than CO2 emissions. Sulfur and carbon black emissions, which are responsible for increased lung cancer, acid rain and respiratory problems, are thought to increase by more than 30% in the next 12 years. Health issues related to emissions from maritime operations will be particularly serious for the United Kingdom and other countries contiguous to the Strait of Malacca, one of the busiest shipping lanes in the world.

A recent co-author study on marine emissions said the industry directly leads to 60,000 deaths worldwide each year. However, the shipping industry itself has taken steps to cut emissions. "The number of ships and world trade has increased steadily, but with larger and more efficient vessels. Smaller vessels have gradually reduced fuel consumption over the past 20 years. One liter of oil on a modern large-scale transporter carries a ton of cargo that goes more than 2,800 kilometers, twice as high as 20 years ago. The UK government also announced it would support the development of a global emissions trading scheme through the IMO and is studying the feasibility of taking into account marine emissions in the EU's trade program. It is time for the maritime industry to take on its "responsibility" in tackling climate change.

Biofuels include: Biodiesel is a liquid fuel with similar functionality and can be used in place of traditional diesel. Biodiesel is derived from a number of biodiesel (vegetable oils, animal fats) [25],[26], usually made by transesterification by reacting with the most common alcoholic beverages, methanol. Biogasoline is a liquid fuel, which uses ethanol as a fuel additive mixed into gasoline instead of lead. Ethanol is processed through the fermentation of organic products such as starch, cellulose, lignocellulose. Ethanol is formulated with a suitable ratio of gasoline to form a completely replaceable gasoline for gasoline using conventional lead additives. Biogas is an organic gas of Methane and other peers. Biogas generated after fermentation of organic biomass for agricultural waste, mainly cellulose, forms gaseous products. Biogas can be used as a fuel for gas instead of petroleum products. B5 biodiesel (5% biofuel with 95% fossil diesel), biodiesel B10 (10% biofuel with 90% fossil diesel) was used pilot on small diesel engines [27]. After more than a year of running tests, the engine is stable in terms of power, noise and stability. Remarkably, the results of monitoring emissions of the engine on the ship's generator: CO poisonous gas decreased 10 times [28],[29]. In addition to the advantages, bio-diesel still has limitations such as: high fuel consumption, about 5% compared to the general fuel consumption of about 2.5%. Especially, when the temperature drops below 100°C, the engine will hardly start exploding at start-up; 100% bio-diesel oil in the freezing warehouse when the temperature drops below 100°C; Filter of the fast clogged machine, must be replaced (using conventional diesel 6 months instead of filtered filter, using bio-diesel 2 months must change the filter filter) [30]. If the filters last longer than 2 months, do not provide enough oil for the operation of the engine. Despite the limitations, bio-diesel has confirmed the outstanding advantages of 100% clean fuel and does not generate emissions that pollute the environment [31]-[33].

Developing biofuels helps countries take the initiative not to rely on imported fuels, especially for countries without oil and coal. At the same time, curb the rise in oil prices, stabilize the energy situation for the world. Developing biofuels on the basis of utilizing huge biomass resources and being made from renewable resources will be a real priority in ensuring safety, energy security for nations.

II. UTILIZATION OF WASTE HEAT

The method of combining electric-exhaust gas is the method in which the fuel is first circulated through an exhaust gas exhaust device and then it is circulated back to the tank. Here, the fuel continues being heated by electricity if necessary to achieve a certain temperature before being supplied to the engine. If the fuel after the heat from the exhaust is below this temperature, the electric heater will turn on to allow the fuel to heat up to the required temperature. So far, the method of combining electric-exhaust gas has not been used on the means of transport for the following reasons:

- Fuel used on combustion engines by compression is mostly fossil fuel. In this case the following possibilities will be used:
  - If the engine uses DO oil, no heating system is needed.
  - If the engine uses HFO or IFO, it is essential to install the fuel booster system and also use the DO fuel when starting and stopping the engine ie the dual fuel system. Due to this complexity, the dual fuel system is often used for larger engines such as thousands of tonnage vessels. At the same time, onboard ships using a fuel oil or steam heating system, reheat using an electric heating device.

Exhaust gas energy is usually only utilized in the boiler exhaust gas or exhaust gas boiler sector, and is only available on large vehicles fitted with boilers or turbocharged engines, exhaust gas turbine. For the above reasons, an integrated electric-exhaust gas heating system cannot be used on large vehicles, long-time engine power. However, the object to which the subject is addressed is small engines mounted on transport vehicles or agricultural machines, forestry or diesel generators of great age, with a short operating period. There is no exhaust system utilizing the exhaust so that it is suitable for the type of electric-exhaust gas not only help the engine start cold but also utilize the waste heat energy of the engine. In the thermal losses of diesel engines, the exhaust gas heat losses are the largest. Exhaust emissions from the engine account for about 25 - 30% of the total heat generated when fuel is burned. At present, on large and medium-sized ships (larger than 1000cv), exhaust gas is utilized through an auxiliary boiler to produce steam for on-board needs such as boiler heating, heavy fuel, salt water production ... However, on small vessels, the utilization of exhaust gas has not been paid attention due to the low exhaust gas, the equipment used on board the ship is difficult.
The exhaust temperature of the engine at different load modes will vary. In the rated mode, the exhaust gas temperature of the engines is as follows [34]:

Four-stroke engine without turbocharger: \( T = (300 - 410) \degree C \)

Four-stroke engine with turbocharger: \( T = (380 - 450) \degree C \)

Two straight stroke engine: \( T = (360 - 380) \degree C \)

Two-stroke sweep engine: \( T = (270 - 310) \degree C \)

According to calculations, exhaust gas heat from the engine is calculated as follows:

\[
Q = (\alpha L_o + 1) C_p T_1 - \alpha L_o C_{phk} T_2 \quad (kW)
\]

or \( Q = G C_p (t'_1 - t'_2) \quad (kW) \)

\( G \): exhaust gas flow, kg/h; \( G = g_e . N_e . (\alpha L_o + 1) \)

\( g_e \): useful fuel consumption, kg/cv.h

\( N_e \): useful power of the motor, cv

\( \alpha \): theoretical scanning airflow

\( L_o \): the amount of theoretical air required to burn 1 kg of fuel completely, kg/kg.h

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III. CALCULATION OF DIRECT FUEL HEATING SYSTEM

The direct-heated biodiesel fuel system can be applied on small vessels. This method has the advantage of high thermal efficiency, simplified system is the disadvantage is not high reliability, the system only works when the main engine operation, causing hydraulic impedance on the discharge. The calculation and installation faced many difficulties. This method is calculated on the basis of the liquid-gas continuous partition heat exchanger. The temperature of biodiesel in and out of the heater is \( t_2' \) and \( t_2 \), respectively, the amount of biodiesel needed to be warmed is \( G_2 \) (kg/h), \( C_2 \) is the specific heat of biodiesel (kJ/kg).

To design the partition heat exchangers, we need to determine the area of the heat exchange surface of partition \( F \) (m²). The surface area of the heat exchanger is determined by the heat transfer equation and the energy balance through the partition:

\[
Q_2 = k . F . \Delta t = G_2 . C_2 (t'_2 - t'_1) = n . Q
\]

\( k \): coefficient of heat transfer, W/m². K

\( \eta \): performance of the heat exchanger

\( \Delta t \): average temperature difference of exhaust and fuel

\( t'_1, t'_2 \): exhaust gas temperature and exhaust gas from the utilization system, \(^\circ\)C

\( C_p, C_{phk} \): specific heat of exhaust gas and air intake, kJ/kg.K

\( T_1, T_2 \): exhaust and air temperature, K

For two exhaust gas lines and fuel, the mean temperature difference \( \Delta t \) in the device is calculated [35]:

\[
\Delta t = \frac{\Delta t_1 - \Delta t_2}{\ln \frac{\Delta t_1}{\Delta t_2}}
\]

\( \Delta t_1 \) and \( \Delta t_2 \) is the temperature difference between the two media streams when entering and leaving the device. With the heat exchanger we are considering, this may be
considered to be the opposite. Therefore,

\[ \Delta t_1 = t_1' - t_2' \text{ and } \Delta t_0 = t_1' - t_2 \]

The heat transfer coefficient \( k \) is determined: \( k = \varphi.k_0 \)

\( \varphi \) - coefficient of surface contamination

\( k_0 \) - wall heat transfer coefficient when there is no surface contamination [36]:

\[
k_0 = \frac{1}{\frac{1}{a_1} + \frac{1}{a_2} \ln \left( \frac{d_2}{d_1} + 1 \right)}
\]

\( a_1, a_2 \) - coefficient of convective heat exchanger with exhaust and fuel, W/m².K

\( \lambda \) - thermal conductivity of the wall, W/m.K

\( \delta \) - wall thickness, m

The convective heat transfer coefficient \( a_i \) is defined as:

\[
\text{Nu} = K.Re^m.Pr^n.(Gr.Pr t_1)^{1/3} \cdot (Pr/Pr_0)^{0.25} \cdot \delta \cdot 0.3 \cdot G \cdot \text{Gr}
\]

\( \text{Nu} = a_i.\delta \)

Average heat flux coefficient \( \alpha_i \) of the wall with the flow of exhaust gas passing across the tube beam:

\[
\alpha_i = \frac{\alpha_{01} + \alpha_{02} + (z - 2)\alpha_{03}}{z}
\]

\( \alpha_{01}, \alpha_{02}, \alpha_{03} \): average heat transfer coefficient of the first, second and third tubes.

With beam staggered: \( \alpha_{01} = 0.6\alpha_{01}; \alpha_{02} = 0.7\alpha_{03} \)

With parallel tube beam: \( \alpha_{01} = 0.6\alpha_{01}; \alpha_{02} = 0.9\alpha_{03} \)

\( d_i \): diameter in d₁, in addition to d₂ of the tube, m (pre-selected in standard), the average diameter d of the pipe, m.

The coefficients \( \delta_i, \sigma_{1}, \sigma_{2}, \sigma_0 \) include the effect of tube length, curvature of pipe, tube step and impact angle.

Thermal conductivity of fuel \( \lambda \), W/m.K

The total number of hinged pipe elements from the two ends of the hose:

\[
n = \frac{4G_2}{\pi.d_1^2.\rho.\alpha_{01}}
\]

From the equations, it is possible to determine the required heat exchange area of F (m²), which allows the design of the waste heat recovery system with the number of pipes, pipe size and pipe type (with wings or without wings) in accordance with the engine room space of the vessel using this equipment. However, the hydraulic impedance on the discharge path must be taken into account so that the utilization does not affect the engine exhaust. In the heat exchanger, the hydraulic impedance consists mainly of two components: the friction impedance \( \Delta p_m \) and the local impedance \( \Delta p_c \):

\[
\Delta p_m = \xi \cdot \rho \cdot \sigma^2, \text{ N/m}^2
\]

\[
\Delta p_c = \xi \cdot \rho \cdot \frac{\sigma^2}{2}, \text{ N/m}^2
\]

Specific mass of exhaust gas at medium temperature: \( \rho \) (kg/m³)

Average discharge velocity: \( \omega \) (m/s)

Partial loss factor: \( \xi \)

In the case of intermediate heat, fuel is continuously heated in the storage tank to temperature \( t_2' \), then put into the safe and reheated to the temperature \( t_3' \). The two safes are heated by two different heating systems, but slightly warmers are removed from the boiler. Therefore, the calculation of the system is similar. This method has the advantage that the system is highly reliable, can be used as soon as the main engine does not work and easy to control the fuel temperature is warmed up the disadvantage is the layout of the heating tube complex. Checking the system is difficult. The amount of heat needed to fuel the storage tank and the safe deposit box is [37]:

\[
Q_m = G_m.C_2(t_2' - t_1')
\]

\[
Q_m = G_m.C_2(t_3' - t_2')
\]

The heat generated by the steam is: \( Q_h = G_s(t_1 - t_e) \)

\( i_1; i_e \): enthalpy slightly out of leverage system and of water level, kJ/kg

The calculation of the surface area of the heat exchanger F, the average temperature difference and the heat transfer coefficient \( k \) are based on equation. However, the heat flux coefficient of the inner tube is calculated:

\[
\alpha_1 = C.A_1.\omega^{0.5}.L^{0.35}.d_1^{-0.25}
\]

C = 1.26 for steel pipe

\( q \): density of heat flow, W/m²

\( L, d_1 \) - the length and diameter of the tube, m

The A₁ value of the steam depends on the output temperature of t₁ steam given in the table below:

| \( t_1' \) (°C) | 100 | 110 | 120 | 130 | 140 | 150 | 160 | 170 | 180 | 190 |
|---------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| A             | 8.42| 8.11| 7.75| 7.42| 7.11| 6.78| 6.47| 6.14| 5.81| 5.49|

The thermal factor \( \alpha_2 \) of the fuel at the outer surface of the tube is calculated:

\[
\text{Nu} = C'.(\text{Gr}_m.\text{Pr}_m)^n = \frac{\alpha_2. d_2}{\lambda}
\]

C', m, n: experimental coefficients

After calculating the thermal coefficient \( k \) and thus determining the required heat exchanger area F, it is possible to design the fuel booster in two storage tanks and in the direct current. Thereby, we can calculate the time needed to heat the fuel from the initial temperature \( t_0 \) to the temperature \( t \) needed in the tanks:

\[
\tau = \frac{1}{a_1} \ln \frac{t_{m1} - t_0}{t_{m1} - t}
\]
\[ a_i = \frac{k \cdot F + k_2 \cdot F_2}{m \cdot C_2} \quad (s^{-1}) \]

\[ t_{ml} = \frac{k \cdot F \cdot t_1 + k_2 \cdot F_2 \cdot t_{kk}}{k \cdot F + k_2 \cdot F_2} \quad (^{\circ}C) \]

\( k_2 \): heat transfer coefficient from the fuel tank to the environment, \( W / m^2\cdot K \)

\( F_2 \): Heat exchange area of the fuel tank, \( m^2 \)

\( t \): ambient temperature, \( ^{\circ}C \)

At the storage tanks and in the tank, when the fuel is heated to the required temperature, it will switch to the heating mode in order to maintain the temperature of the fuel always within the allowed range. This method does not need to calculate the hydraulic impedance because the fuel in the tanks is considered to be zero speed. However, it is important to pay attention to the proper arrangement of the chassis to ensure that the vessel is tilted or sideways without compromising the safe operation of the system.

IV. CONCLUSION

By calculating the use of exhaust air with two direct leverage and utilization through an intermediate steam engine to heat biodiesel / bio-oil fuels, we can improve the properties of the fuel, through that can meet the demand for fuel on ships not only for large engines but also for use on river ships or generators on ships. The method of direct fuel combustion with exhaust has the advantage of simple, compact equipment, high efficiency has the disadvantage is not high reliability, difficult to adjust the temperature in the fuel tank, the method of heating fuel through intermediary steam is more reliable, easy to adjust the temperature of the fuel system before the engine. Utilizing the exhaust gas energy for biodiesel / bio-oil heating will increase the engine's thermal energy utilization and diversify the fuel supply. However, during design and exploitation calculations attention is paid to the reaction on the discharge line so that the utilization does not affect the engine's charging and discharging process. In addition, it is necessary to calculate for a particular vessel the temperature range needed to heat biodiesel / bio-oil so that it can be used as a basis for calculation and application in practice, suitable for different types of ships.

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