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ANALYSIS OF DIESEL OIL SPECIFIC HEAT IMPACT FOR OPERATION OF THE SUPPLY PUMP

Piotr Bzura
Dominik Kreft

Gdansk University of Technology
ul. Narutowicza 11/12, 80-952 Gdańsk, Poland
tel. +48583472573
e-mail: pbzura@pg.edu.pl
e-mail: dominik.kreft@gmail.com

Abstract

The article describes a test rig that allows the measurement of fuel oil specific heat changes based on the cooling time of liquids. After that, by analysing the test results, a research hypothesis was created and verified. The hypothesis is that the specific heat energy of fuel oil impact the operation of the circulation pump.

***Key words**: pump load, research hypothesis, fuel oil*

1. Introduction

Piston engines used in the propulsion systems of sea vessels are adapted to burn heavy fuels oil, characterized by too high viscosity in low temperature. To ensure the required viscosity of the fuel (about 12 ÷ 14 cSt) injected into engine combustion chamber, the fuel system is heating up. The process involves, among others, fuel supply pump, fuel heater and viscometer. The specific heat of the fuel, affects the speed of the heating process. It is a parameter that informs how much heat must be supplied by the heater that temperature increases to such a value that the viscosity of the fuel measured in viscometer reaches the value required by the engine manufacturer.

It is well known that one parameter determining the quality of fuel injected into the combustion chamber is insufficient, so this article proposes to check the specific heat of the fuel. If specific heat is higher it will slow down the heating process in the same condition.

In order to present the possibility of analysing the value of the specific heat of the fuel, the test rig was built to analyse the specific heat impact of the fuel oil on the displacement pump operation.

2. Test rig to identify changes of specific heat

The experimental (measurement) system to determine changes in the specific heat of fuel oil is made from elements shown in Fig. 1. Firstly the sample of the tested liquid is heated in the heating tank 1 to a constant temperature T_1, which is set by a thermostat. Then heated diesel oil is transfer by a displacement pump into an insulated tank inside the calorimeter 2. The fuel oil temperature in the calorimeter tank is T_k. The operation of pumping from tank 1 to tank 2 should take place with the lowest possible heat loss.

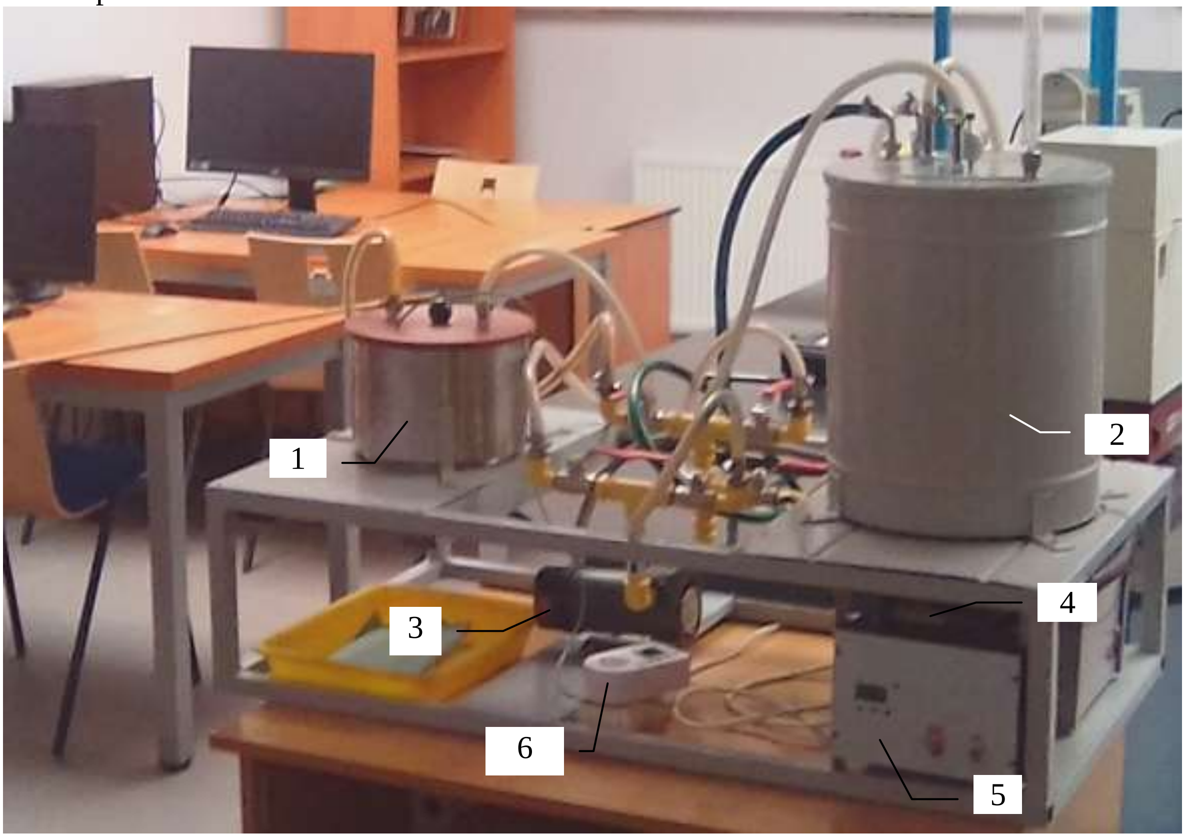

Fig. 1. Test rig photography, with marked equipment: 1 –heating tank, 2 – calorimeter, 3 – fuel oil pump, 4 – thermometer, 5 – power supply, 6 – electricity meter

Secondly, to speed up the cooling process the cold water cooling pump started (fig. 2). By measure fuel oil temperature by sensor 4, in the range from T_K to T_2, we can obtain the amount of heat that the test liquid lost in the calorimeter.

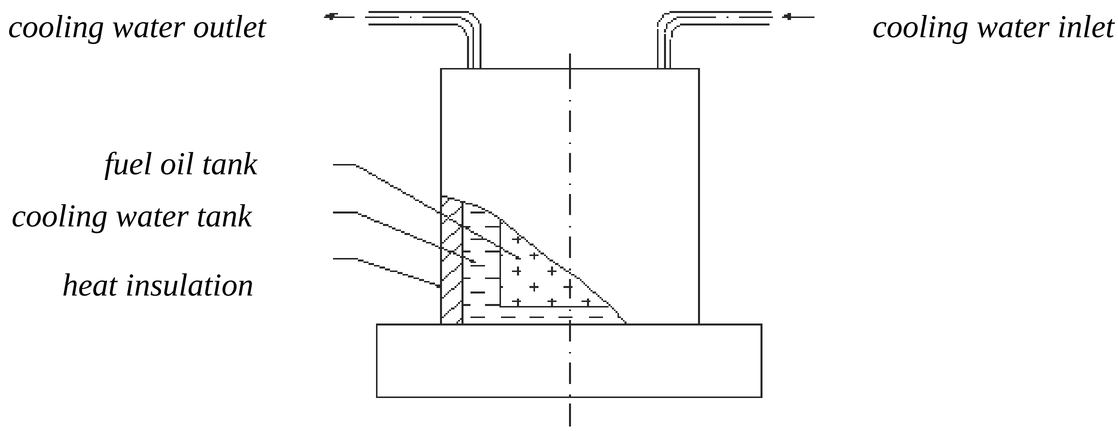

Fig. 2. Calorimeter cross-section

Based on the energy balance of the system [4] we get:

$$C_K \cdot T_K + m \cdot c_p \cdot T_1 + N \cdot \tau_p \pm \Delta Q_s = \left(C_K + m \cdot c_p\right) \cdot T_2 \tag{1}$$

so:

$$m \cdot c_p = \frac{-N \cdot \tau_p \pm \Delta Q_s + C_K \cdot \left(T_2 - T_K\right)}{T_1 - T_2} \tag{2}$$

where:

T_K – calorimeter initial temperature,
C_K – calorimeter thermal capacity,
m – fuel oil weight,
T_1, T_2 – fuel oil temperature at the beginning and in the end,
N – circulation pump power,
τ_p – measurement time,
ΔQ_S – heat losses,
ε- correction coefficient describes temperature increase in the calorimeter,
c_p – fuel oil specific heat.

The main problem in the calorimetric system is elimination of thermal losses, because they (mainly) determine the accuracy of the measurement. It was assumed that the amount of heat losses to the environment can be compensated by the power of the calorimeter cooling pump during the measurement. After formula simplification, we get the final one that allows to determine the specific heat:

$$m \cdot c_p = \frac{C_K \cdot \left(\Delta T \pm \varepsilon\right)}{T_1 - T_2} \tag{3}$$

The fuel oil pump operation was consider as a parameter identifying the specific heat of the fuel. It can be interpreted as, the transformation of the power supply (5) electric energy by a pump (3), which allows liquid flow from the heating tank (1) to the calorimeter (2) under given conditions and time t.

Since the energy value E depends on the time (t), equation D = D (t), should be determined from [1]:

$$D = \int_0^t E(\tau)\,d\tau \tag{4}$$

where:

E – the amount of electricity consumed during the operation of the fuel pump (using the electricity meter (6)),
[0, t] – duration of cooling process in calorimeter.

3. Displacement pump operation

Three models of fuel oil used during marine engines operations were tested:

1. Clean fuel oil – symbol A.
2. Fuel oil with 10% distilled water – symbol B.
3. Fuel oil with 20% distilled water – symbol C.

The tests were performed due the following procedure:

1. Heat fuel oil sample (symbol A, B, C) in heating tank, until temperature grow to switch off the thermostat T_1 = 328 K.
2. Open the valves to allow fluid flow from the heating tank to the calorimeter.
3. After starting the displacement pump, in order to transfer the liquid from the heating tank to the calorimeter, measure the amount of energy E consumed during this work with the electricity meter.

4. Open inlet of cooling water system.
5. The time of cooling of each sample begins with the stopwatch at the moment when the test liquid reaches the temperature equal to T_K = 323 K.
6. Measurement of the total cooling time of the fuel oil, e.g.τ = 120 s.
7. Opening the valve to empty the calorimeter.
8. Switch on the pump and transfer the liquid from calorimeter to the drain tank.

All measurements were repeated four times, the results were registered in tab. 1

Tab. 1 Results for fuel oil

No.	Symbol A		Symbol B		Symbol C	
	c_p [Nm/kg·K]	E [Nm]	c_p [Nm/kg·K]	E [Nm]	c_p [Nm/kg·K]	E [Nm]
1	2100	168,09	2487,15	180,56	2111,73	182,74
2	2100	174,72	2346,37	177,76	2721,79	185,5
3	2100	175,28	2064,8	180,49	2956,42	184,79
4	2100	177,47	1736,31	183,21	2768,72	182,85

4. Measurement error calculation

The measurement is a sequence of activities which can be defined at a given moment, under certain conditions, with use of the specific measures (methods and measuring devices), the measured quantity D had a value in the interval [a, b], i.e.

$$a \le E \le b \tag{5}$$

where: $b - a = 2\varepsilon$ – sensitiveness range, $2\varepsilon > 0$ – basic metrology assumption

The measurement error determines the inconsistency of the measurement result with the actual value. The error is determined to let us known how much the measurement result E differs from the actual value. There are different kinds of errors:

Absolute error:

$$\Delta E = \left| E - E_{rz} \right| \tag{6}$$

Relative error:

$$\delta_z = \frac{\Delta E}{E_{rz}} = \frac{E - E_{rz}}{E_{rz}} \tag{7}$$

Relative error divided by the length of measuring range:

$$\delta_{zakr} = \frac{\Delta E}{E_g - E_d} = \frac{E - E_{rz}}{E_{zakr}} \tag{8}$$

where:

E_g – the pump energy highest value of measuring range,

E_d – lowest value of measuring range,

E_{zakr} – measuring range.

It can be assumed that the arithmetic mean value $\overline{E}$ obtained from measurements is closest to the real value E_{rz}. Therefore, we can write that:

$$E_{rz} = \overline{E} = \frac{1}{r}\sum_{i=1}^{r} E_i \tag{9}$$

where:

r – number of physical quantity E single measurements.

Most often in engineering practice, three physical measurements are made. However, it should be assumed that these measurements should be at least four. This is due to the value $\overline{E}$ is the statistics of physical quantity E, and it should be assumed as random variable. This is important, because the statistic has an asymptotically normal distribution, quickly growth to a normal distribution, when $r \geq 4$. That rule allows the use of a normal distribution to carry out an observational error.

Measurement errors of all measurements have been presented in tab. 2. For the measured sample for each model (symbol A, B, C) it was assume energy quantity E which was the most deviating value from E_{rz}.

Tab. 2 Measurement error

no.	*Symbol A*	*Symbol B*	*Symbol C*
Absolute error	*5,38*	*2,745*	*1,23*
Relative error	*0,031*	*0,015*	*0,0067*
Relative error divided by measuring range	*0,57*	*0,5*	*0,45*

Based on preliminary test results, there can be use a research hypothesis that the specific heat value of the examined fuel oil has influence on the circulation pump operation. In the next chapter, this hypothesis will be verified.

5. Research hypothesis verification

Testing of hypothesis [1,2] : there has been change in the operation of the fuel oil pump, which is why there has been a change in the value of specific heat, was made in the following three stages:

- The amount of energy consumed by a diesel circulating pump is expressed as a random variable. As a null hypothesis (H_0) it was consider that, the specific heat of fuel oil does not affect the amount of energy E consumed by the pump. As an alternative hypothesis (H_a) it was assumed that the specific heat of diesel fuel affects the amount of energy consumed.
- From Kolmogorov–Smirnov test for sample size $n < 100$ and confidence interval $\beta = 95\%$ it follows that the function which describes the principle of assigning probabilities to particular values of a random variable is a normal distribution.
- After completing Fisher's exact test research hypothesis test for the significance level $\alpha = 0,05$ hypothesis H_0 was rejected and an alternative hypothesis H_a was accepted.

6. Final remarks and conclusion

The measurements on the test rig were carried out for three different physicochemical properties of the fuel oil. After analysing the results of measuring the specific heat of fuel oil, it was found that the value of specific heat affects the amount of energy consumed by circulation pump.

The presented analysis shows that increasing the specific heat of fuel oil, caused by a higher content of distilled water increases the amount of energy E needed to supply the circulation pump and increases heating energy required by fuel oil to obtain viscosity $12 \div 14$ cSt.

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