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FRICTION BEHAVIOURS OF LUBRICATION OIL CONTAMINATED WITH COOLING WATER IN MARINE DIESEL ENGINES

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ABSTRACT

Lubrication is used for both cooling and lubricating in marine diesel engines which are used for producing electricity and propulsion system on ships. Furthermore, lubrication oil is cooled with both sea water and fresh water in conventional and central cooling systems, respectively. In this study, friction behaviours are experimentally investigated between piston ring and cylinder liner pairs in marine diesel engines when the cooling sea water or fresh water are mixed into the lubrication oil in tubular and plate type heat exchangers. Experiments are carried out with marine type crankcase lubricant and under varied engine speeds, temperature and sea/fresh water mixture ratios of 5% and 10% on the reciprocating test engine. Frictional forces are measured by the three-axis Kistler 9027C force sensor. Furthermore, Taguchi L16 orthogonal arrays experimental design method is used in the analysis of the results.

Keywords: *Cooling water, Friction, Marine Diesel Engine, Marine Lubricant*

INTRODUCTION

Although researchers have extensively explored alternative methods to replace internal combustion engines, they have not been able to go beyond small-volume engines, such as used in automobiles [1]. Therefore, the internal combustion engine especially diesel engine is expected to remain the common ship propulsion power source for the foreseeable future.

There are still significant opportunities for these engines to increase the efficiency with reducing fuel consumption and increasing power. Researchers have conducted studies to improve the efficiency of diesel engines under two main subjects. Some studies have been aimed at increasing combustion efficiency [2, 3], whilst others have been aimed at reducing mechanical losses [4-6]. It has been observed that mechanical friction losses can range from 4% to 15% within these studies [7]. The part of the friction between 50% and 68% occurs in the piston cylinder group and between 25% and 35% occurs at the crankshaft. Diesel engine performance and longevity can be improved by controlling friction losses between piston and cylinder liner. Within this context, lubricants play an important role in reducing friction, which is a major effect on engine performance [8]. Besides, different materials tribological performance are investigated in accordance with friction force, oil film thickness variation, temperature variation and rotational speed [9].

Lubrication oils are products that protect diesel engines against friction and wear by forming a protective film layer between the moving parts of the engine; notwithstanding, they cannot keep their first day performance. Since, lubrication oil is subject to chemical changes due to oxidation during operation and especially additive contamination [10, 11].

Lubrication oils are cooled with sea and fresh water with the systems of conventional and central cooling on ships. Furthermore, many different substances are likely to be contaminated with lubrication oil thus mixing with these fresh water and sea water is the most common occurrence [12]. The main reasons of these contamination

are leakages from cylinder cooling water system, piston cooling water system, sump tank heating coils, LO cooler water leakages and condensation of water vapor inside crankcase.

The objective of this study is to investigate the effects of fuels in two stroke low speed diesel engine cylinder oil on friction behavior between piston ring and cylinder liner pair under various conditions for different number of revolutions, temperature and different water/oil mixture ratio parameters.

MATERIALS AND METHODS

Experiments were performed in a tribological tester device, which enables the control of temperature, and stirring speed. The test device which is developed by the authors, was driven by an electric motor via a tire coupling. The friction coefficients were measured with a three-axis Kistler 9027C force sensor. The cylinder liner was heated via heaters. Temperature of the liner was set by measuring the temperature with thermocouples mounted on different positions of the stroke.

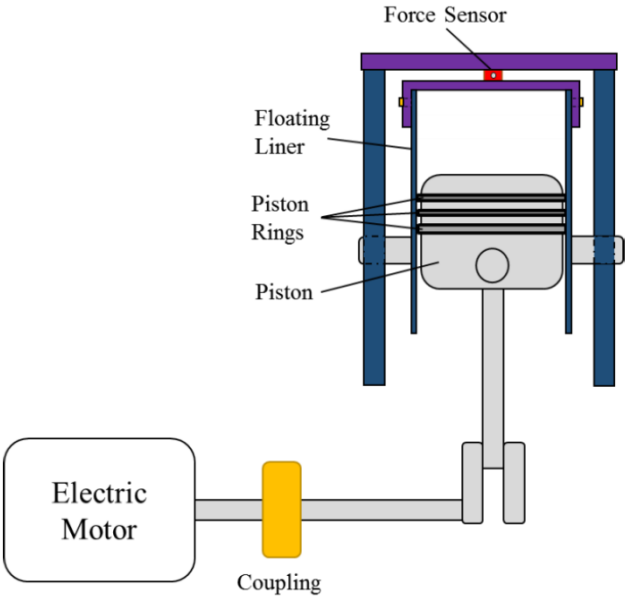


Figure 1. Experimental set-up

Before the each experiment, a new piston ring, piston and liner were cleaned and then piston ring were installed on the piston. The cylinder liner was heated up to desired temperature value. The lubricant samples were prepared by adding water and seawater according to the procedures as described in Table 2. Moreover lubricant samples were added to top of the piston by capillary tube which is operated according to gravity method. The properties of the oil used in the experiments were given in Table 1.

Table 1. The properties of the oil

Parameter	Value
Viscosity (cSt)	12.5-16.3
TBN (mgKOH gr)	29-31
Flash Point (°C)	Min. 246
Pour Point (°C)	Max. -18

In order to determine the friction performance of lubricants on the diesel engine piston ring and liner pair, three parameters: type/content of water in lubricant, speed and temperature was selected at four different levels. The chosen parameter ranges and their levels for the experiments are shown in Table 2. Taguchi's L16 factorial design of experiment was used in the experiments, design matrix was given in Table 3 and the corresponding experiment results with the S/N ratio.

Table 2. The chosen parameter ranges and their level

Parameters		Levels			
		1	2	3	4
A	Type/content of water (%)	Water/5	Water/10	Sea water/5	Sea water/10
B	Speed (rpm)	40	80	120	160
C	Temperature (°C)	60	80	100	120

Table 3. The chosen parameter ranges and their level

No	A	B	C	Friction Force (N)	S/N
1	1	1	1	24.56	-27.80
2	1	2	2	17.90	-25.06
3	1	3	3	19.11	-25.62
4	1	4	4	17.53	-24.88
5	2	1	2	19.29	-25.71
6	2	2	1	15.48	-23.79
7	2	3	4	19.05	-25.60
8	2	4	3	18.16	-25.18
9	3	1	3	23.40	-27.38
10	3	2	4	20.24	-26.12
11	3	3	1	13.20	-22.41
12	3	4	2	12.45	-21.90
13	4	1	4	31.48	-29.96
14	4	2	3	22.03	-26.86
15	4	3	2	13.54	-22.63
16	4	4	1	13.10	-22.34

The present study aimed to optimize friction losses and so smaller-the-better formulation was used to compute the S/N ratio with the following Equation 1. Analysis of variance (ANOVA) was used to determine percentage contribution of each parameter and parameter affecting the performance of the processes [13,14].

$$\textit{Smaller the better}: S/N = -10\log\frac{1}{n}\left(\sum y^2\right) \quad (1)$$

RESULTS AND DISCUSSION

In present study, the Taguchi L16 orthogonal array was used to determine the optimum experimental condition to obtain minimum friction forces. The experiments were carried out using three control parameters: type/content of water in lubricant, speed and temperature. Friction force was taken as a system responses. The experimental results for friction forces with the S/N ratio was given in Table 3.

According to the Taguchi Method, to get optimum experimental condition the S/N ratio should have a maximum value. The S/N ratio is plotted against test level for each factors as shown in Fig. 2. From this figure

optimal levels of the process parameters were determined as type/content of water in lubricant is seawater/5, speed is 160 rpm and temperature is 80 °C. As can be seen on Fig. 2, friction force was highly sensitive to speed and temperature. In other words, changes of speed and temperature during the experiments, markedly increased or decreased average of friction force.

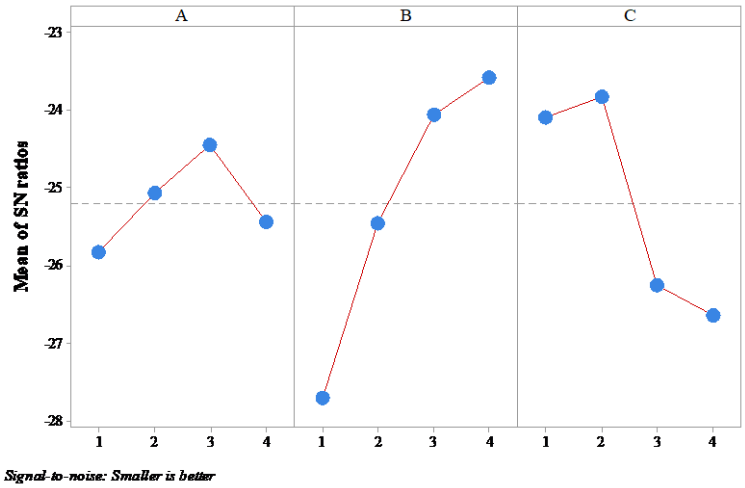


Figure 2. Effect of the each parameter on coefficients of friction.

ANOVA tests were used to determine the percentage contribution of individual parameters to the response at a level of confidence of 95%. The speed appeared as the most significant parameter influencing the friction force between piston ring-cylinder liners because of its highest contribution of 57.18%. The second significant factor was the temperature which is having 30.16% contribution.

Table 4. Analysis of variance (ANOVA) of Taguchi results for friction coefficient

Source	DOF	SS	MS	F_c	F_{exp}	Contribution (%)
Type/content of water	3	21.25	7.08	4.76	1.63	5.69
Speed	3	213.70	71.23	4.76	16.40	57.18
Temperature	3	112.71	37.57	4.76	8.65	30.16
Error	6	26.06	4.34			
Total	15	373.72				

R-sq: 93.03

Marine diesel engines should be lubricated with system oil which could be cooled with both sea water and fresh water inside the coolers. Considering that temperature of the lubrication processes should be optimum level under these condition. From the experimental study, friction force was decreased with the increase of speed (under the present experimental condition). Since, lubricant film thickness between the two working surfaces has become inadequate to prevent contact area of the surfaces for the lower the speed, thus increasing the friction force.

Experimental results also reflects that better lubricating effect with contamination of seawater into lubricant than water contaminated. This is because active element Cl^- will be react with the iron on the working surface, and so ferric oxide, ferric sulfide and ferric chloride being formed which shows good lubricant effect [15]. The friction forces has decreased to a certain levels when seawater content of 5 vol.%, and furthermore, it has increased again. The increase ratio of seawater in lubricant has reduced the lubricating effect of seawater and increase the friction forces of surfaces.

According to Taguchi method, experimental result for the optimum condition has to be validated with the prediction value. Hence, confirmation experiment was performed at the optimum condition. The predicted and experimental value are given in Table 5. The 95% confidence interval of the experimental value should be 6.83-14.89 for confirmation experimental result.

Table 5. Predicted and experimental value for confirmation experiment

Parameter	Level	Value	Predicted	Experimental
Type/content of water (%)	3	Sea water/5	10.86	11.96
Speed (rpm)	4	160		
Temperature (°C)	2	80		

The best and worst experimental results for friction forces were shown in Figure 3. Best experimental result is an optimum condition and it is obtained 12. test run. Worst experimental result find out 13. test run.

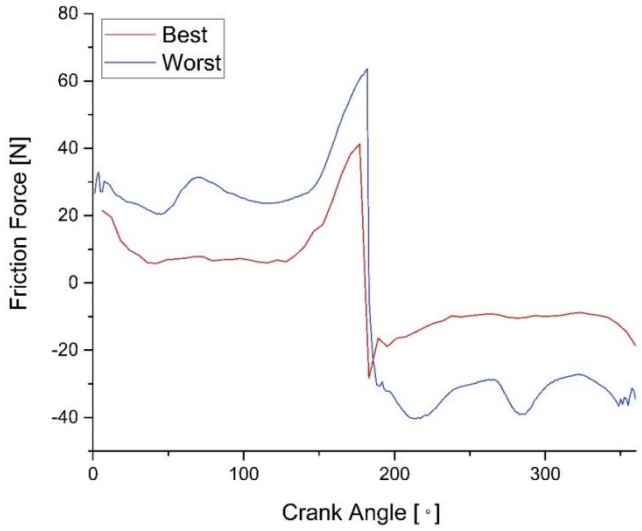


Figure 3. Change of friction forces vs. crank angle.

CONCLUDING REMARKS

The effect of various parameters such as type/content of water, speed and temperature on friction forces between piston ring-cylinder liners was investigated using Taguchi method. The results are summarized as follows:

- The optimum condition of the friction force was found to be at type/content of water in lubricant of seawater/5, speed of 160 rpm and temperature of 80 °C.
- The speed and temperature were identified as the two most critical process parameters influencing the friction forces.
- Contamination of sea and fresh water from cooling systems to lubrication oil deteriorates oil properties. Friction forces have increased when the lubricating oil deteriorates. Hence, contamination of foreign matter should be prevented to obtain engine performance.
- The experimental results also demonstrate that seawater in oil has a lubricating effect between moving parts.

NOMENCLATURE

N	Newton
g	Gram
S/N	Signal/Noise
°C	Degree Celsius
rpm	Revolutions per minute
cSt	centistokes

ANOVA Analysis of variance (ANOVA)
DOF Degree of Freedom
SS Sum of Squares
MS Mean Squares

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