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DEVELOPMENT OF THE COOLING SYSTEM OF A SINGLE CYLINDER DIESEL ENGINE

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ABSTRACT
Although the cooling system of diesel engines has been subjected to many sophisticated improvements, some developed countries still using diesel engines equipped with a basic open cooling system. In these engines the only function of the cooling system is to preserve the engine temperature acceptable for a wide range of operation and operating conditions. In this research, the effect of overcooling on the performance of a water cooled single cylinder diesel engine has been experimentally investigated. The study showed the increase of warm up period, low steady state temperature of both cooling water and lube oil, increase of pollutants concentrations, increase of fuel consumption and increase of blow by gases flow rate. Experimental results showed improvement in fuel consumption, blow-by gases flow rate and reduce time of warm up after the amendment process where the temperature of the cooling water has been raised. The effect on lube oil properties has been recorded.

KEYWORDS
Friction, oil viscosity, overcooling, warm up, fuel consumption, blow-by gases, ICE.

INTRODUCTION
The engine thermal management system (TMS) interacts strongly with various other systems in the engine, most notably the lubricating and combustion processes. The TMS is gaining importance in the search for reduced fuel consumption, [1, 2]. Some automotive conventional cooling systems are passive systems where a mechanical pump is directly linked to the engine and the pumping power is directly linked to engine speed. A wax element thermostat reacts to top hose coolant temperature and distributes flow accordingly either through the radiator or straight back into the engine without significant cooling. Many applications have attempted to introduce active control, [3, 4], the most common being replacing the mechanical pump and wax element thermostat with an electric pump and an electronic valve.

Torregrosa and co-workers, [5],have investigated the cooling system optimization offers potential to reduce fuel consumption and emissions through:

- **•A reduction in auxiliary power requirements.**
- **• Adjusting the thermal state of the engine and noticeably by changing the friction characteristic of the engine;**
- **• Influencing the combustion process.**

Allen and co-workers, [6], have been quoted to reduce coolant flow rate by up to 90% and using a downsized pump with rated power a few orders of magnitude smaller electric pump rated 60W replacing a mechanical pump rated 2kW. The resultant change in fuel consumption is offset by increased power conversion losses associated with the electrical system.

The effect of engine warm up on engine fuel economy was quantified by Kunze et al., [7], to compare between the fuel consumption over a cold start and hot start New European Drive Cycle (NEDC). It was seenthat 10% higher fuel consumption was observed for the hot test over the cold one.Heat was added to the coolant during the warm up period by installing a coolant heat exchanger in the exhaust manifold. The heat was then transported to the oil via another heat exchanger with the coolant. Tests were run from cold start on a steady state rig. The additional heat increased the warm up rate of the oil by an average of 8 to 12ºC, yielding a 12-15% reduction in fuel consumption.

An interesting comparison to these studies is the work published by Choukroun and Chanfreau, [8],using an electric coolant pump and control valve.They limited coolant flow, achieved higher steady state operating points and reduced fuel consumption by 2% for a 20ºC temperature increase. By completely stopping coolant flow in the engine over the first 300s of a cold start NEDC cycle, warm-up by 50% was cut. A 2 – 3% benefit in fuel consumption was observed. A second phase of the work, on a different drive cycle and vehicle, separated the two factors as initially a low coolant flow rate system that offers a 2% benefit in fuel consumption whereas a "no-flow during warm-up" system offers very little further benefits. This suggested that although suppressing coolant flow rate during warm-up seems to reduce coolant warm-up time, this is not reflected in engine fuel consumption due to the non-uniformity of surface temperatures as a result of reduced coolant flow rate. Oil temperature would be an obvious choice, but studies may involve a more complex description including localized metal and fluid temperatures.

Torregrosa and co-workers, [9], simulated the effect of reducing coolant volume as well as reducing flow rate and found that reducing the mass of coolant was the most significant effect to shorten warm up time. The concept was then produced experimentally and the combination of reduced coolant volume and flow reduced fuel consumption by 1.64% was obtained. A reduction of up to 30% in carbon monoxide (CO) and total hydrocarbons (HC) was observed combined with an increase of about 10% in nitrous oxides (NOx). Kay et al., [10],observed the reductions of 1% and 9.5% in fuel consumption for engine start temperatures of 20°C and -18°C respectively.

Automotive engine oil viscosities are highly dependent on temperature and reduce exponentially with increasing temperature. The relationship between viscosity and temperature is quantified by the viscosity index (VI) which is an arbitrary scale assessing the change in viscosity between 38ºC and 100ºC. Initially the scale of VI was 0-100, though to perform satisfactorily in modern engines, oils now have VI levels above 150, [11]. Shayler et al., [12], showed the overall effect of engine temperature on engine friction. Increasing oil temperature causesd a drop in oil viscosity which showed a reduction in overall engine friction.

The individual component contributions with coolant temperatures of 25 and 85ºC were studied, [13]. The study was conducted on a spark ignition engine, though no

combustion events occurred as motored breakdown tests were used and this will result in significantly lower local temperatures. The increased coolant temperature caused an increase in oil sump temperature from 25 to 77ºC. The breakdown tests showed significant reductions in piston assembly and main bearing friction, 66% and 85% respectively, but an increase in valve train friction (33%).Due to the relative friction contributions of each component group, the overall FMEP in the study by Daniels and Braun was seen to reduce by 26%.

A further improvement to the model presented by Jarrier et al., [14], included a detailed hydraulic circuit model with which they pointed other areas of potential warm-up improvement. They show that whilst bulk oil temperature is important for reducing total friction, increasing local temperatures of oil at the operating point (for example in the bearings) can also reduce friction. They use the example of reducing bearing clearance which they predict would locally rise oil temperatures by 12°C which can reduce total friction by 5% following cold start. The characteristics of total frictional loss, the friction of piston assembly and the friction of cam was studied, [15]. The authors calculated the value of the total friction mean effective pressure on a single cylinder engine with four piston rings and two valves. However, the experiment measured the net power losses due to the pumping losses of gas exchange, the mechanical frictional losses of piston, bearings, transmission and valve train system and the power consumed to run the auxiliary. However, on the indicator diagram, it has been found that the gas pumping losses change with speed and load, and so any generalization will be an approximation. The engine speed and load have significant effect on oil and coolant warm up, [16].

The experimental results showed that there is an evident disparity between the oil and coolant thermal responses, [17]. The author argues that the coolant reaches the peak operating temperature in 7 minutes while the oil reaches the same temperature 4 minutes later for a specified running condition. Nonetheless, lubricant is the last component of the engine to get warmed up and the coolant heats up much faster than the oil. A rapid warm-up of the engine is very critical in attaining low fuel consumption and emissions because the fuel consumption and engine out emissions are highest during cold start and improve as the engine warms up.

Blow-by gasses are present with all internal combustion engines, [18]. As pistons and cylinders wear, compression decreases and blow-by increases. Allowing our engines to warm up even in hot weather prolongs the life of pistons and cylinders. Pistons are forged or cast as an oblong shape by design to allow for expansion. Pistons grow round as they reach operating temperatures. Cylinders are bored true round when new, and wear into an oblong shape from front to rear. Placing a load on the engine such as driving off to work while pistons are not up to temperature causes accelerated wear on the cylinders. Worn cylinders means loss of power producing compression and increased blow-by gases.

Although the cooling system of internal combustion engines (ICE) has been subjected to many reliable and developed improvements in order to enhance engine performance, the KirlosKar single cylinder diesel engine which is widely spread in the country side of many developed country still operate on the principle of open cooling system. In this basic water cooled open system the inlet water permanently allowed at ambient temperature and rejected or discarded just few Celsius degrees above. Literature review

shows that running an ICE in an overcooling mode is detrimental to fuel consumption, oil operating life, exhaust emissions and engine operating life, [19]. The temperature of the oil in the crank case below 60 ^{0}C tends o accelerate cold sludge.

In the present work, the effect of preheating on the performance of a water cooled single cylinder diesel engine has been experimentally investigated.

EXPERIMENTAL

Figure 1 shows an illustration of the current basic open cooling system, where the coolant enter the engine without preheating or mixing with the outlet water.

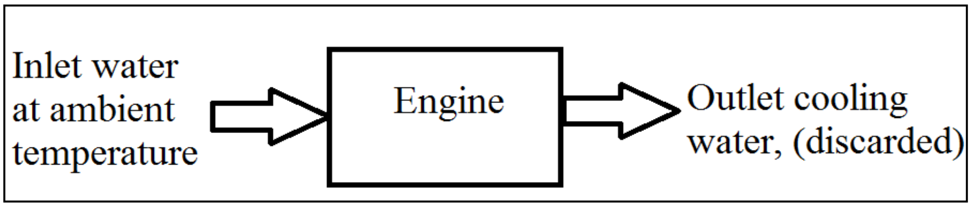

Fig. 1 Illustration of the basic open cooling system.

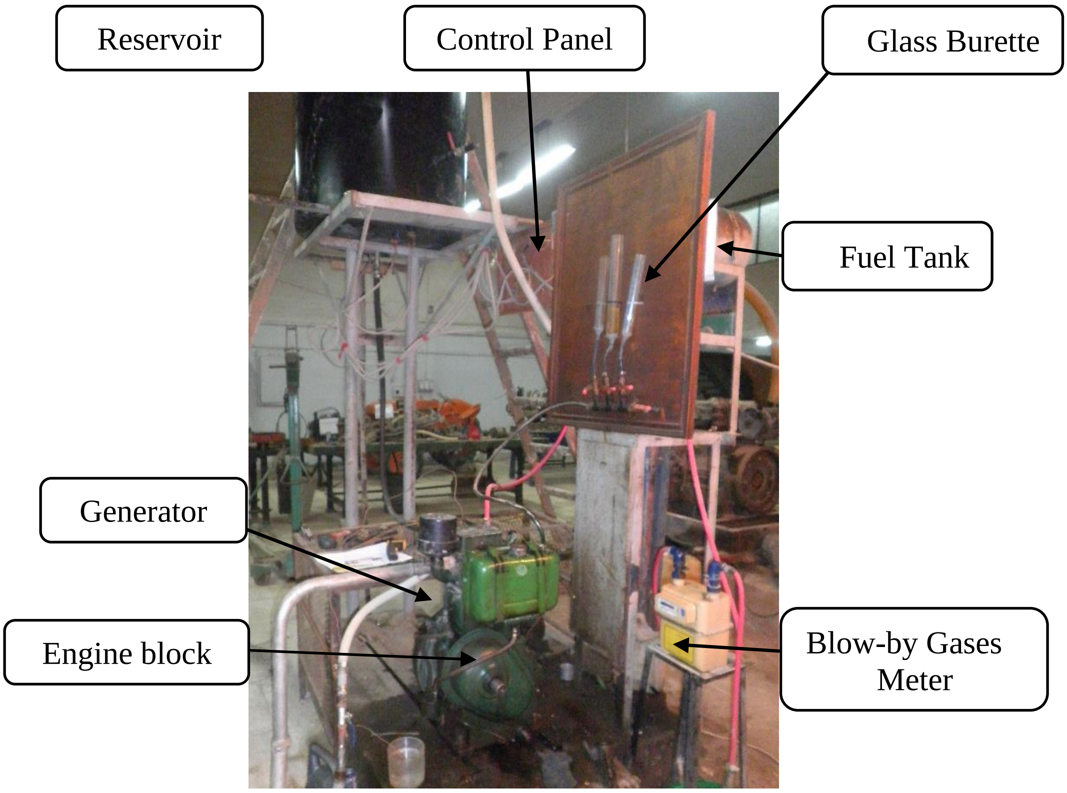

Fig. 2 Test rig.

Figures 2, 3 show the test rig used to conduct the course of experiments in order to investigate the effect of inlet cooling water temperature on engine performance. Test has been carried out on a KIRLOSKAR AV1 single cylinder diesel engine. It is a four stoke water cooled engine. The main specifications are as follows:

Swept volume = 0.553 liter,
Max. Power = 5 HP at 1500 rpm,
Bore = 80 mm, Stroke = 110 mm,
Compression ratio =16.5,
Fuel injection release pressure = 200 - 210 kg /cm^2,
The lubricant used was SAE 50 lube oil.

The engine has been attached to an AC dynamometer illuminating a number of electric bulbs, as shown in Fig.3. There is a tank provided by electric heaters in order to control the inlet water temperature. Blow by gases flow rate has been measured by a turbine flow meter. Oil and cooling water temperatures have been measured by thermocouples. There are also provisions to measure fuel consumption. Experiments have been carried out at inlet water temperature either 25ºC or 50 ºC. Each test last for 30 hours at 1.8 kW engine load and 1500 rpm.

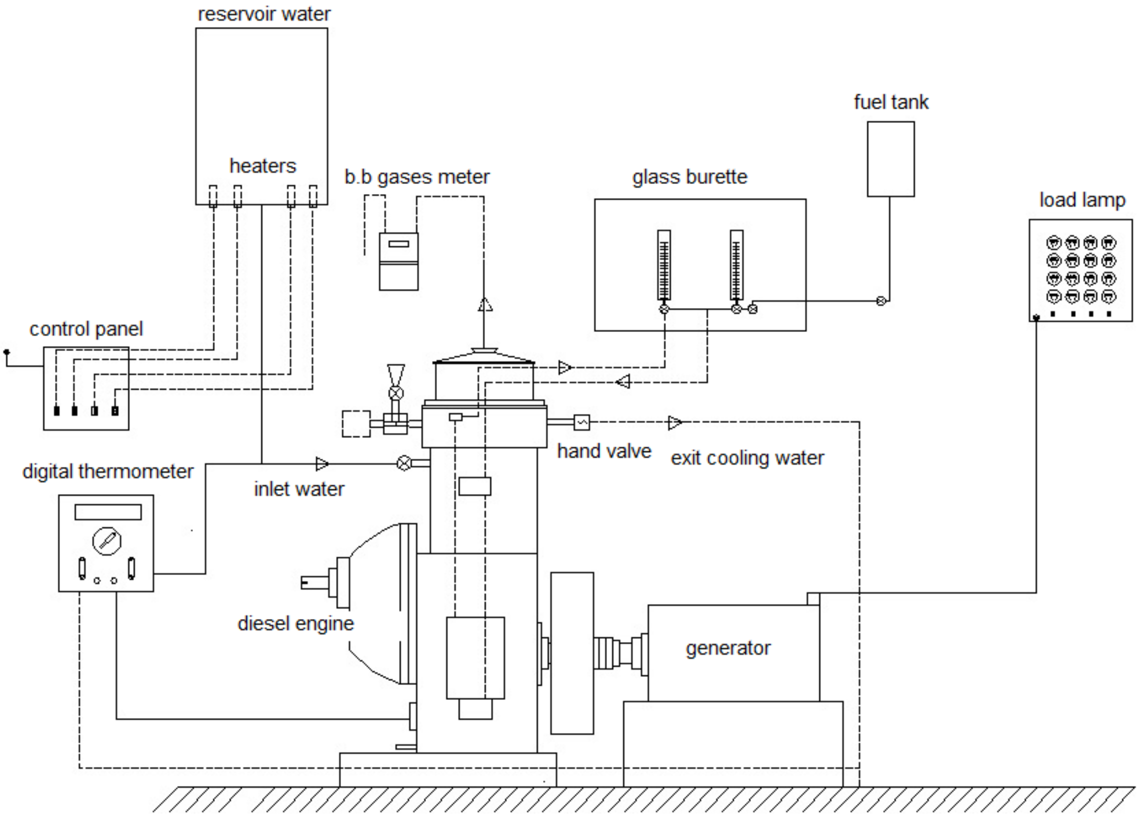

Fig. 3 Schematic drawing of the test rig.

RESULTS AND DISCUSSION

Figure 4 shows the amount of blow-by gases versus time at two cases. The first case, the inlet cooling water temperature has been allowed at ambient temperature, 22-27 °C. During the second case the inlet water has been heated up to 48-52 °C. It was observed that increasing inlet water temperature results in significant reduction in blow by gases flow rate. The detrimental effect of blow by gases on lube oil is well known. Blow by gases is also a source of pollution and energy dissipation. Although the higher inlet water temperature could raise lube oil temperature and reduce its viscosity and its

ability to seal blow by gases, this effect has been counteracted by minimizing the dilution of oil by condensing fuel near the cold cylinder wall and enhance the uniformity of cylinder liner surface. Due to the increase of inlet water temperature, the volume of blow by gases has been reduced to be 54%, as shown in Fig. 5, according to the results of a 30 hour test at 1500 rpm and % load.

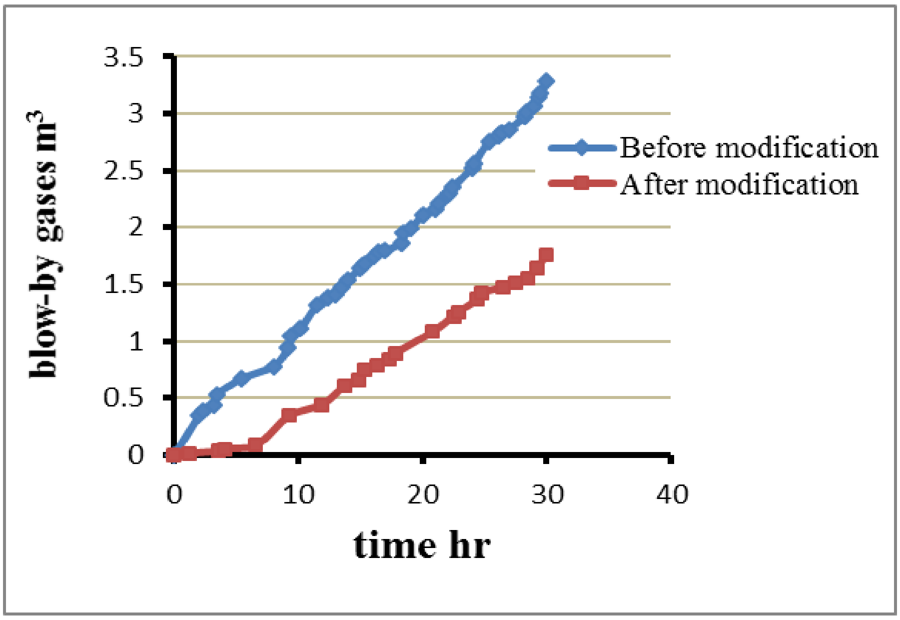

Fig. 4 Effect of inlet water temperature on the volume of blow-by gases.

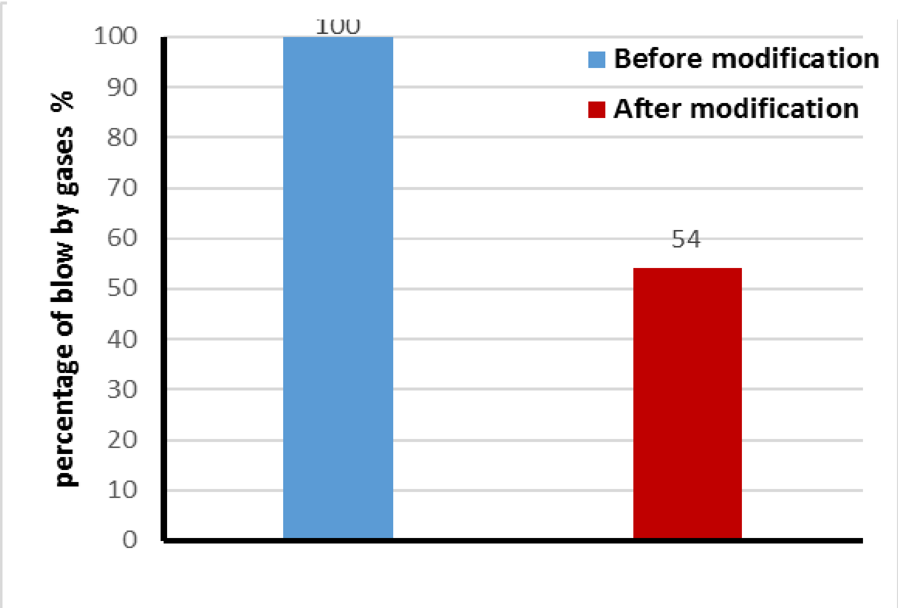

Fig. 5 Reduction of the volume of blow by gases as a result of inlet water temperature.

Figure 6 shows that the fuel consumption has been improved to be 93% due to the increase of water inlet temperature. Increase of engine temperature enhance combustion efficiency and reduce engine friction. Operating conditions at low inlet water

temperature led to dilution of the lube oil with fuel and consequently reduces lube oil viscosity.

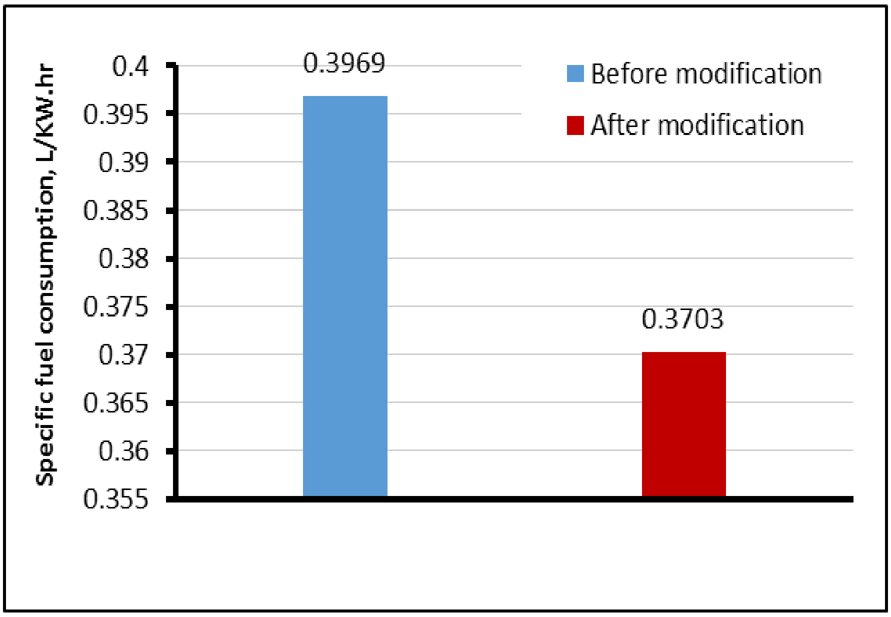

Fig. 6 Effect of cooling water inlet temperature on the fuel consumption.

In order to investigate the effect of inlet water temperature on the warm up period the lube oil temperature has been depicted versus time when the inlet water temperature was kept constant at either 22-27 °C or 48-52 °C, as shown in Fig. 7.

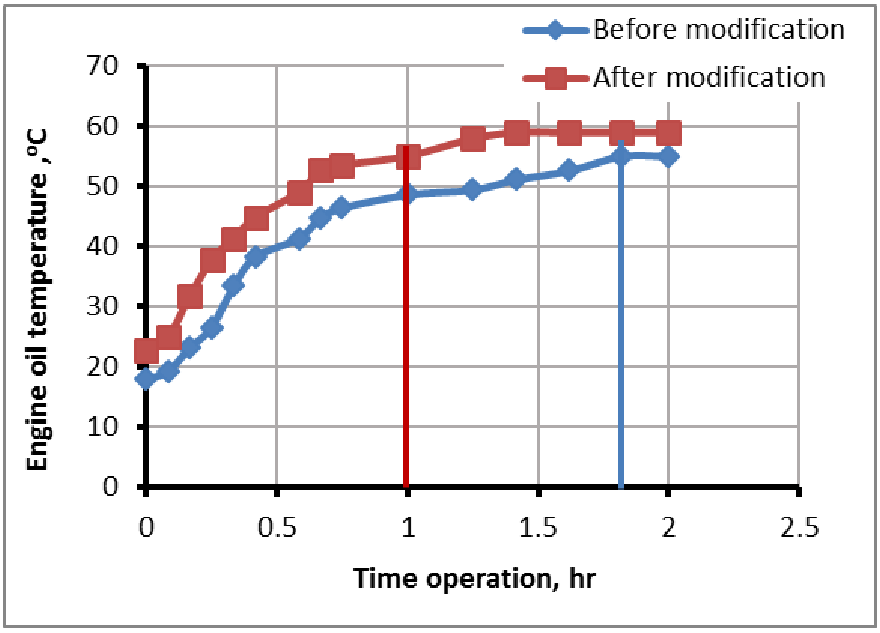

Fig. 7 Effect of inlet cooling water temperature on lube oil temperature.

The lube oil temperature stabilized at 55 °C after 1.83 hour when the cooling water temperature was kept at 22 - 27 °C. The stabilized temperature became 60 °C after one hour when the cooling water temperature was kept at the range of 48 - 52 °C. Thus increasing inlet water temperature resulted in the decrease of the warm up period up to 50 as shown in Fig. 8. As a result of increasing inlet water temperature, the lube oil bulk temperature has been stabilized at 60 °C instead of the 52 °C when the inlet water temperature was allowed at ambient temperature. From 60 °C to 140 °C the antioxidant and anti-corrosion properties should come into play. Above 140 °C, these properties might be less effective; more over at that temperature certain additives began to deteriorate, [19].

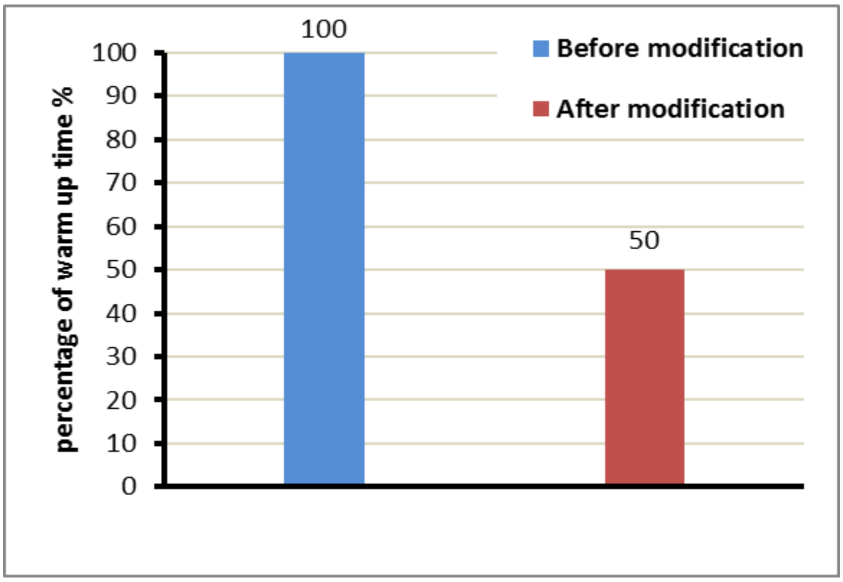

Fig. 8 Reduction of warm up period as a result of increase of inlet water temperature.

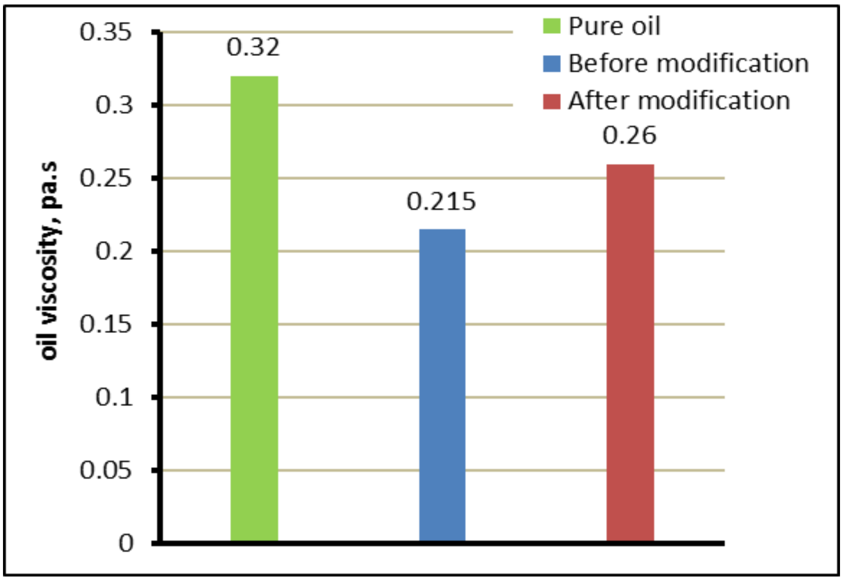

Fig. 9 Change of the lube oil viscosity.

Fig. 9 compares the lube oil viscosity after the 30 hour test and the viscosity of the fresh oil. Measurements of lube oil viscosity have been carried out at the same temperature for the three specimens. Operation at cold inlet water resulted in a reduction in lube oil

viscosity. This may be attributed to the dilution of oil by condensed fuel nearby cylinder wall. Comparison between the specific gravity of the three specimens shows that the specific gravity has been reduced in case of cold inlet water. The reduced specific gravity confirms the dilution effect of the condensed fuel.

CONCLUSIONS

1. The flow rate of blow by gases has been reduced to 0.54 % as the inlet water temperature increased from 22 - 27 °C to 48 - 52 °C.

2. Specific fuel consumption has been improved t0 be 93 % due to the increase of inlet water temperature from 22 - 27 °C to 48 - 52 °C.

3. Increasing inlet water temperature resulted in the decrease of the warm up period to 50 %.

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