EXPERIMENTAL STUDY OF TRIBOLOGICAL PARAMETERS OF MOTORIZED MULTI CYLINDER IC ENGINE

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Abstract: *The understanding of tribology is more important in reducing friction of an IC engine ie. piston ring assembly (PRA). There are many different types of four stroke multi cylinder IC engine in the market with fuel efficiency of 10 km per liter to 20 km per liter. So, it is preferable to select PRA system of same vehicle for study of piston ring assemble friction. Objective of the present study is to understand the fundamentals of friction in piston ring assembly. The experimental results under different operating parameter the performance of engine varies under different cooling condition. Variation in friction force is observed under different manufactured engine oil. The nature of the curve obtained is in line with Stribeck curve nature, means initially the system operates in boundary or mixed lubrication condition and later on mixed to hydro dynamic conditions. The different lubricants play role differently with variation in temperature at different location of engine. Lubricant oil 3 and 1 offered better results in comparison to lubricant oil 2. The power consumption in standard PRA system the ranking of three lubricant oil is 3-1-2. Experimental results find in good agreement with published literature so far nature.*

Keywords: IC engine, Tribology, Friction, Performance

1. INTRODUCTION

Congratulations! Engine friction is the primary difference between the energy input from the fuel and the energy available at the drive shaft of the engine. In an era where fuel conservation is becoming increasingly important, reduction in mechanical friction is an outstanding way to increase fuel economy without sacrificing performance. Gasoline and diesel are used as fuel in IC engine. Around 13-18% frictional losses are observed in automotive vehicles. Approximately 45-50 % losses of total losses are contributed by only Piston Ring Assembly (PRA) system. If these losses are reduced even by in turn of 1% it may result in saving of scare petroleum fuels. PRA is the heart of the IC engine. The various tribological factors which can influence the piston ring assembly such that piston and ring materials, piston ring clearance, lubricant properties, piston design and ring geometry etc.

1.1. Engine Tribology

Tribology derived from Greek word "Tribos" which means rubbing processes, is defined as the science and technology of interacting surfaces in relative motion. It focuses on friction, wear and lubricants of interacting surfaces in relative motion. Wear is the major cause of material wastage and loss of mechanical performance of many industrial systems. Tribology deals with surface interactions in machining components. If one wants to develop a highly efficient and reliable IC engine with miniature size at optimum running cost and less maintenance then one must have sufficient knowledge of tribological behavior which designing IC engine PRA system. To control friction between two surfaces, it is necessary to analysis the contribution of adhesion and deformation components of friction. Wear is a progressively loss of material from the mating surfaces of a pair of bodies in relative motion. The prime cause of wear is friction. Thin low shear strength layers of gas, liquid and solids are interposed between two surfaces in order to improve the smoothness of movements of one surface over another, to reduce chances of actually touching each other and carry away wear particles & other contaminates between two surfaces. In automotive industry, there are different type of lubricant developed as per requirement of engines, like two stroke engine, four stroke engines, gear oil, crankcase oil etc, In an IC engine there is a greater

number of parts that comes into contact with each other during their motion. So, friction is bound to be there. In order to obtain maximum efficiency of an engine it is required to reduce this friction force. The contribution of various experimented and estimated frictional losses reported by different scientist are shown in Table 1.

Table 1. Losses in IC Engine System

Total Losses	PRA (%)	Valve System (%)	Crank / Engine Bearing (%)	Auxiliaries (Pumping)	References
-	44	11	22.5	22.5	Michele
13	40	7	33	20	Domkundwar
7.5	40	60			Sushil Kumar
17	35-45	10-15	20-30	10-20	Heywood
-	44	25	10	15	Willard

From table 1 it is clear that about 40-50% losses occur due to friction in PRA mechanism. So, it is required to go into depth to reduce the friction in PRA mechanism to increase the efficiency. Efficiency suffers because the energy used to overcome friction represents a part of the input to the engine, which can never be converted to useful work from entering the combustion chamber.

1.2. Methods of Friction Measurement

Due to the importance of friction losses in an internal combustion engine, many methods have been developed to measure the engine friction loss with high accuracy. According to the ring friction is determined by the ring load, the surface properties and the lubrication conditions as determined by the sliding velocity and viscosity and availability of oil [1]. Experiments with two ring and three ring pistons have shown that the number of rings influences the frictional behavior of the ring pack but that the total tension of the piston rings in the ring pack finally determines the friction losses [2]. (a) Motoring Friction – Motoring by an engine by an electric dynamometer is the easiest method of quantifying friction. They have used this method and it was found to increase with speed. (b) Simulation of ring and cylinder friction – Measurements were made on test bench where parts of PRA and cylinder were elastically mounted and the friction force was directly determined from displacement [3,4]. They have experimented following observation the PRA friction force was found to increase linearly with the piston speed, decrease with increasing oil film temperature and slightly increase with gas pressure [5]. Piston rings operate most of the time in the partial film region. Piston lubrication was mostly hydrodynamic under normal condition. Use of low viscosity oil sudden increase in wear at TDC or BDC. (c) Oil Film Thickness Measurement – Measuring oil film thickness under engine operating condition through measuring the electrical resistance between the piston ring and cylinder liner. Gulat developed and used a mini transducer which could be mounted on the ring to measure the electric resistance between the piston ring and the cylinder liner along the stroke. (d) Indicated mean effective pressure – The method is based on an axial force balance around the piston assembly, which includes gas force, crankshaft force, inertial force and friction force. The instantaneous PRA friction was determined by substituting the axial force on the connecting rod from the gas force acting on the piston top. This method requires major engine modification since it needs a linkage device to support the wires needed to supply voltage to get signal from the strain gauge mounted on connecting rod. The problem of lubricant selection therefore to be considered early in design of a machine, but it is fact of life that machine often reach their users with lubrication problems still unsolved. Lubrication oil selection therefore an important subject for users of machine as well as their manufacturers to understand. In the present work study and analysis of the tribological

parameters of automotive engine oil. SAE20W40 multi grade engine oil is widely used in Indian condition.

2. LITERATURE REVIEW

The study of friction in PRA system is an active topic since 1925 in the field of engineering. An understanding of piston ring lubrication is vital in reducing engine friction. The piston ring has been the subject of many theoretical and experimental investigations from many viewpoints. They developed a simple yet reliable method to evaluate the overall friction power of an internal combustion engine by modification of the direct motoring method in which the engine is motored by an external means under conditions as close as possible to firing [6]. The major advantage of this method is no need for an external means of motoring and the test is performed under realistic temperature. They developed one dimensional, ring lubrication model for multi grade oils and rough surfaces to predict oil film thickness and piston ring pack friction [7]. The model can be applied to study the effects of oil properties, surface roughness, ring tension, shape, liner temperature, and engine operating condition on friction, oil film thickness and oil transportation between the ring and liner. They has experimented on 4-Stroke 4-Cylinder commercial SI engine to measure oil consumption at a speed 800, 2000 and 6000 rpm with variation in load such that no load to full load and observed that fluctuation in oil consumption observed at 4000 rpm that is due to instability of top ring [8]. They have experimented on motorized piston and cylinder system with application of different lubricants such as SAE15, SAE20, SAE30 and 2T along with different piston ring geometry at an rpm range from 500 to 1850 [9]. It was observed that ring geometry responses differently in case of same lubricant. One side chamfering on TDC side has offered the minimum friction among the tested other three types of ring geometry including the market available piston ring. He has put efforts to measure oil film thickness between piston and cylinder on a single cylinder engine. The experiments done at 700, 1300 and 1900 rpm show that oil film observed between 20 to mu at specified speed and it gives single location status of oil film thickness so it may not have the same thickness between the same defined crank angle position of piston [10]. They developed a one-dimensional mixed lubrication, wear and frictional model for the piston rings and cylinder liner. The model can predict the effect of surface roughness, asperity contact, and temperature pressure viscosity on wear lubrication and friction of the piston rings and cylinder liner [11]. Major conclusions are with increase in temperature the oil viscosity reduces as a result of smaller film thickness formation between the ring and cylinder liner. The viscous shearing friction decreases but asperity friction increases with the temperature. Higher surface roughness leads to higher friction and wear. They have work on thermodynamic analysis of piston friction in spark ignition internal combustion engine. The effect of piston friction on engine performance was examined during cold starting and normal working conditions [12]. A parametric study was performed covering wide range of dependent variables such as engine speed taking into consideration piston friction combined with variation of the specific heat with temperature and heat loss from the cylinder. The efficiency on piston friction observed decrease with the increase of engine speed. They developed versatile friction measurement systems for main engine assemblies of Recardo Hydro Gasoline engine. Major two types of friction losses are observed with components such that shear losses and metal to metal friction [13]. The study was carried out under realistic fire engine for the effect of two different lubricant using four temperature variation and three engine speeds. The power loss due to friction is measured for compression ring, oil control ring and piston skirt and the total loss. The major conclusion observed are IMEP method has been applied to measure piston assembly friction in a fired engine. The viscous oil reduced friction at higher lubricant temperature but relatively higher shear losses were observed at low lubricant temperatures. They presented this paper to show micro review on prediction of oil film thickness in piston ring cylinder assembly. Oil film thickness has been predicted by renowned researchers by identification of important variables affecting OFT

and assumed certain parameters as constant having insignificant impact on OFT while developing various models [14]. They have experimented on multi cylinder motorized test rig for non-fired engine system of multicylinder 800 cc engine and strip method is used to measure friction in terms of power consumption but in this method the effect of cylinder pressure is not measured and test will not be operating at realistic temperature [15]. Power consumption in different operating conditions is measured by running the PRA system with all three pistons. Performance effect of change in piston ring geometry can also be explained and compared with standard set of PRA system performance. The observations from the literature are maximum friction takes place at dead center, lubrication regime vary from boundary to mixed to hydro dynamic per cycle, oil film viscosity which reduces with the increase of temperature seriously affects the lubrication between ring and liner, surface texturing also plays an important role in reducing friction force, effect of coolant on friction force, the friction force between ring and liner decreases with speed of an engine. The major objective of present work is to modify multi cylinder motorized engine test rig, experimental work under different tribological parameters and validation of test rig with published literature.

3. EXPERIMENTATION

In the PRA friction measurement test rig, Maruti 800 cc multi cylinder IC engine system with crank mechanism, piston cylinder head, and engine lubrication system with engine cooling system without gear box is used. Overhauling and lubrication at various components is carried out through disassembling engine PRA system and put it into working condition as it was designed. The engine specification is shown in Table 2.

Table 2. Engine Specification

Type	4 Stroke Cycle, Water Cooled
Number of Cylinder	3
Lubricating System	Wet pump high pressure splash system
Cylinder bore size	68.505 – 68.520
Stroke Length	72 mm
Piston Displacement	796 cc
Compression Ratio	8.7:1
Maximum Output	37 bhp at 5000 rpm
Maximum Torque	59 Nm at 2500 rpm

A three phase AC motor with variable frequency drive is used for running the engine. A VFD is a system for controlling the rotational speed of an induction electric motor by controlling frequency of the electrical power supplied to the motor. With it we can adjust the speed at any value. The motor drive specification is shown in Table 3.

**Table 3. VFD Motor Drive Specification**

Model Number	VFD – XXXB, DELTA Electronics Inc.
Max Output	Applicable Motor Output 7.5 kW
Rated Output Capacity (KVA)	13.4
Rated Output Current (A)	13.5
Maximum Output Voltage (V)	3 phase proportional to input voltage
Output Frequency (Hz)	0.1 – 400 Hz
Rated Input Current (A)	13.8
Rated Input Voltage (V)	3 phase 500-600 V

A multimeter also known as a volt or ohm meter is an electronic measuring instrument that combines several measurement functions in one unit. This is a typical multimeter which

measure voltage, current and resistance. A multimeter device is very useful as it measures reading with high degree of accuracy. To measure the temperature of engine system at different eight location of Platinum Resistance Thermometer (PRT) are used. PRT offer excellent accuracy over a wide range of temperature. The principle of operation is to measure the resistance of a platinum element. PT 100 is most common type of PRT. It has a resistance of 100 ohms at 0°C and 138.4 ohms at 100°C. In experimental study three different types of engine oils were used. The idea behind the using different types of grades of oil is to find the most suitable oil for a particular application and find the effect of different grade of oil. The speed of engine taken during experiments 600, 900, 1200, 1500, 1800, 2100 and 2400 rpm. The type of coolants used were water. The three types of lubricants used are Maruti Genuine oil, Shell Helix and Castrol magnatech. The test sequence to conduct the experiment work on multi cylinder IC engine test rig are as follows (a) First of all select piston ring set and lubricating oil, (b) Prepare the engine for selected piston ring and lubricating oil, (c) check the foundation of test rig, (d) check all electrical connection of test rig including VFD and watt meter, (e) switch on the power supply and set the frequency on VFD to required rpm, (f) now switch on the VFD as soon as the VFD is on the motor will start to rotate and the engine is also rotating, (g) Initially the system is to be run for at least 5 to 10 minutes so that the system get stabilize and the lubricating oil can reach properly up to the surface of piston ring and cylinder liner, (h) after getting the stable condition of the system records the actual power consumed by the system rpm of the system and also the temperature of different eight location of an engine, (i) now for the next measurement change the frequency on VFD to change the rpm of the system (j) now run the system for at least 5 minutes so that the system get stabilize recorded the actual power consumption by the system along with rpm and temperature of eight location of an engine, (k) repeat the step (i) and (j) for measuring the power consumed for different revolution of the system, (l) switch off the power supply and allow the system to come in rest condition, (m) now repeat the same procedure for another measurement and (n) repeat procedure for 9 set of experiment and record all measurement.

4. RESULTS AND DISCUSSION

The power consumed by the engine was recorded for different lubricant at different engine speed. The temperatures of the system at eight different locations are recorded. The observations from the Figure 1 shows that power consumption increases as speed increases except 600 rpm. Power consumption is comparatively higher for oil 2 than oil 1 and oil 3. Power consumption is observed less for oil 3 with water as coolant.
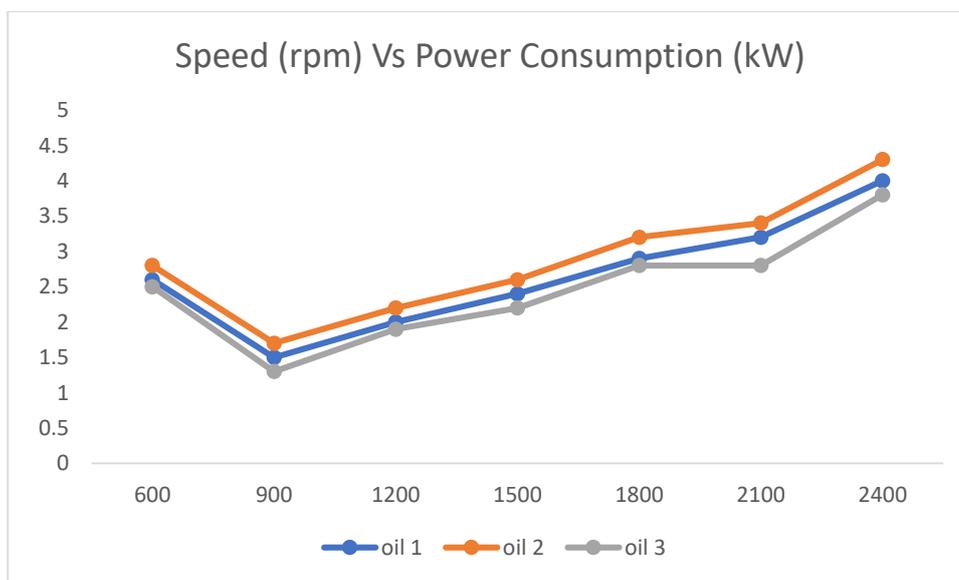
Figure 1. Speed versus Power Consumption with water coolant

The experiment was carried out on developed multi cylinder IC engine test ring under different lubricant and the temperature at crank bearing (T1) is recorded after steady running condition of the engine for about every 5-10 minutes. The minimum temperature for oil 1 is 37°C, for oil 2 is 44°C and for oil 3 is 51°C at 600 rpm whereas the maximum temperature for oil 1 is 65°C, for oil 2 is 77°C and for oil 3 is 66°C at 2400 rpm. The variation of crank bearing temperature T1 with change in rpm of engine is shown in Figure 2.
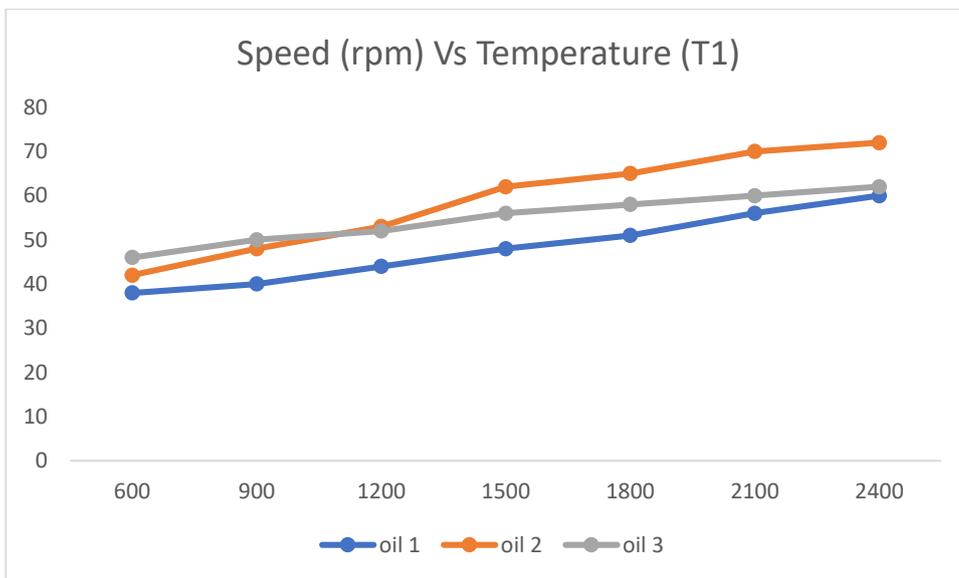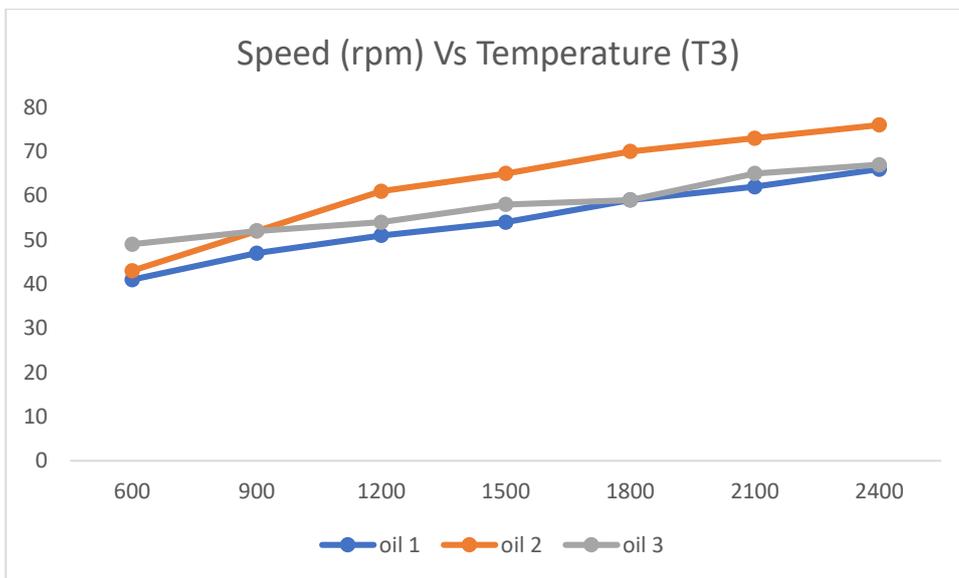

Figure 2. Bearing Temperature T1 versus Speed of engine

Engine test rig under different lubricant with water as coolant and temperature at cylinder 1 center such that T2 is recorded after steady running condition of the engine for about every 5-10 minutes. The minimum temperature for oil 1 is 52°C, for oil 2 is 55°C and for oil 3 is 61°C at 600 rpm whereas the maximum temperature for oil 1 is 85°C, for oil 2 is 96°C and for oil 3 is 86°C at 2400 rpm. The average minimum temperature is offered by oil1 and average maximum temperature is offered by oil 2. The variation of Cylinder 1 temperature T2 with speed of an engine is shown in Figure 3.
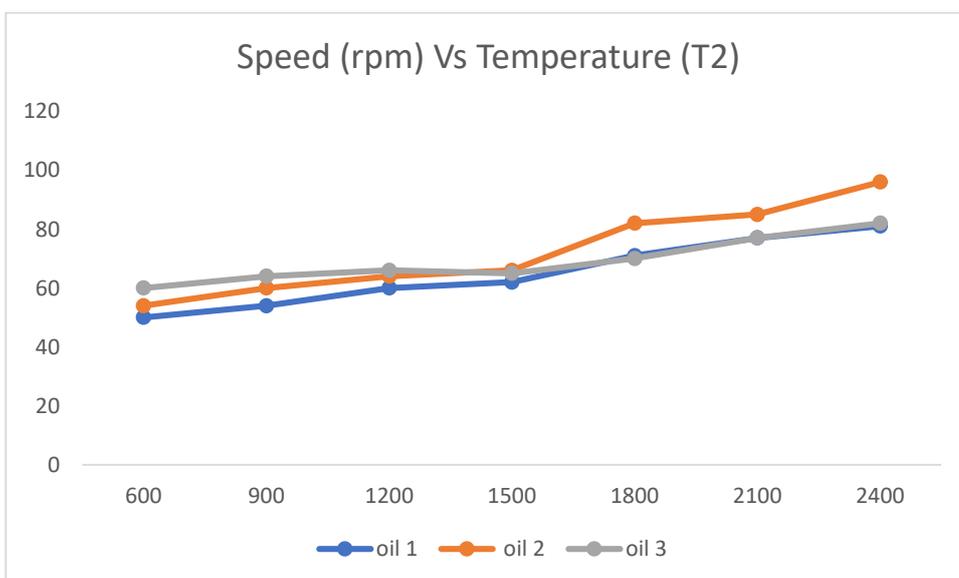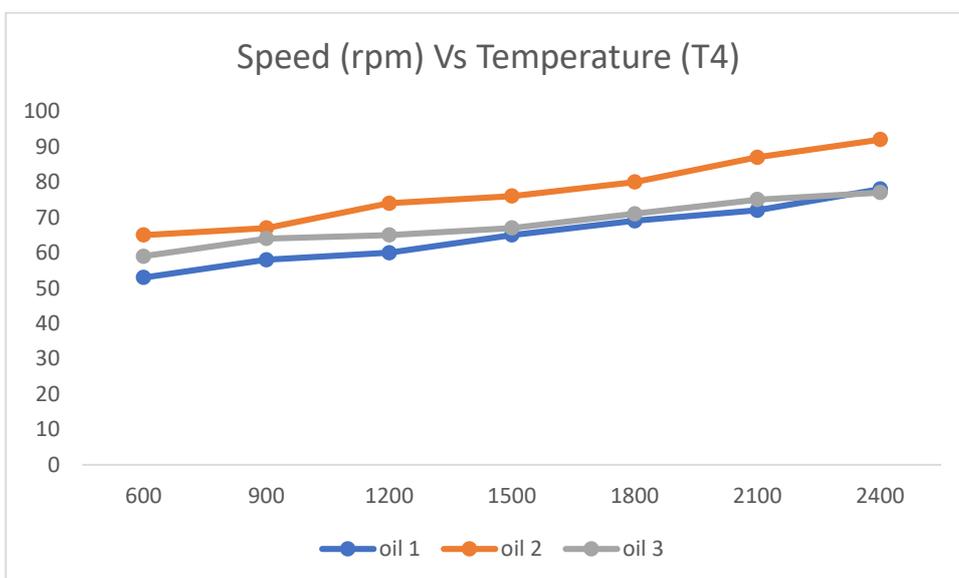
Figure 3. Cylinder 1 Centre Temperature T2 versus speed of engine

Engine test rig under different lubricant with water as coolant and temperature at cylinder 3 center such that T3 is recorded after steady running condition of the engine for about every 5-10 minutes. The minimum temperature for oil 1 is 42°C, for oil 2 is 44°C and for oil 3 is 52°C at 600 rpm whereas the maximum temperature for oil 1 is 68°C, for oil 2 is 80°C and for oil 3 is 70°C at 2400 rpm. The average minimum temperature is offered by oil1 and average maximum temperature is offered by oil 2. The variation of Cylinder 3 temperature T3 with speed of an engine is shown in Figure 4.
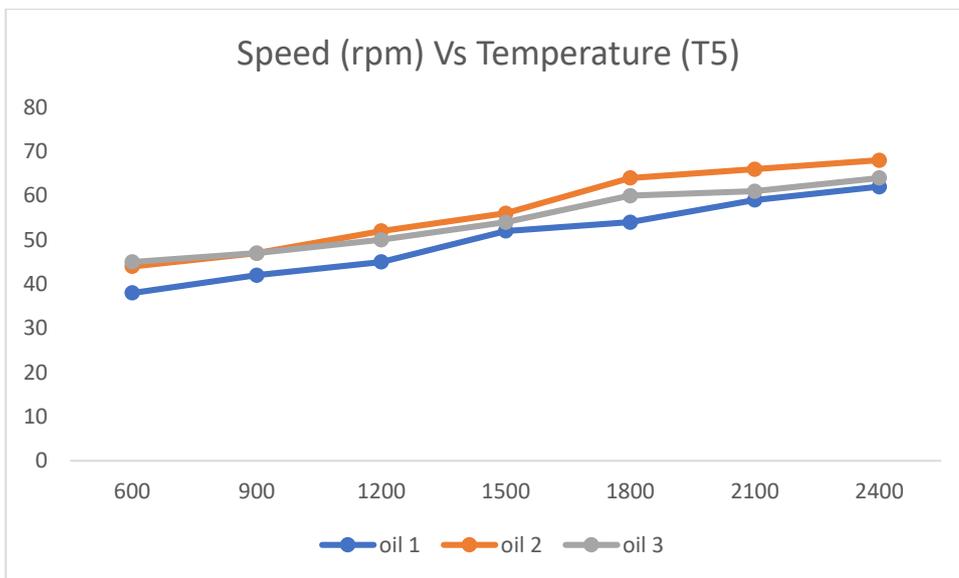

Figure 4. Cylinder 3 Temperature T3 versus speed of engine

Engine test rig under different lubricant with water as coolant and temperature at Spark Plug such that T4 is recorded after steady running condition of the engine for about every 5-10 minutes. The minimum temperature for oil 1 is 53°C, for oil 2 is 62°C and for oil 3 is 60°C at 600 rpm whereas the maximum temperature for oil 1 is 82°C, for oil 2 is 96°C and for oil 3 is 80°C at 2400 rpm. The average minimum temperature is offered by oil1 and average maximum temperature is offered by oil 2. The variation of Spark Plug temperature T4 with speed of an engine is shown in Figure 5.
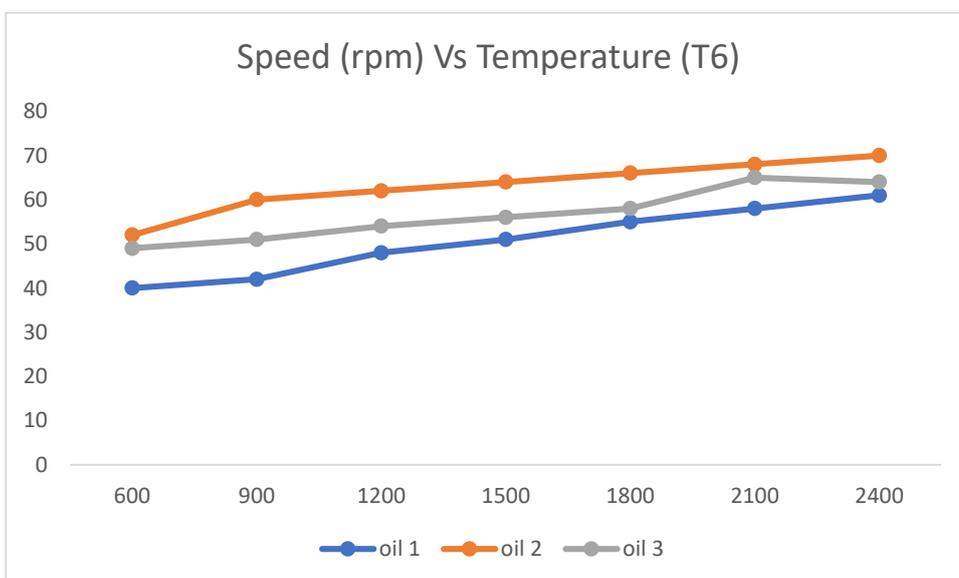
Figure 5. Spark Plug Temperature T4 versus speed of engine

Engine test rig under different lubricant with water as coolant and temperature at Cylinder 1 Top Dead Centre (TDC) such that T5 is recorded after steady running condition of the engine for about every 5-10 minutes. The minimum temperature for oil 1 is 38°C, for oil 2 is 45°C and for oil 3 is 47°C at 600 rpm whereas the maximum temperature for oil 1 is 58°C, for oil 2 is 68°C and for oil 3 is 62°C at 2400 rpm. The average minimum temperature is offered by oil1 and average maximum temperature is offered by oil 2. The variation of cylinder 1 TDC temperature T5 with speed of an engine is shown in Figure 6.
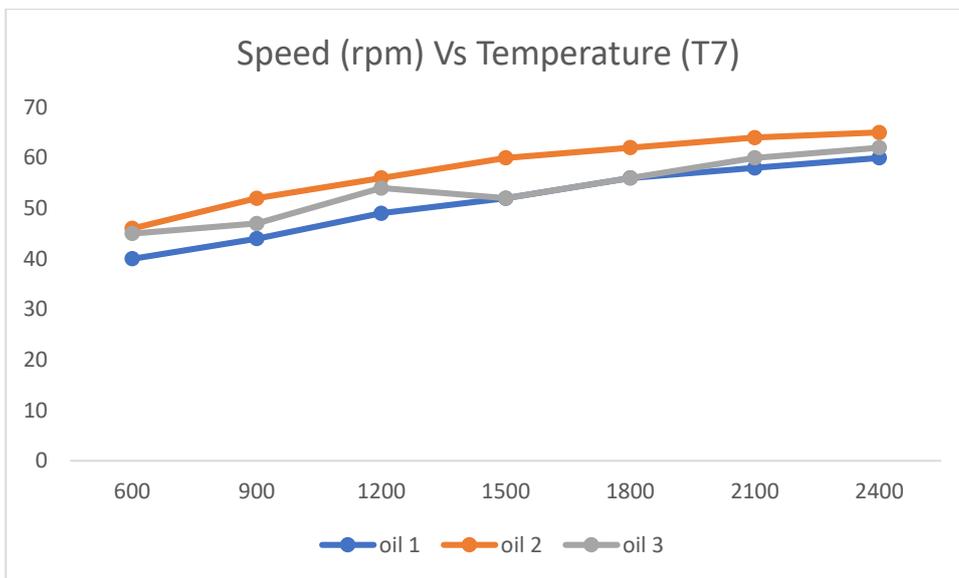

Figure 6. Cylinder 1 TDC Temperature T5 versus speed of engine

Engine test rig under different lubricant with water as coolant and temperature at Cylinder 3 Top Dead Centre (TDC) such that T6 is recorded after steady running condition of the engine for about every 5-10 minutes. The minimum temperature for oil 1 is 40°C, for oil 2 is 52°C and for oil 3 is 49°C at 600 rpm whereas the maximum temperature for oil 1 is 58°C, for oil 2 is 69°C and for oil 3 is 64°C at 2400 rpm. The average minimum temperature is offered by oil1 and average maximum temperature is offered by oil 2. The variation of cylinder 3 TDC temperature T6 with speed of an engine is shown in Figure 7.
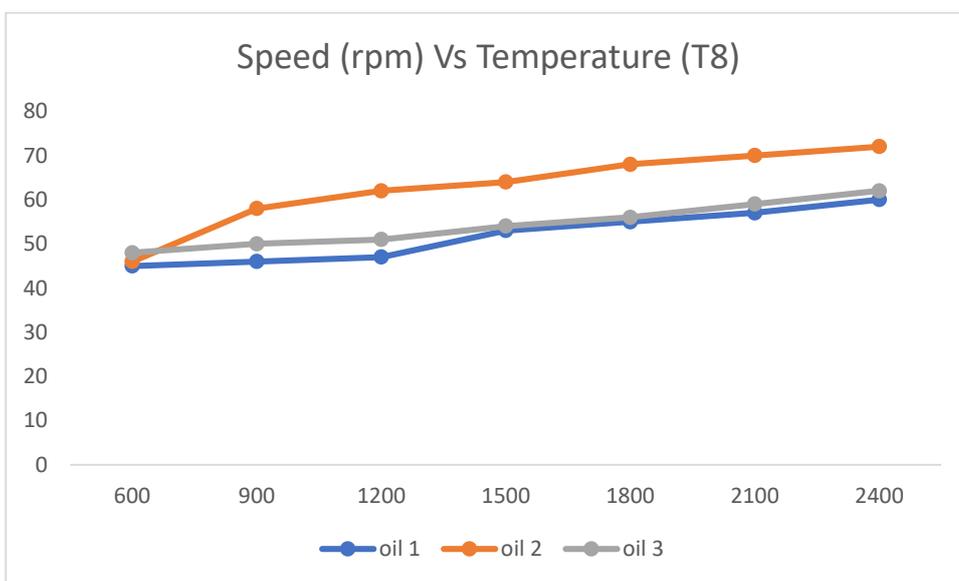
Figure 7. Cylinder 3 TDC Temperature T6 versus speed of engine

Engine test rig under different lubricant with water as coolant and temperature at Cylinder 1 Bottom Dead Centre (BDC) such that T7 is recorded after steady running condition of the engine for about every 5-10 minutes. The minimum temperature for oil 1 is 41°C, for oil 2 is 47°C and for oil 3 is 48°C at 600 rpm whereas the maximum temperature for oil 1 is 61°C, for oil 2 is 66°C and for oil 3 is 64°C at 2400 rpm. The average minimum temperature is offered by oil1 and average maximum temperature is offered by oil 2. The variation of cylinder 1 BDC temperature T7 with speed of an engine is shown in Figure 8.

Figure 8. Cylinder 1 BDC Temperature T7 versus speed of engine

Engine test rig under different lubricant with water as coolant and temperature at Cylinder 3 Bottom Dead Centre (BDC) such that T8 is recorded after steady running condition of the engine for about every 5-10 minutes. The minimum temperature for oil 1 is 46°C, for oil 2 is 50°C and for oil 3 is 52°C at 600 rpm whereas the maximum temperature for oil 1 is 62°C, for oil 2 is 70°C and for oil 3 is 66°C at 2400 rpm. The average minimum temperature is offered by oil1 and average maximum temperature is offered by oil 2. The variation of cylinder 3 BDC temperature T8 with speed of an engine is shown in Figure 9.

Figure 9. Cylinder 3 BDC Temperature T8 versus speed of engine

It is observed that initially power consumption is high for 600 rpm for all lubricants then power consumption reduced and after 900 rpm for all lubricants with water as coolant power consumption increases. Experimentally it is observed for power consumption oil 3 has offered maximum in compression due to hydrodynamic lubrication at all the tested observed rpm while this may not be in case of oil 2. Oil 3 has offered lowest temperature at all the observed temperature in compression to other lubricants while oil 2 has offered highest temperature. This may be because of higher side viscosity of oil 2 at all operating. Thus, the performance with respect to tribological parameter such that temperature varies under different lubricants which proves the importance of right selection of lubricant for a particular mechanism. Oil 3 performed best for all speeds.

5. CONCLUSIONS

Referring all the results and observations for the experiments carried out under different operating parameters the conclusion drawn are as follows. Performance of engine can vary under different conditions means all operating parameters have a vital role on engine performance. Lubricant temperature varies with different location in PRA system which also varies under different coolant application. Different brand lubricants of same specification exhibit different performance under same operating condition. The power consumption for the oil 3 is found to be least whereas oil 2 is found to be maximum. It is rather difficult to establish the lubricant ranking under multi variables dynamic performance of PRA system. However, with respect to power consumption for this system the ranking of lubricating oil is found to be 3, 1 and 2 respectively and with respect to temperature measured ranking of lubricant is 3, 1 and 2 respectively. Performance ranking of different brand lubricants found same under different operating condition validates the test rig design. In future we can change the piston ring profile, location of piston ring and effect of coating on piston ring.

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