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Experimental Investigation & Analysis of Gear Oil for Power Loss and Oil Temperature in Helical Gearbox

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Abstract — *A gearbox is a set of gears for transmitting power from one rotating shaft to another. They are used in a wide range of industrial, power plant, automotive and home machinery application. A gear heads are available in different sizes, capacities and speed ratios. Mostly their main function is to convert the input provided by an electric motor into an output of lower r.p.m and higher torque or high r.p.m and lower torque. This continuous transmission of the torque in gearbox increase the wear and temperature between to rubbing surface of gear teeth due to friction. The gear oil which is use to reduce this friction loss have high viscosity. This viscosity of gear oil will increase power losses of gear box. So this work is consent for find out power loss for same viscosity index gear oil. For finding this power loss in reduction helical gear box, three EP series gear lubricant oil (EP-90, EP-140 and EP-220) and one vegetable castor oil is considered for experimentation and the input power of gear box, output power of gear box, motor current and temperature of gear oil is considered as response parameter. From this study, finally conclude that Power loss of Caster oil is less compared to other gear oil. The results of the experiments confirm with the existed CFD results.*

Keywords *– Experiment And Investigation Of Gearbox, Gear Oil for Power Loss, Oil Temperature in Helical Gearbox.*

I. INTRODUCTION

EFFECTIVE FACTORS ON GEARBOX EFFICIENCY

Total system efficiency (motor plus gearbox) is neither clearly understood nor easily calculated. This makes gearbox efficiency specifications unreliable because they typically provide only a single efficiency rating. Efficiency depends on a number of factors, especially gearbox loading, but most manufacturers do not list efficiency tolerances, or the difference in efficiencies between a heavily loaded gearbox and one running under normal loads. The electrical input power to a gearbox (the product of voltage and current to the motor) multiplied by motor efficiency is the input power to the gearbox. Output power is the gearbox speed and load torque. The ratio of output power to input power equals efficiency. Power loss in the gearbox is mostly due to friction, which generates heat. In miniature gearboxes, heat is not much of a problem because the power losses (and absolute amounts of power involved) are relatively small. However, large gearboxes use oil coolers and pumps to compensate for gearbox inefficiency. Gearbox friction in turn depends on the quality of the gearing, the number of tooth engagements (how many times one gear drives another).

GEAR OIL

Gear oil is a fluid lubricant used in gears (gearboxes) for reduction of friction and wear of the gear tooth surfaces, removal of the heat generated by the operating gear and corrosion protection of the gear parts. The following properties of gear oils are important.

- Proper viscosity
- Ability to withstand extreme pressures (Ep)
- Thermal and oxidation stability
- Corrosion and rust protection
- Compatibility with seal materials.

VISCOSITY OF GEAR OILS

Viscosity of gear oil is a compromise between the gear parameters requiring low viscosity and those requiring high viscosity. Low viscosity is favorable for high speed, low loaded gears with a good tooth surface finish. Low viscosity provides thin oil film, low friction (high mechanical efficiency), good cooling (heat removal) conditions. High viscosity is favorable for low speed, highly loaded gears with a rough tooth surface. High viscosity provides thick 13 oil film, high wear resistance and low galling even at high pressure (Ep). Viscosity of gear oil depends on the temperature therefore oil selected for a particular gear should provide its reliable operation within the expected temperature range. The low temperature limit of gear oil is 9°f (5°c) higher than its pour point (the lowest temperature, at which the oil may flow). Mineral oils possess relatively high pour point about 20°f (-7°c). Pour point of synthetic oils may reach 50°f (-46°c). The highest operation temperature in spur gears is about 130°f (54°c). In the worm gears the temperature may reach 200°f (93°c).

DESIGNATION OF GEAR OILS BY PERFORMANCE

American petroleum institute (API) established a performance grading system for gear oils.

Gl-1:- Gl-1 gear oil has rust and oxidation protection effect but it does not contain extra pressure (Ep) additives. The oil is used in low load applications only.
Gl-2:- Gl-2 gear oil contains more additives than Gl-1, but without Ep effect. It is used in medium loaded worm gears.
Gl-3:- Gl-3 gear oil possesses light Ep effect.
Gl-4:- Gl-4 gear oil possesses moderate Ep effect. It is most widely used oil.
Gl-5:- Gl-5 gear oil possesses high Ep effect. It is used in hypoid and other highly loaded gears.

Choosing the right gearbox lubricant provides the benefits of lower wear rates, lower operating temperatures and greater energy efficiency. Viscosity index is important because it indicates how the oil's viscosity varies at high temperatures. The higher the viscosity index, the less the oil viscosity change has to be considered. The pressure viscosity coefficient is defined by how the oil changes viscosity under load. The pressure is increases at that time the viscosity increase. Plant professionals need to understand that gear oil affects several design considerations, including reliability. Gearbox energy efficiency increase can be achieved by using high-quality oil depends on the gear type. Depending on specific plant operating conditions, lubricants might perform a variety of wide ranging functions. There are several additional elements to consider when selecting an appropriate lubricant. These include operating speed, type of friction, load and environmental conditions, and industry standards. Depending on the machine, component or application, the plant engineer should look at different fluid properties by considering factors like the load, speed, type of gearing, number of stages and the combination of metals in the gearbox.

TYPES OF GEAR OILS

Combinations of additives impart special functions to gear oils

Rust and oxidation preventive gear oils rust and oxidation preventive oils are mainly mineral base. They contain rust and oxidation inhibitors. The viscosity of rust and oxidation oils according to the ISO grading system is between 32 to 320.

Compounded gear oils

Compounded oils are mineral base. They contain rust and oxidation inhibitors, demulsifies and up to 10% of fatty oils for better lubricate. Compounded oils are used mainly in worm gears. The viscosity of compounded oils according to the ISO grading system is between 460 to 1000.

Extreme pressure (Ep) gear oils

Ep oils may be either mineral or synthetic base. They contain Ep additives, rust and oxidation inhibitors, anti-foaming agents and demulsifies. The viscosity of Ep oils according to the ISO grading system is between 68 to 1500.

Synthetic gear oils

Synthetic gear oils may be based on poly alpha olefins, esters oils or poly glycols. They may contain Ep additives, rust and oxidation inhibitors, anti-foaming agents and demulsifies. The viscosity of synthetic oils according to the ISO grading system is between 32 to 6800. Synthetic gear oils are used for gears operating under extreme conditions.

II. EXPERMENT SETUP

A special-purpose test set-up was developed in this study to allow a direct measurement of the power loss of gear box under varying oil. A schematic layout with each component labeled is provided in Fig.1. And an image of the experimental test set-up is shown in Fig.2.

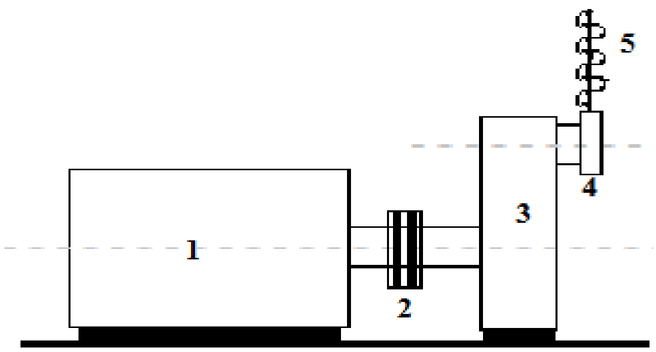


Figure 1. A schematic diagram of experimental setup.

Fig.1 shows a schematic diagram of experimental setup, which are place on working model where, 1-induction three-phase motor, 2-star coupling, 3-gearbox, 4-pulley, 5-rope brake dynamometer.

Figure 2. Experimental testing model

In this arrangement, gear box was held by metal plate. A set of bolts were used to hold the plate. At the input side, 1 hp 3-phase AC induction motor was used to drive gearbox. The output shaft of the induction motor is connected to gear box. The output shaft of gear box is connected to motor shaft by star type love jaw coupling. Output shaft of gear box is connected to rope break dynamometer. The different load applied at rope break dynamometer is adjusted by spring load. The input power is measured with the help of ammeter at different time. The proximity sensor measures input and output shaft speed of gearbox. The 3-phase AC induction motor was capable of reaching input speeds up to 1450 (±10) rpm. The rope break dynamometer measure output torque and two thermocouple measure temperature of oil.

Specification of Motor

Motor type	3 phase AC induction motor
Rated power supply	1 hp (0.75 KW)
Rated voltage	440 volt (±5)
Rated Speed	1450 (± 10) r.p.m

Selection of Gear Oil

From the Gear oil specification given by "LAXMI TRANSMITION" the common gear oils used in industry for reduction gear box is EP- series gear oil. The viscosities for gear oil are given as below.

Product	viscosity (cst)at 40°c	viscosity (cst)at 100°c	Viscosity index
EP-90	90	10	90
EP-140	140	14.80	90
EP-220	220	19	90
Castor	315	--	--

Measuring Parameters

- Input current
- Input r.p.m
- Output r.p.m
- Temperature

Measuring The Electric Current.

Ammeter (0-20 amp)

An ammeter is a measuring instrument used to measure the electric current in a circuit. Electric currents are measured in amperes (A), hence the name. Instruments used to measure smaller currents, in the microampere range, are designated as micro ammeters. Early 41 ammeters were laboratory instruments which relied on the Earth's magnetic field for operation. By the late 19th century, improved instruments were designed which could be mounted in any position and allowed accurate measurements in electric power systems.

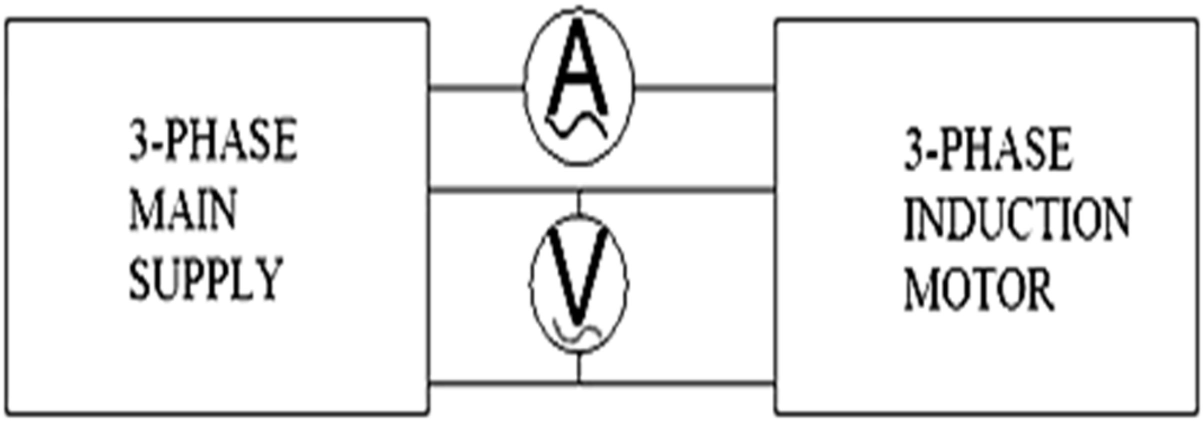


Figure 3. A schematic diagram of a –meter and volt meter electrical circuit.

Measure The Speed Of Motor And Transmission.

Proximity sensor (0-5000 r.p.m)

High speed counting applications, mechanical switches are not suited. Firstly they cannot handle the rapid switching on/off expected of them (responses faster than 10 times per second are rare), secondly the number of switching cycles can be very high which is a concern given the limited switching life of these switches and thirdly contact bounce is a major concern with the use of these switches. Proximity switches, given their electronic construction do not suffer from these disadvantages, they can switch up to 5000 times per second, they have almost unlimited life and their 'contacts' switch cleanly without bounce. They are thus ideally suited to rotational speed measurement or for high speed counting applications. A sensor is essential to sense shaft speed. Typically, devices used for this purpose are shaft (rotary type) encoders, photoelectric (optical type) sensors and magnetic rotational speed (proximity type) sensors. All of these sensors send speed data in the form of electrical pulses. Shaft encoders offer a high resolution of typically 1-5000 pulses per revolution (PPR) and clearly defined, symmetrical pulses. Proximity sensors provide medium resolution sensing, depending on the number of pulses measured per revolution. Photoelectric sensors usually sense a reflective target on the rotating shaft. Magnetic rotational speed sensors use various magnetic proximity measuring principles to monitor the speeds of machine components in a range between 0 and 30,000 rpm. In principle, RPM sensors convert mechanical motion into electric pulses with or without direct contact when positioned near a turning rotor, gear, shaft or other regularly moving device. The resultant output signals are then fed to a digital counter or other monitoring and control device.

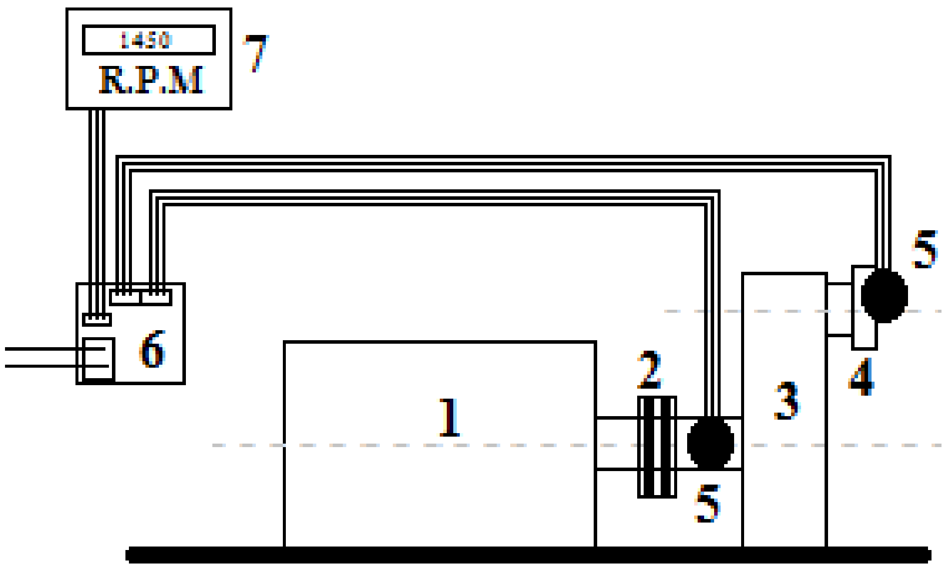
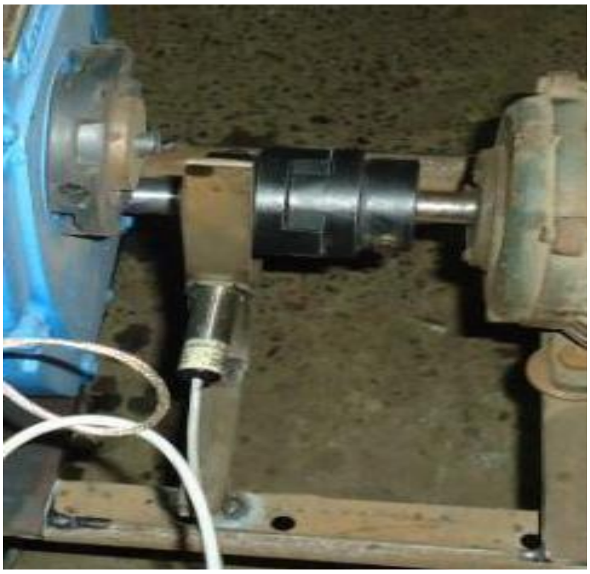


Figure 4. A schematic diagram of proximity sensor electrical circuit.

Fig.5 shows a schematic diagram of proximity sensor electrical circuit, which are place on working model where, 1-induction 3phase motor, 2-star coupling, 3-gearbox, 4-pulley, 5-proximity sensor, 6- 2way switch, 7-r.p.m indicator.



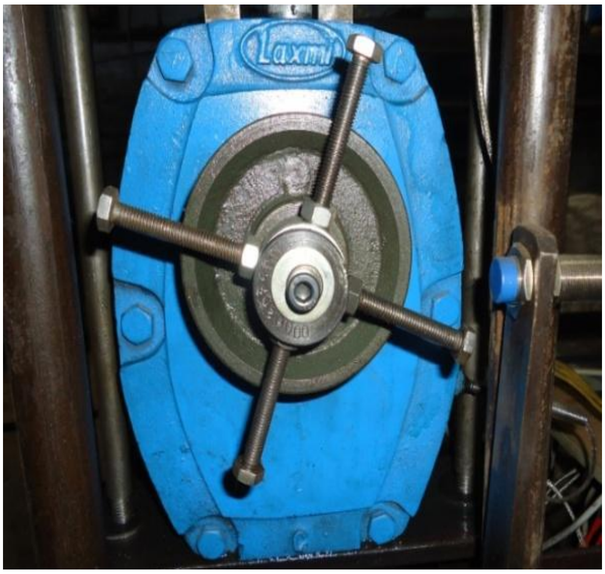


Figure 5. Proximity sensor at input and output shaft.

Measure The Temperature Of Oil.

- **Thermocouple (0-200°c)**

The general circuit for the working of thermocouple is shown in the figure 6 above. It comprises of two dissimilar metals, A and B. These are joined together to form two junctions, p and q, which are maintained at the temperatures T1and T2 respectively. Remember that the thermocouple cannot be formed if there are not two junctions. Since the two junctions are maintained at different temperatures the paltrier emf is generated within the circuit and it is the function of the temperatures of two junctions. If the temperature of both the junctions is same, equal and opposite emf will be generated at both junctions and the net current flowing through the junction is zero. If the junctions are maintained at different temperatures, the emf will not become zero and there will be a net current flowing through the circuit.

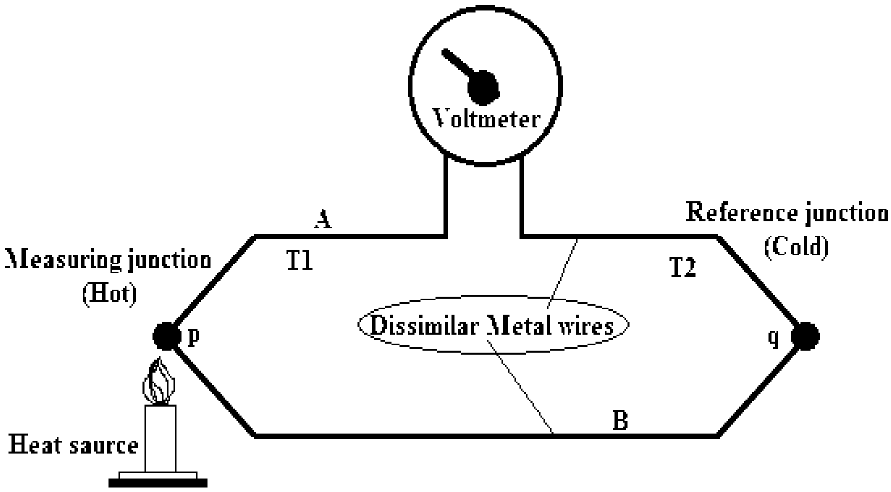


Figure 6. Thermocouple circuit

The total emf flowing through this circuit depends on the metals used within the circuit as well as the temperature of the two junctions. The total emf or the current flowing through the circuit can be measured easily by the suitable device. The device for measuring the current or emf is connected within the circuit of the thermocouple. It measures the amount of emf flowing through the circuit due to the two junctions of the two dissimilar metals maintained at different temperatures. In figure, Point 2 the two junctions of the thermocouple and the device used for measurement of emf (potentiometer) is shown. Now, the temperature of the reference junctions is already known, while the temperature of measuring junction is unknown. The output obtained from the thermocouple circuit is calibrated directly against the unknown temperature. Thus the voltage or current output obtained from thermocouple circuit gives the value of unknown temperature directly.

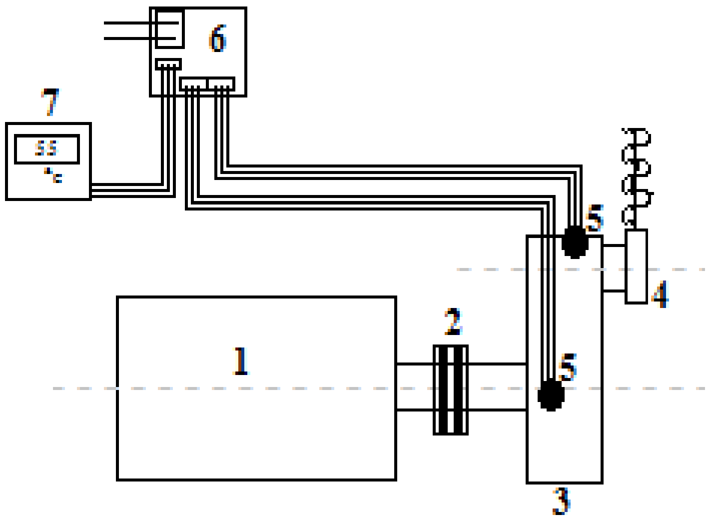


Figure 7. A schematic diagram of thermocouple electrical circuit.

Fig.7 shows a schematic diagram of thermocouple electrical circuit, which are place on working model where, 1-induction three phase motor, 2-star coupling, 3-gearbox, 4-pulley, 5-thermocouple, 6- 2way switch, 7-temprature indicator.

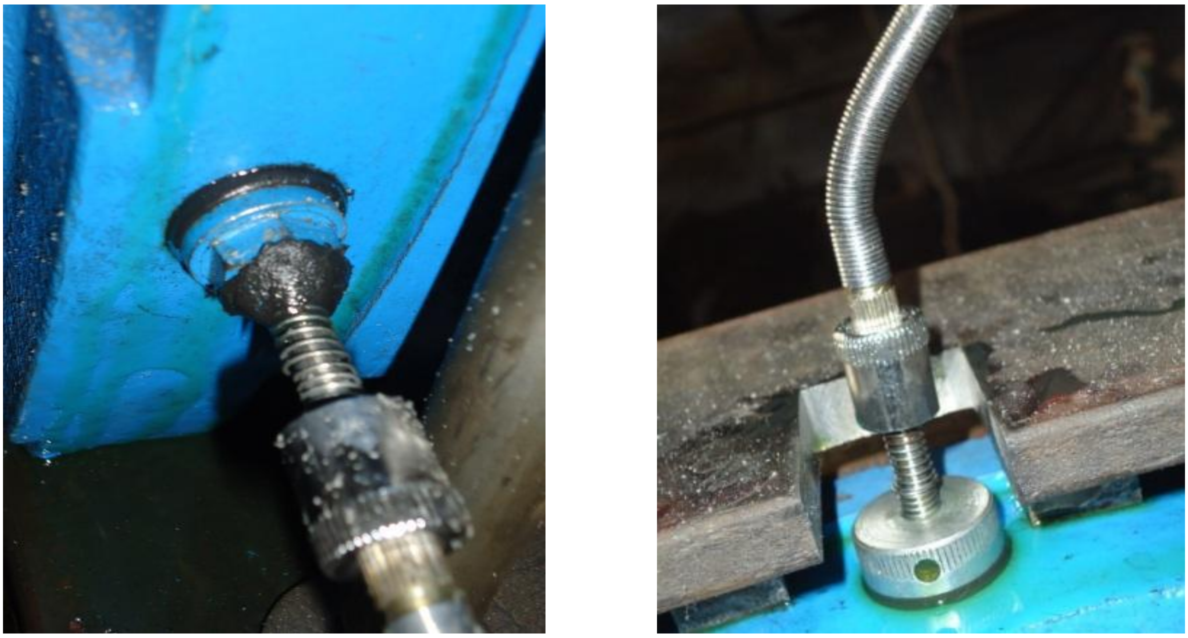


Figure 8. Thermocouple at side and top on gear casing.

Experiment Process

In the experimental process, first, oil is filling from the top side of gear box. Oil filling hole fit by the aluminum bolt. Thermocouple is fitted inside the bolt. Run the motor at 1450 RPM and check the input current of the motor, input and output speed of the gear box, and temperature of gear oil. After the completion of 100 min. test, collect the oil from the bottom and closed hole by bolt. After than for cleaning of the gear teeth fill up the one liter kerosene into the testing gear and run a gear box for 15 to 20 seconds. The cooling of the gear box approximately takes one day so it is put on empty and rest potion for one day. This experimental procedure is repeated for three another types of gear oils.

III. EXPERIMENT RESULT

Experiment of Ep-90 gear oil at 1450 r.p.m of 1-hp 3-phase AC induction motor is conducted for different time and the measured value of input speed, output speed, input current of motor and Temperature of oil are shown below in Table 1.

Table 1. Experiment result of EP-90 oil

Time (min)	Input speed (r.p.m)	Output speed (r.p.m)	Current (AMP)	Temperature (°c)
0	1442	71.50	1.69	32.0
5	1443	71.75	1.68	34.0
10	1444	71.75	1.67	35.5
15	1444	72.00	1.67	37.5
20	1445	72.00	1.66	40.5
25	1445	72.00	1.66	42.0
30	1445	72.00	1.66	43.5
35	1445	72.00	1.65	45.0
40	1446	72.00	1.65	46.0
45	1446	72.00	1.65	47.0
50	1446	72.00	1.64	48.5
55	1447	72.00	1.64	49.0
60	1447	72.00	1.64	49.0
65	1447	72.00	1.64	49.5
70	1447	72.00	1.63	49.5
75	1447	72.00	1.63	50.0
80	1447	72.00	1.63	50.5
85	1447	72.00	1.63	50.5
90	1447	72.00	1.63	51.0
95	1447	72.00	1.63	51.0
100	1447	72.00	1.63	51.0

Experiment of Ep-140 gear oil at 1450 r.p.m of 1-hp 3-phase AC induction motor is conducted for different time and the measured value of input speed, output speed, input current of motor and Temperature of oil are shown below in Table 2.

Table 2. Experiment result of EP-140 oil

Time (min)	Input speed (r.p.m)	Output speed (r.p.m)	Current (AMP)	Temperature (°c)
0	1438	71.25	1.71	33.0
5	1439	71.50	1.70	34.5
10	1440	71.75	1.69	36.5
15	1441	71.75	1.68	41.5
20	1441	72.00	1.68	42.5
25	1441	72.00	1.67	43.5
30	1441	72.00	1.67	45.5
35	1442	72.00	1.66	46.5
40	1442	72.00	1.66	47.5
45	1442	72.00	1.66	49.0
50	1443	72.00	1.65	51.0
55	1443	72.00	1.65	51.5
60	1444	72.00	1.65	52.0
65	1444	72.00	1.64	52.5
70	1444	72.00	1.64	52.5
75	1444	72.00	1.64	53.0
80	1445	72.00	1.63	53.5
85	1445	72.00	1.63	53.5
90	1445	72.00	1.63	54.0
95	1445	72.00	1.63	54.0
100	1445	72.00	1.63	54.0

Experiment of Ep-220 gear oil at 1450 r.p.m of 1-hp 3-phase AC induction motor is conducted for different time and the measurd value of input speed,output speed, input current of motor and Temperature of oil are shown below in Table 3.

Table 3. Experiment result of EP-220 oil

Time (min)	Input speed (r.p.m)	Output speed (r.p.m)	Current (AMP)	Temperature (°c)
0	1437	71.25	1.75	34.0
5	1438	71.50	1.74	35.5
10	1439	71.75	1.73	38.0
15	1440	71.75	1.72	41.5
20	1440	71.75	1.71	42.0
25	1440	71.75	1.70	43.5
30	1440	71.75	1.69	44.5
35	1441	72.00	1.69	46.0
40	1441	72.00	1.68	47.5
45	1441	72.00	1.68	48.5
50	1441	72.00	1.68	49.0
55	1441	72.00	1.67	49.5
60	1441	72.00	1.67	50.5
65	1441	72.00	1.67	51.5
70	1442	72.00	1.66	53.0
75	1442	72.00	1.66	54.0
80	1442	72.00	1.65	54.5
85	1442	72.00	1.65	55.5
90	1442	72.00	1.65	56.5
95	1442	72.00	1.64	57.0
100	1442	72.00	1.64	57.0

Experiment of Castor oil at 1450 r.p.m of 1-hp 3-phase AC induction motor is conducted for different time and the measured value of input speed, output speed, input current of motor and Temperature of oil are shown below in Table 4.

Table 4. Experiment result of castor oil

Time (min)	Input speed (r.p.m)	Output speed (r.p.m)	Current (AMP)	Temperature (°c)
0	1443	71.50	1.69	33.0
5	1444	71.75	1.68	34.5
10	1445	72.00	1.66	36.5
15	1447	72.00	1.65	41.0
20	1447	72.00	1.65	43.5
25	1447	72.00	1.65	45.0
30	1447	72.00	1.64	47.0
35	1447	72.00	1.64	48.5
40	1447	72.00	1.64	50.0
45	1447	72.00	1.64	50.5
50	1447	72.00	1.63	51.5
55	1448	72.00	1.63	52.5
60	1448	72.00	1.63	52.5
65	1448	72.00	1.63	53.5
70	1448	72.00	1.62	54.0
75	1448	72.00	1.62	54.0
80	1448	72.00	1.62	54.5
85	1448	72.00	1.62	55.5
90	1448	72.00	1.62	56.0
95	1448	72.00	1.62	56.0
100	1448	72.00	1.62	56.0

III. CONCLUSION

The experimental processer carried out for find out power losses due to gear oil (EP-90, EP-140, EP-220, and CASTOR) in gear box it is concluded that the power losses in gear box is decreasing with increasing of gear running time. Also it is seen form fig 9 for power losses due to gear oil vs. time that the power loss is directly proportional to viscosity.

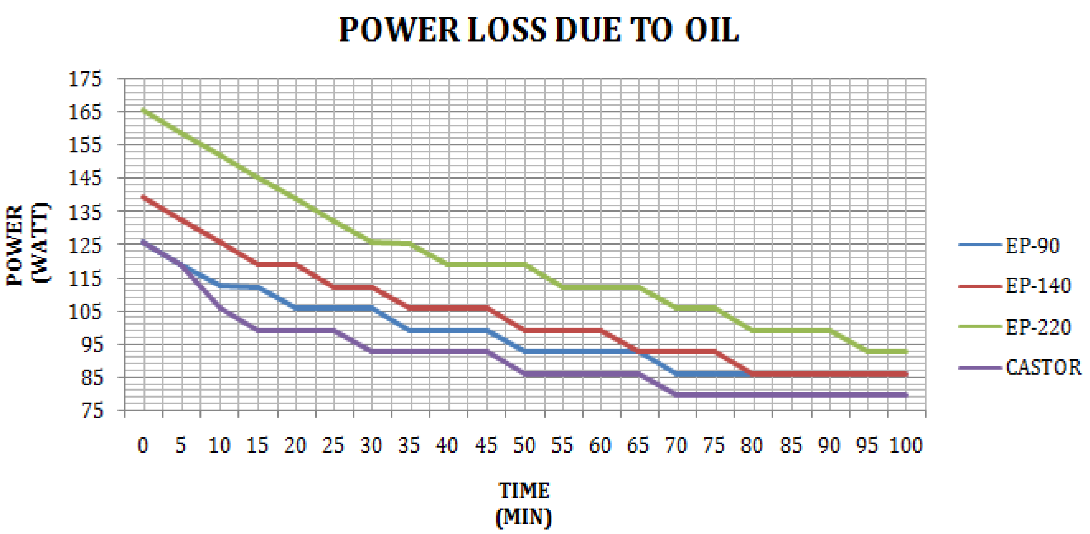


Figure 9. Graph of power loss due to oil vs. time

The experimental analysis for find out the power losses in gear box due to different gear oil (ep-90, ep-140, ep-220, castor) is carried out for 100 min. from the experiment it is conclude that,

1. The input power is decreases with increases of gear running time for all the gear oil. The EP-220 having very high input power during the hole running time of the gear box, while the castor oil having less input power compare to all other gear oil in hole gear running time.

2. The output power is increasing with increase of the gear running time but after 35 min it's become maximum for all the gear oil. The EP-220 has required more time compare to other oil for reaching maximum output power, while the castor oil has required very less time to reach at maximum output power compare to other gear oil.

3. The current of the motor is decreases with increases of gear running time for all the gear oil. The EP-220 has required more motor current compare to other oil, while the castor oil has required very less motor current compare to other gear oil.

4. The temperature of the gear oil is increasing with increase of the gear running time. The EP-220 having high temperature of oil compare to other gear oil, while the EP-90 oil having less temperature compare to other gear oil.

5. The power loss due to the gear oil is decreases with increases of gear running time for all the gear oil. The EP-220 having higher power loss compare to other gear oil, while the castor oil having very less power loss compare to other type gear oil.

6. The castor oil is best alternative lubricant in reduction gear box for reducing power losses with low cost.

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