Study of Margosa Oil (Neem Oil) Added Lubricants for Automotive Tribo-materials

By
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Submitted in Partial Fulfillment of The Requirements for The Degree Of Master of Philosophy in Chemistry

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Declaration

It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

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Certificate

This is to certify that the work incorporated in this thesis "***Study of Margosa Oil (Neem Oil) Added Lubricants for Automotive Tribo-materials.***" submitted by Md. Abu Sayed has been carried out under my supervision. The work embodied in this thesis is original and I declare that it has not been submitted in part or in full for any degree or diploma of any other university or Institution.

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Dedicated
To
My Parents

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Thesis Approval

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Abstract

A comparative study on physico-chemical properties of palm and margosa oil blended lubricants and on the corrosion behavior of automotive tribo-materials was conducted. In this work viscosity, density, flash point, fire point, total acid number, IR spectroscopic analysis and electrochemical corrosion were studied. Experimental parameters were: different percentages of palm and margosa oil in lubricants, temperatures and specially for corrosion three different tribo-materials.

Viscosity and density of base oil and palm or margosa oil added base oil were decreased with the increase of temperatures. The highest and lowest viscosity found at 30^0C and 100^0C respectively. At 100^0C, increase of viscosity and density with the increase of palm and margosa oil in lubricating oil was found. Although viscosity and density of margosa oil blended lubricants were found higher than palm oil blended and 30,40,60, and 80^0C. But at 100^0C, the palm oil blended lubricant showed higher viscosity and density than margosa oil blended lubricant. No changes of flash and fire point was found in palm and margosa oil blended lubricant in this work.

The degradation of palm and margosa oil blended lubricants were studied by the determination of total acid number and IR spectroscopic analysis. Total acid number increased with the increase of oxidation (heating) time. The highest total acid number was found for 8% palm and margosa oil added lubricants after 24 hours oxidation. Comparison of palm and margosa oil blended lubricants, showed high acid value for margosa added lubricants at all times. Larger changes of margosa oil blended lubricants than palm oil blended lubricant were found from the IR spectroscopic analysis of 8% palm and margosa oil blended lubricants.

Electrochemical corrosion behavior of three tribo-materials was studied by potentiostatic method at 30, 40 and 60^{0}C. The corrosion rate of 0.16% and 0.79% carbon steel increase with the increase of palm oil percentage in the lubricating oil at all temperature. Corrosion rate of brass was negligible in all palm blended lubricants at all temperature. From the comparison of corrosion characteristic of different palm oil blended lubricants, it is found that 2% palm oil has the highest inhibiting property among the three tribo-metals under study.

But in margosa oil added lubricants the corrosion rate of 0.16% and 0.79% carbon steel increases with the increase of margosa oil upto 6% at all temperature. However, at 60^{0}C, 8% margosa oil blended lubricating oil showed the highest inhibiting property than other margosa oil blended lubricating oil. Although 8% margosa oil blended shows the general character at room temperature.

In the case of brass alloy a steady corrosion rate was observed at all temperature in all types of margosa blended lubricants. At room temperature slightly increased corrosion current was observed at higher potential.

Comparison of corrosion behavior of palm and margosa oil blended lubricating oil showed that any percentages of palm oil blended lubricants showed better inhibiting property than the corresponding margosa oil blended lubricant. 2% palm oil added lubricant showed the highest corrosion inhibition at all temperature for three tribo-materials under study. At 60^{0}C, 8% margosa oil added lubricant showed significant inhibiting character than any other margosa oil blended lubricants.

Chapter-1

Introduction

INTRODUCTION

1.1 General

Most mechanical engines and machines have components, which slide over other surfaces. As a result, friction develops, even in the finely smooth surfaces(1,2). This may be due to the molecular cohesion forces or may be due to the Vander Waal's attraction between the particles of the two surfaces. In the science of lubrication the friction is considered as the thief of power and destroyer of bearings. At the same time generation of heat also takes place due to friction. On finely polished metal surface, peaks and valleys of different heights and depths are observed microscopy. The highest peaks are called "asperities" when two such fine metal surface contact with each other then friction arises between "asperities" (Fig 1.1).

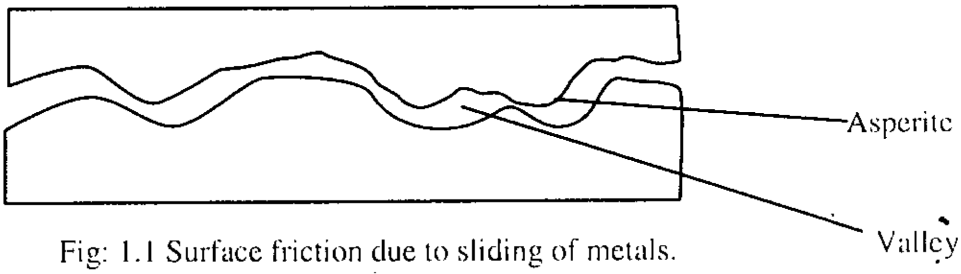


Fig: 1.1 Surface friction due to sliding of metals.

Leonardo da Vinchi (1452-1519) was first describe a friction Amonton and Coulomb developed the concept of friction. The systematic investigation to reduce the frictional effect was started by Osbon Reynold in 1886.

The Classic laws of friction as evolved from these earlier studies can be summarized as follows(1,2):

1. Frictional force is proportional to load.
2. Coefficient of friction is independent of apparent area of contact.
3. Static coefficient is greater than kinetic coefficient.
4. Coefficient of friction is independent of sliding speed.
5. The coefficient of friction is material dependent.

Mechanical interloging, molecular attraction, electrostatic force, welding forces, machinery are to explain the nature of friction.

To reduce the detrimental effects lubricant is used. Lubricants are the substances that are used to reduce or minimize the frictional resistance between two solid surfaces, which are in contact(1,2). There are different types of lubricant-a) solid b) semi-solid c) liquid and d) gases lubricant. Graphite, chalk, talk, gold, is the solid lubricant. Grease, tallow, foam etc are used as semisolid lubricants. Vegetable oil, mineral oil, etc are used as liquid lubricants. Air is the best example of gaseous lubricants.

Now a days different types of liquid lubricants such as vegetable oil, animal fats, mineral oils, blended or compounded lubricants are used in modern machinery (1,2).

Before the advent of petroleum industry, the main liquid lubricants were the fatty oils of *animal and vegetable origin*(1,2). Vegetable oils and animal fats are ester of higher fatty acids. Since they decompose on heating they can not be distilled. That is why they are called fixed oil. The example of such oils are; castor oil, rapeseed oil, colza oil, lard oil, sperm oil etc. Fixed oil have an important property called " oiliness" by virtue of which they are adsorbed on metal surface tenaciously and offer lower coefficient of friction and higher load carrying capacity than the petroleum oil. After the advent of petroleum industry the use of vegetable oils as lubricant becomes limited.

Now a days *lubricant of mineral origin* are generally used, because of many advantages over lubricants of plants or animal origin. The main advantage are their low cost and inertness to humid weather. A large number of lubricants or lubricating oil are obtained as a heavy residue from the fractional distillation of crude oil at atmospheric pressure. The residue is mainly composed of paraffinic and asphaltic substances. Their boiling points are quite high and are not suitable for distillation under atmospheric pressure. Distillation normally produces three main lubricating oil fractions such as light, medium and heavy stocks. These lubricating oil fractions contain large number of impurities such as paraffin waxes, resins, asphalts, oxy, and thio derivatives etc. These impurities are undesirable for a good lubricating oil, as because these impurities have some detrimental effects on the properties of lubricants(1,2).

In recent years, commendable progress has been made in the improvement of refined oils by adding small quantities of various additives. The oils thus prepared are known as *blended oils or compounded oils*. The types and the quantities of the various additives used for a lubricating oil for a particular purpose is a complex and specialized job and should be decided only after careful and judicious balancing of the effects of the individual additives. Additives such as detergents and deflocculents, dispersents, anti-oxident, corrosion inhibitor, anti-wear, extreme pressure, antifoam etc. are used in blended lubricant(1,).

A good lubricating oil must obtain some properties, the most important properties of lubricating oils are considered during their choice for suitable use are: specific *gravity, viscosity index, carbon residue, colour, oxidation stability, cloud point, fire point, flash point, pour point etc*(1,2).

In the petroleum industry, specific gravity of liquid is usually expressed in degrees of API.

Degrees of API are expressed as:

$$\text{Degree API} = \frac{141.5}{\text{Specific gravity } 60^{\circ F}/60^{\circ F}} - 131.5$$

The API degrees are approved by the American Petroleum Institute and are extensively used in specifying petroleum products. It should be noted that as the specific gravity of oil increases the degree API decreases, i.e. lighter liquids like paraffin base oils have higher degree API and heavier liquid like napthanic base mineral oils.

Viscosity and it changes with temperature are very important properties of lubricating oils. Viscosity is a measure of internal friction in the liquid which is considered as the inherent principle of lubrication of fluid. A good lubricating oil must have an optimum viscosity (neither too high to shear force nor too low which is unable to bear the load) (1,2).

The unit of viscosity usually used is centipoise poise. This is one hundredth of a poise. i.e. 0.01 poise. Poise may be defined as force in dyne which is necessary to impart a velocity 1 cm. per sec. to I (one) sq. cm. layer relative to another parallel layer 1 cm. away.

In the petroleum industry of United States, viscosity is almost invariably expressed on arbitrary scale as the number of second required for 60 cm^3 of the oil to run through a standard orifice from a cylinder filled to a definite level at a standard temperature.

The instrument used for making such measurement is the Saybolt Universal viscometer and the viscosity thus determined is called Saybolt Universal Viscometer (S.U.V) (1,2).

The variation of viscosity with temperature is known as viscosity index. Viscosity index may also be regarded as the rate of change of viscosity with temperature and is a measure of paraffinic nature of lubricating oil, because the rate of change of viscosity of paraffinic oil with temperature is very low.

When lubricating oil is used in an engine, there is a tendency to form residue at the end, which is known as *carbon residue*(1,2). It is usually expressed, as the weight percentage of carbon residue in the original weight of oil taken. The percentage of carbon residue in oil is proportional to the amount of carbon deposited in the combustion chamber. In addition to carbon residue, other conditions in the engine also influence carbon deposits.

Colour of lubricating oil mainly depends upon its constituents(1,2). It varies from almost transparent to pitch black with all intermediate shades of yellow, red and brown. The colour of an oil to some extent indicates its origin. For example, paraffine base oils show green bluish appearance while naphtha base oils have a bluish appearance. In general heavier is the fraction, higher is the boiling point and darker is the colour. Sometimes, the degree of deterioration or contamination of lubricating oil is reckoned by comparing the colour of the unused oil.

Specific heat(1,2) may be defined as the quantity, which is required to raise the temperature of one gram of a substance by 1^0. The specific heats of most lubricating oils vary form 0.44 to 0.49. Information of specific heat is required in heat transfer problems. Such as, pertaining to the design of plain bearings where lubricating oil functions both as lubricant and as a coolant.

Oxidation stability (1,2)is also an important property of lubricating oil, particularly when it is used for a longer period of time, particularly in automobile engine. Oxidation of straight mineral oil proceeds slowly at room temperature, but greatly accelerated at higher temperature. Oxidation is also accelerated by the presence of moisture in the environment as well as by the presence of oxidation catalyst like Fe, Al and Cu. The resistance of oils to oxidation largely depends on the nature of crude oil and the method of refining. Oxidation stability of lubricating oil, is related to sludge formation, carbonization, thickening and the development of oil acidity during service. In general paraffinic base lubricating oils have higher oxidation stability than olifinic and naphthenic oils. The most reliable tests for oxidation stability are actual engine and service tests. But these are very expensive and time consuming. A variety of short time standard tests at higher temperature and sometimes with catalyst have been devised. Many of the tests are very important if the results are interpreted with caution. Oxidation products are undesirable because the insoluble oxidation products or sludge may clog oil lines, filters and other parts of the lubricating system. On the other hand, the soluble oxidation products circulate with oil may corrode or pit bearing surfaces or may form harmful and tenacious varnish like deposits or gums. Thus reduce oxidation of lubricating oil oxidation inhibitors such as phenyl β-naphthylanine is used.

For low temperature working lubrications *pour point* is very important(1,2). It may be defined as the temperature which the oil becomes semisolid and ceases to flow when cooled at a standard rate. Pour point is dependent upon wax present in a given sample of lubricating oil and determines the temperature below which oil can not be used as lubricant in the engine. In general, lower is the pour point better is the quality of oil. Now a days some substance are used as additive to lower the pour points. These are called pour point depressant.

Cloud point is another important property of lubricating oil, which depends upon the presence of wax. It may be defined as the temperature at which lubricating oils become hazy or cloudy when cooled at a standard rate. Cloud point of oil always occurs at a higher temperature than the pour point(1,2). At this temperature cloudiness develops due to separation of wax in crystalline or amorphous forms.

Flash point and fire point indicates the volatility and tendency of the oil to be burned in the engine(1,2). Flash point is defined as the temperature at which lubricant oil gives off enough vapors to ignite for a moment by flashing but will not continue to burn, when an open flame is passed over the oil.

Fire point may be defined as the temperature at which the oil will burn continuously at least for five second when a flame is brought nearer to it(1,2). These properties do not correlate any way to the lubrication properties of oil but serve as a guideline to be used in machine functioning at high temperature. Flash point should always be higher than temperature at which the machine will function. Fire point in most cases are higher than the flash point by 5-40^{0}C.

Ash content is the percentage of solid substance remain after burning a known amount of lubricating oil(1,2). The percentage of ash in a lubricating oil may cause wear and abrasion. In fact the origin of ask content in lubricating oil is the presence of inorganic substance either in dissolved or in colloidal form. On ignition these substances oxidize to form ash.

Lubricating oils are hydrocarbons. Hydrocarbons are neither *acidic nor basic*. But during refining treatment followed by neutralization with alkali, minute amount of acids may remain along with organic constituents of lubricating oils(1,2). This small intrinsic acidity may not be harmful in it self, but the degree to which it increases in used oil is usually considered as the deterioration of the oil due to oxidation.

The *acidity or alkalinity*(1,2) of lubricant oil is determined in terms of *Neutralization number*. It is defined as the number of milligram of KOH required to neutralize all the free acid present in 1gm of oil. It is just similar to the acid value or acid number of oil. The neutralization of oil is determined by titrating a definite amount of oil with a 0.1N standard KOH solution. Acid number greater than 0.1 is usually considered as the indication of oxidation of oil.

Corrosive substances like H_2S, Sulfur and polysulphides are always found in petroleum(1,2). So when lubricating oil containing these substance are in contact with metals particularly copper, zinc etc. the metallic parts are corroded. Thus the refining processes remove these corrosive substances. To prevent corrosive effect of lubricating oil some organometallic substances such as organic compounds of Arsenic, Antimony, Chromium, Bismuth, Lead etc. are added. These substances are called inhibitors.

Pure oil and water are completely immiscible liquid pair. They do mix with each other, if these two liquids are brought together and thoroughly shaked even then they separate out forming two layers fairly quickly. But there are some lubricating oils which mix with water forming emulsions. Thus *emulsification* is the property of oil to get intimately mixed with water forming an emulsion(1,2). Emulsion has the tendency to attract dirt, grit, and foreign matter etc. as a result of which abrasion and wearing out of lubricated parts of the machinery may take place. Sometimes thy clog the oil lines also. Thus, formation of emulsion in one sense is beneficial but persistence of emulsion is harmful. Therefore a good lubricating oil is one, which forms an emulsion with water but undergoes de-emulsification very quickly. This particular property of lubricating oil is expressed as de-emulsification number. This is determined by allowing the emulsion to stand and to undergo de-emulsification. The time required in second, to separate out emulsion into its constituents is called steam emulsion number (SEN). The lower the steam number, the quicker the oil separates out form the emulsion formed. Good lubricating oil possesses low steam emulsion number.

Oiliness is a very important property of the lubricant by virtue of which lubricating oil can stick on the surface of the matching parts operating under high pressures(1,2). Oiliness of mineral oil is very low. On the other hand animal and vegetable oils have good oiliness property. Hence oiliness of mineral oils is generally improved by adding small quantities of high molecular weight fatty acids, like oleic acid, stearic acid, chlorinated esters of these acids etc. There are no perfect method for the determination of absolute oiliness of oil. However, relative oiliness is considered while selecting lubricating oil for a particular job.

Volatility is one of the important properties of lubricating oil; particularly it is used for high temperature work(1,2). Mineral oils of relatively higher molecular weight such as lubricating oil greases etc. have low volatility and are used as lubricants. Vegetable and animal oil also have low volatility.

If the lubricating oils are used at high temperature as in heavy machinery, a part of it may volatilize off. The residual oil left behind may have different properties such as high viscosity and different viscosity index etc. than the original oil. A good lubricant therefore, naturally has low volatility.

Lubricants take position in between the two surfaces in form of a film and separate two surfaces so that no contact takes place between them. The film formation mechanism is known as lubrication mechanism(1,2). There are different types of lubrication mechanisms such as hydrodynamic lubrication, extreme pressure lubrication and boundary lubrication. Which are discussed in section-2.4. Within this range of operation the bulk properties of the lubricant, such as its density and viscosity, are of relatively little importance. While the chemical composition of the lubricants as well as that of the underlying metals or substrates, become increasingly significant.

The properties of lubricants during admixture with additives and use are carefully monitored so as to ascertain their performance during use. Automobile engine environment is oxygen rich and involves flame, which generates high combustion temperature. However, beyond a certain threshold load and temperature, the lubricant fails to form an effective film. The lubricant film forming ability under such circumstances can be enhanced by the use of different additives, such as friction modifier, extreme-pressure agents, viscosity modifier, anti-oxidant and corrosion inhibitors etc.

Early research reported that the best additives for use in lubricating oils are long chain molecules with an active end group, e.g. alcohols, amines or fatty acids (6-10). Goyan et al. (11) explained that the polar nature of vegetable-based oils makes them good lubricants, as it can be readily fastened to the metal surface. Their polar nature also makes them fairly good solvents, which will flush dirt and wear particles off the metal surfaces. On the other hand vegetables oils, starch, tars, mineral oils are used as corrosion inhibitor for long time. Palm and Margosa oil is also vegetable oil composed of fatty acids and non-glyceried substance. So these oils may provide effective boundary lubrication and may act as a corrosion inhibitor. It may also be used as additives to the commercially available lubricants for automobiles. Palm oil blended lubricants for automotive tribo-matrieals is studied extensively (3-6). Literature Survey reveals that till now no work has yet been done on Margosa oil blended lubricants. Under these circumstances, the present study has been undertake in order to investigate the suitability of Margosa oil as lubricant and as additive to commercially available lubricants particularly those have mineral origin. Comparative study of palm oil and Margosa oil blended lubricants are also studied here.

1.2 Objectives with specify aims and possible out come

The objective of this study is to continuously monitor the corrosion behavior of mineral oil based lubricants containing different percentage of Palm and Margosa Oil as additives.

In this study, oil analysis methodology has been used to characterize Margosa oil added lubricants. The main objectives of this study are:

i) to study the corrosion characteristics of different Palm and Margosa oil added lubricants on automotive tribo-materials under static condition.

ii) to find out the optimum percentage of Palm and Margosa oil in order to reduce the corrosion of tribo-materials.

iii) to analyze the used lubricating oil for monitoring the degradation properties of Palm and Margosa Oil added lubricants with the objective of finding the cause and effect of Palm and Margosa oil additive that could lead to better understanding of the process of corrosion.

iv) to study thermal stability of Palm and Margosa oil added lubricants.

1.3 Out line of the Dissertation

As a first step to set the foundation for this study a literature review (Chapter 2) focuses on the metals and alloys, lubrication regimes and lubricants, the vegetable-based lubricants, additives for the improvement of lubricants, lubricant degradation characteristics has been carried out. A special emphasis is given on the application of vegetable-based lubricant additives and its application which increases the useful life of the oils and extend the pressure and temperature stability of the lubricant. A list of lubricant additives, their chemical structure, typical compounds and functions are presented in the Chapter-2. Apart from this oil properties analysis methodologies, thermal stability test oxidative and corrosion test under static condition are described in experimental part of this thesis (Chapter 3). The influence of Palm and Margosa oil blended lubricants on electrochemical corrosion phenomenon has been described in the Chapter-4. The chemical composition of the tested materials, physicochemical properties of the tested lubricants and decomposition of the lubricants are also shown here. However, the results and discussion are presented in Chapter-4, which includes research findings through testing and analyses of the results. Finally, Chapter-5 presents the conclusions drawn from the research findings, evaluation of the research and recommendations for future research.

Chapter-2

Literature & Review

LITERATURE AND REVIEW

2.1 Introduction

Lubricants are the substances that are used to reduce or minimize the frictional resistances between two sliding solid surfaces, which are in contact. Although the main function of lubrication is to reduce the friction and wear between two sliding solid bodies, lubrication also performs a variety of functions in engins and machines, such as, it pionrotects metal surfaces against corrosion, it acts as heat transfer agent, it flushes out contaminants, it adsorbs shocks and it seals foam.

Recently, much effort has been focused on research and development of new types of corrosion inhibitors and additives for lubricating oils to reduce corrosion in the tribological system. It has been noticed that additives are used to improve the lubricating capacity and durability of oil. Many investigations reported in the past paid attention to the use of different anti-wear and corrosion inhibitors. Among the numerous examples of additives the vegetable oil based lubricant additives got large attention for their potential use. However, the mechanisms of corrosion and degradation of lubricant under-vegetable-based lubricant additives is not quit clear. The scientific works appear in literature are meanly related to the following few areas: (1) Corrosion of metals and alloys, (2) Tribo-material of automotive (3) Lubrication regimes, (4) Effect of lubrication on tribo-material (5) Lubricant and the vegetable-based lubricants (6) Additives for the improvement of Lubricants characteristics, (7) Chemistry of additives (8) Lubricant degradation characteristics and (9) Research on vegetable-based lubricants and additives. In this work a special emphasis has been given on the application of vegetable-based lubricant additives in order to reduce the corrosion of the automotive engine component materials. The materials those are used in automobile engine are mainly metals and alloys.

2.2. Corrosion of Metals and Alloys

Metals and Alloys are used for various purposes. Industries and machinery are mostly made of steel and other alloys. Engineering works cannot be imagined without steel or other alloys. Corrosion is severe problem for mild steel. Corrosion is the destruction of metals and alloys by the chemical interaction of the these with the environment. The environment can be atmosphere, water, soil or any other things where metallic articles are placed for their use. Corrosion reactions are mainly electrochemical in nature. The necessary condition for almost all corrosions is the oxidation of metal and the reduction of any component of environment at the metal-environment interface. In aqueous environment, metallic corrosion arises from the electronic charge transfer at the metal environment interface. The charge transfer process can be divided into two partial reaction: oxidation of metal at the anodic site (electron source) and reduction of a species at the cathodic site (electron sink). In general the overall corrosion reaction can be represented as –

$$M \rightarrow M^{+} + ne$$

Depending on the environment various mechanisms have been suggested for the above reaction (12-16).

Corrosion of an automotive tribomaterial is dependent on the mating material (or material pair), surface preparation, sliding velocity, contact pressure and operating conditions (17-19). Corrosion can be caused by adhesion, by abrasion, by oxidation, by melting, as well as by varieties of other phenomena. Steel form the most commonly used family of materials for structural and tribological applications. Based on chemical composition and processing, a variety of microstructure and physical properties of steel can be obtained for improved corrosion resistance. Co. Mo and Cr are common alloying elements in steels to reduce corrosion. For high temperature applications, cobalt-based alloys are used which exhibit good galling resistance. Considerable improvement in wear resistance can be achieved by coupling dissimilar metals and also by alluring the surface characteristics, such as surface treatment, adding coating etc. The corrosion properties of mating components depend on different factors, some of them are discussed below:

2.2.1. Effect of temperature on corrosion

The tribilogical properties of mating components of engine and machines, where relative motion is involved, generally depend on factors such as temperature, speed, sliding time, base oil and additives formulation. As the operating conditions of the engines and machines become servere, trouble occurs on the contact surface due to damage caused by corrosion, wear, seizure, fretting, pitting, etc.

An increase in temperature generally results in metal softening. The increase of temperature may result in solid-state phase transformation as well, it may either improve or degrade physical and mechanical properties. High temperature increases the rate of oxidation, which in many cases results in low adhesion and low friction. Oxidation of iron and many other metals follows a parabolic law, with the oxide film thickness increase with the square root of the time,

$$h = K\sqrt{t}$$

where 'h' is the oxide film thickness 't' is the average growth time and K is the parabolic rate constant at elevated temperatures.

Since diffusion is thermally activated, growth rate in oxide film thickness as a function of temperature, similar to thermal oxidation under static conditions, follows an Arrhenius type of relationship(20)

$$K = A \exp(-Q/RT)$$

Where K is the parabolic rate constant for the growth of the oxide film, A is the parabolic Arrhenius constant ($kg^2/(m^4s)$) for the reaction, Q is the parabolic activation energy associated with oxide (kJ/mole), R is the universal gas constant and T is the absolute temperature of the surface. It has been reported that Arrhenius constant for sliding is several orders of magnitude larger than that for static conditions. This means that oxidation under sliding conditions is much more rapid than that in the static condition. Increased diffusion rate of ions through a growing oxide film generally consists of high defect density due to physical and mechanical perturbations.

2.2.2. Effect of Oxides films

Interface temperature produced at asperity contacts during sliding of metallic pairs under nominally unlubricated conditions result in thermal oxidations, which produced oxides films of several micros thickness. A thick oxide film reduces the shear strength of the interface, which suppresses the wear as a result of plastic deformations (21). Many studies in tribology have focused on the investigation of the effect of oxide films as wear and corrosion protectors as well as wear precursors. Johnson et al, (22) found that the oxide film formed on the rubbing surface may, in themselves, function as lubricant and suggested that αFe_3O_4 is more effective than Fe_2O_3.

Oxygen and other molecules are adsorbed on clean metals and form strong chemical bonds with them. Many papers have focused on the importance of thickness and composition of the oxide films. Some studies have focused on the effect of oxygen in the presence of lubricants with additive. Tomaru et al, (23) measured the effect of oxygen on the load carrying capacity action of several additives, and found that an iron oxide film is responsible for the protection of the surface. Sakai et al, (8) presented the effects of dissolve oxygen on the performance of oil containing organic sulfide. He found that there is a particular amount of oxygen that optimizes the formation of films of sulfides and oxides in terms of the inhibitor properties of the oil.

2.2.3. Tribochemical and Tribocorrosion

Friction modifies the kinetics of chemical reactions of sliding bodies with each other, and with the gaseous or liquid environment, to the extent that reactions, which occur at high temperatures, at moderate or even at ambient, temperatures during sliding. Chemistry dealing with this modifications of chemical reactions by frictions or mechanical energy is referred to as tribochemistry , and the wear controlled by this reactions is referred to as tribochemical wear (24,25).

The most obvious mechanism by which friction increases the rate of chemical reaction is frictional heat produced at contacting asperities. Besides friction, heat and other factors are: removal of product scale resulting in fresh surfaces, accelerated diffusion and direct mechanochemical excitation of surface bonds. The formation of a 'viscous' or 'sticky' material on the surface under tribocontact, which is often called 'friction polymer'. This is believed to be one of the features of tribochemical reactions (26).

Wear is sometimes affected by corrosive environments (known as corrosive wear or tribocorrosion wear) under constant or varying contact load, resulting in failure of the components due to severe wear or seizure (27). Triborrosion is the degradation of a tribological contact resulting from simultaneous metal removal by mechanical wear and by chemical or electrochemical oxidation. The two-metals-removal mechanisms depends on each other in a complicated way and the total metal removal rate is usually not simply the sum of the corrosion rate and the wear rate measured in separate experiments(28).
Corrosion can occur because of chemical or electrochemical interaction of the interface with the environment. In many cases corrosion is accelerated by wear and similarly, wear may be accelerated by corrosion (29). In air, the most dominant corrosive medium is oxygen. In the sliding action, the chemical film away and thus chemical attack is being continued.

2.3. Materials for Automotives Tribo-components

The automotives engine system is divided in three components (30) : (1) a piston component composed of a piston, a piston ring and a cylinder, (2) a crank component composed of a crank shaft, bearing and a connecting rod, and (3) a valve-train component composed of a valve guide.

1) Piston, Piston Ring and Liner Materials

Piston and cylinder liners are important components in reciprocating engines. The piston moves inside the liner, separated by a set of rings which functions as liner bearings and a seal to the crankase. A piston ring in the vicinity of the top and bottom dead centers operates under boundary lubrication conditions including partial solid-solid contact. So far, hard chromium electroplating and Ni-P plating on cast iron, stainless steel have been utilized for the piston ring. Four ring materials (such as Mo-coated cast iron, textured Cr-coating cast iron, Ti coating cast iron, nitrided stainless steel) and three cylinder liner materials (such as plain cast iron, Aluminum matrix reinforced by SiC and Nickel/SiC composite coated aluminum alloys) were investigated for application as advanced piston-ring /cylinder-line pairs. It was concluded that the wear rate, including scuffing resistance and corrosion, was strongly dependent on material properties and the combination of the ring/liner pair.

2) Bearing Materials:

The tribo materials used for crankshaft bearings require high performance in terms of anti-seizure, running-in, wear resistance and embeddability of foreign particles. Traditionally, sliding bearing materials are alloy of tin and lead and referred to as ' *White-metal*' alloys or '*Babbitt-metal*'. Copper base alloys, aluminum base alloys and polymeric materials are also used now-a-days for sliding bearings. Some typical bearings materials, their composition, properties and applications can be found in. Timings Volume-1, (31). Carbon-chrome alloy steel (viz. AISI 52100) also known as bearing steels are the most widely used for making balls rollers and races of antifriction bearings.

3) Valve Train Component Materials

Valve-train components are operated under cyclic loading and exposure to high temperature exhaust of about 900° C. So heat resistance materials such as valve steel or high alloy steels (32) are required for the valve train components. A cam is usually made of chill-hardened alloy cast iron or ductile cast iron. The flower materials is ferro-based powder-sintered metal with high percentage of chromium content.

2.4. Lubrication Regimes

A regime of lubrication, in which a thick film is maintained between two surfaces with little or no relative motion by an external pumping agency, is called hydrostatic lubrication. The regimes of lubrication are sometimes identified by a lubricant film parameter equal to h/σ - (mean film thickness)/(composite standard deviation of surface heights of the two surfaces). Descriptions of deferent regimes of lubrication are given at the following sections.

1) Hydrodynamic (HD) lubrication:

Hydrodynamic (HD) lubrication is sometimes called fluid-film or thick-film lubrication. In HD lubrication, corrosion of the bearing surfaces can occur as a result of interaction with the lubricant. One of the most effective ways to minimize corrosion, is by the participation of the lubricant and bearing surface in the formation of a relatively complete inert film on the bearing surface. In ferrous bearing systems, this can be accomplished with phosphate-containing additives or organo-metal salts.

2) Elastohydrodynamic Lubrication:

Elastohydrodynamic ((EHD) Lubrication ((EHL) is a subset of HD lubrication, in which the elastic deformation of the contacting solids plays a significant role in the HD lubrication process. The lubricant film is sufficiently developed to separate the interacting surface completely so that all shearing takes place within the Elastohydrodynamic film. The film thickness in EHL lubrication is thinner (typically $h = 0.025\text{-}5\ \mu m$) than that in conventional HD lubrication. In ELH, corrosion of the bearing surface can occur as a result of interaction with the lubricant.

3) Mixed Lubrication

The transition between the hydrodynamic/elestohydrodynamic and boundary lubrication regimes is a gray area known as ‘mixed lubrication’ in which no lubrication may be functioning. The relative motion of the interacting surfaces is insufficient to generate the hydrodynamic action required to separate them completely. There may be more frequent solid contacts, but at least a portion of the bearing surface remains supported by a partial hydrodynamic film. The solid contacts, between unprotected virgin metal surfaces, could lead to a cycle of adhesion, metal transfer, wear, corrosion and eventual seizure. The mixed regime is also sometimes referred to as quasi-hydrodynamic, partial fluid, or thin-film (typically 0.025-2.5 μm) .

4) Boundary lubrication

Boundary lubrication is the transition state between fluid lubrication and dry friction. Under boundary lubrication, the sliding surface depends not only on the chemical and physical properties of the lubricant but also on the nature of the surfaces and their relative movement. Boundary lubrication exists when the film thickness is equal or greater than the asperity heights, and thus prevents metal-to-metal contact. Under this condition, the lubricant viscosity is relatively unimportant and the physical and chemical interaction of the lubricant with the solid bodies controls friction, wear and corrosion. Boundary lubrication usually occurs under high load and low speed conditions in machine components such as bearing, gears, cam tappet interfaces, piston ring and linear interfaces. Boundary lubrication forms a last line of defense. In many cases, it is the regime, which controls the component life (33).

The *mechanism of boundary lubrication* with the aligned surface film provides a protective coating over much of the interface. The boundary films are formed by physical adsorption, chemical adsorption and chemical reaction (34). The physisorbed film can be either monomolecular (typically > 3 nm) of polymolecular thickness. The chemisorbed films are monomolecular, but stoichiometric films formed by chemical reaction can have a large film thickness. In general, the stability and durability of surface films decrease in the following order: chemical reactions films, chemisorbed films and physisorbed films.

A good boundary lubricant should have a high degree of interaction between its molecules and the sliding surface. As a general rule, liquids are good lubricants when they are polar and thus to grip solid surface (or be adsorbed) (20) Polar lubricants contain reactive functional groups with low ionization potential or groups having high polarizability. Boundary lubrication properties of lubricant are also dependent upon the conformation and lubricant spreading. The structures of non-polar and polar (-OH) organic lubricant molecules are as follows:

Z-15 $CF_3 - O - (CF_2 - CF_2 - O)_m = (CF_2 - O)_n - CF_3$

where m/n ~ 2/3

Z-DOL $HO\text{-}CH_2 - CF_2\text{-}O - (CF_2\text{-} CF_2 \text{-}CF_2\text{-}O)_m - (CF_2 - O)_n\text{-} CF_2\text{-} CH_2\text{-}OH$

In the case of Z-DOL (also known as perfluoro polyether), a hydrogen atom, covalently bonded with oxygen atom in the O-H bond, exposes a bare proton on the end of the bond. This proton can be easily attracted to the negative charge of other molecules because electrons do not shield the proton, and this is responsible for the polarity of the O-H ends. Likewise, the lone pairs of electrons in the oxygen and fluorine atoms in both molecules are unshielded, and can be attracted to positive charge of other molecules, and thus exhibit electro negativity which is responsible for some polarity. The CF_3 end in Z-15 is symmetric and its polarity is low.

For better lubrication, it is believed that the surface should be reactive to the lubricant and highly functional with polar groups and dangling bonds (unpaired electrons) so that they can react with lubricant molecules and adsorb them.

2.5. Effect of Lubrication on Automotive Tribo-components

The reduction of wear and friction losses in an internal combustion engine is largely a function of improved lubrication. Advanced lubricants are now being formulated to reduce the wear and friction of the tribological component of the engine. The development of modern lubricants and their proper use are of great importance for the national economy, individual and environment. Lubricants, optimally adjusted to a given task, can save billions of dollars in the case of an industrialized nation, reduce wear, reduce maintenance requirements and the problem of air pollution (35). The piston ring is the most complex tribological component in an internal combustion (IC) engine. Power fuel consumption, hydrocarbon emissions oil consumption, wear, noise and cooling are affected by the design of the ring-liner interface. Studies of the mechanism of piston ring lubrication and related friction phenomena have found that piston rings contribute significantly to the total engine mechanical friction losses (36). The formation of a hydrodynamic lubrication film at the the interface between the piston rings and cylinder liner is expected while the engine is in operation. However, the lubrication regime of the mating surface affects the efficiency, durability and emission output of the engine. In general, most friction occur at, or near, the top dead center where low piston velocity means the hydrodynamic film thickness is low and where the temperature is higher, due to the proximity of the combustion chamber. In the oxygen rich environment and in absence of lubrication film on the mating surface corrosion occurs easily at high temperature.

Oil related piston, ring and liner faults are usually the result of one of more of the following problems.

- Continuation of the oil by abrasive particles. Abrasion can cause severe wear of piston skirt, rings and liners.

- Inadequate cylinder lubrication. This causes a breakdown of the lubricant film and subsequent metal-to-metal contact. In extreme cases, the damage can result in seizure of the piston.

The above conditions can generate excessive wear, friction and corrosion and if not remedied, lead to severe damage to the piston, rings/or liner.

2.6 Liquid Lubricants

A lubricant performs a variety of functions in engines and machines, such as, it protects metal surfaces against corrosion, it acts as heat transfer agent, it flushes out contaminants, it adsorbs stocks and it seals foam (37). Lubricants are commonly used to reduce the friction and wear between two sliding solid bodies. In some applications, the solid surfaces are so close together that some asperities come into contact and others and are mitigated by a thin film of lubricant. Most lubricants are introduced into a sliding system with the aim of reducing the amount of interaction between the contacting surfaces, often under a variety of equipment speed and loads. Thus, a lubricant may be used to reduce the friction force, the amount of wear, or the degree of surface adhesion. Sometimes, however, the prime task of the lubricant is to reduce the interfacial temperature, which otherwise might produce a harmful change, such as melting, in one of the contacting materials.

Some of the most important properties necessary for satisfactory lubricant performance are: Low volatility under operating conditions. Volatility characteristics are essentially inherent in the chose of base stock oil for a particular type of service. Viscosity gives as indication of the volatility of a lubricant: in general, the lower its viscosity the higher its volatility. Viscosity therefore correlates to some extent with engine oil consumption since other things being equal, consumption is affected by oil volatility.

Satisfactory viscosity characteristics in the temperature range of use. Viscosity of engine oil is one of its most important and most evident properties. Chemical additives, fuel dilution, contaminants from within and outside of the engine, wax in the oil, oil oxidation, volatilization and many other materials found in or added to the oil affect the viscosity in advantageous of disadvantageous ways. For engine oil, a small change in viscosity with temperature (high viscosity index)is desirable a wide range of operating temperatures over which a given oil will provide satisfactory lubrication. At low temperature a relatively low viscosity oil is to permit adequate cranking speed during starting and then adequate flow to the oil pump and the entire engine oiling system after starting.

Superior stability or ability to maintain desirable characteristics for a reasonable period of use. The factor, which affect the lubricant stability, are: temperature, oxygen and contamination with water, unburned fuel fragments and corrosive acids, which limit the useful life of a lubricant. All lubricating oils react with oxygen in the air, eventually forming acid or sludge products. These product could cause surface corrosion or blocking of oil lines. There are numerous laboratory tests for oxidation stability (38). All tests depend on artificially accelerated oxidation, by heating the oil and by blowing air or oxygen through it, in some cases in the presence of a catalyst. This is the area where additives have made a major contribution in improving the performance characteristics and extending the useful life of lubricants.

Compatibility with material pairs in the system. Compatibility of lubricants with bearings, seals, clutch plates etc. may also be partially associated with the base oil.

However, additives chemistry can have a major influence on such characteristics. Lubricating oils find applications in engines, industrial uses and automotive transmissions. The major uses of these oils are in engines (55%), industry (27%) processes (9%), and automotive transmissions (4%) (39).

2.6.1. Principal Classes of Lubricants

Liquid lubricant includes mineral (or petroleum) based oils synthetic organics, natural organics consisting of vegetables oils, animal fat and mixtures of two or more of these materials. Various additives are used to improve the specific properties.

2.6.1(a) Mineral-based Lubricants

Mineral or petroleum based lubricants are produced by the refining of crude oil and are comprised of complex hydrocarbon mixtures. The wide variety of crude oils generates a wide variety of properties in base stock lubricants. In general, a specific machine lubricant will be a selected fraction of a crude oil with some of its original components removed to obtained the desired performance characteristics. Additives compounds blended with the oil provide additional properties (40).

Mineral (petroleum) oils are good boundary lubricants and by far the most widely used. These can be used up to a maximum temperature of 160°C and super refined oils can be used up to 200° C. The chemical components of mineral oils are mainly hydrocarbons, which contain only carbon and hydrogen. The majority of any oil consists of paraffins in which the carbon atoms are straight or branched chains. The second most common type consists of naphthenes, in which some of the carbon atoms form rings. Finally, there is usually a small proportion, perhaps 2% of aromatics, in which carbon rings are again present, but the proportion of hydrogen is reduced.

2.6.1(b) Synthetic Lubricants

Unlike petroleum-base lubricants, synthetic oils are designer lubricants, synthesized by chemical reactions of low molecular compounds to obtain specific properties for specific engine and machinery applications. Similarly to the petroleum lubricants, additives are used to improve the properties of synthetic oils. For example, polyol ester base stock lubricants used in aircraft gas turbine engines are formulated by the reaction of an acid and an alcohol, to yield an ester and water. It is then fortified with antiwear, antioxidant and other additives to provide the necessary performance over the operating range of the engine and machine.

2.6.1(c) Vegetable-based Lubricants

Vegetable-based lubricants are liquid agricultural products and produced from plants and cash crops. The advantage of vegetable-based oils over mineral-based oils are given below:

Vegetable oils are biodegradable, non-toxic and derived from fruits. Whereas, minerals oils are derived from chemicals. The source of vegetable oil is a crop and they promote self-reliance as ample production capacity exists but the source of mineral oil is a finite mineral deposit.

Vegetable oil has higher flash point than mineral oil and always a concern with flammable liquids: they are also generally safer to humans.

It is worth remembering that fatty acid based products from vegetable and animal origins were used as the main source of lubricants the late nineteenth century (41) when mineral oils became available in large volumes at increasingly competitive prices. At sometimes, blends of mineral oil and natural fatty acid products, referred to as fatty oils, were widely used. Vegetable fats and oils (known by the generic term lipids) comprise primarily triglycerides, that is triesters of long chain carboxilic acids (fatty acids) combined with glycerol. Most of these oils contain at least four and sometimes as many as 12 different-fatty acids.

Vegetable oils are usually good boundary lubricants but the major limitations are their high cost, thermal and oxidative instability. Oxidative stability of vegetable oils depends on the level of unsaturated products present. The lower is the unsaturation the better is the oxidative stability but higher is the melting point. In general, vegetable oils can be used up to a maximum temperature of 120° C. However, the use of appropriate antioxidant can solve this problems (41). It must also be noted that vegetable-based oils are hydrolytically stable. These oil when react with alcohol in presence of fatty acids, can make synthetic esters. To do so, branched alcohol are more favorable. Properties are chosen and reacted with pure acid (such as oleic acid) to produce a synthetic ester with better performance characteristics. But all types of vegetable are not suitable for lubricant. For good performance, lubricants special must fulfill requirements i.e. good lubricity, good corrosion protection, compatibility with other materials, fair oxidative and hydrolytic stability and low temperature behavior associated with the triglyceride (43). Rapeseed and castor oils are the most common based stocks for vegetable based lubricants.

Rapeseed oils:

For the economic point of view rape-seed oil is the most suitable oil for lubricants (44,45). Now a days, rape-seed-based lubricants are widely used in total loss system and they are also increasingly used in hydraulic and power transmissions. The seeds are small, dark brown beads of about 1.5 mm diameter. The chief sources of this oil are China and India. It is a good lubricant and used for compounding with mineral oils. This oil can be used as viscosity improver of other oils. The specific gravity of this oil is around 0.913 at 15° C. The most promising vegetable oil being developed for lubricant is low erucic acid rapeseed oil (LEAR). In 1996 about 879,000 tones of LEAR were grown in UK. It was mainly used as foodstuff, raw material for detergent manufacture and also as bio-diesel fuel (41).

Castor oil:

This is obtained by crushing the seed, which is like a small dark, mottled bean. The plant grows wild in most tropical regions but is cultivated in several countries. The seeds may be pressed without prior heating in which case the yield is lower but pressing at elevated temperature results in a greater yield of poorer quality oil. It is very good lubricant and has been used in the past in racing cars and the early aero engines of the rotary type. It has a high content of ricinoleic acid, high viscosity and low coefficient of friction. It is soluble in alcohol but not in petroleum(49).

Olive Oil:

The olive tree is cultivated throughout the Mediterranean area and in California. The fruit has likened to an unripe damson and is cultivated chiefly as a source of oil. The oil is obtained by compressing of the fruit, but can also be extracted with carbon disulfide. Olive oil is a very good lubricant but because of its high cost it is not used generally as lubricants. It is the main source of unsaturated oleic and linoleic fatty acids. The composition of the olive oil has been analyzed using gas chromatography can be found in (41).

Palm Oil:

Palm oil is an important crops and is extracted from palm fruit composed of mainly triglycerides, contains a small amount of partial glycerides, free fatty acids and non-glyceride substances(49). Triglycerides are the ester of glycerol and fatty acids. Fatty acids are straight-chained molecules and have an even number of carbon atoms (refer to table –2.1). Malaysia is today the world's largest producer and exporter of palm oil and accounts for 10% of the country's Gross Domestic Product (GDP). In 1995, Castrol (M) Ltd. launched Castrol Palmtee 2T and 4T the world`s first palm–based motorcycle and passenger car engine oil (46). It is formulated using palm oil as its base fluid together with an additives syatem to enhance its protection and performance capabilities. Masjuki et al., (48) have studies the tribological performance of the castrol palmtee lubricating oil and found that better performance can be obtained from palmtee oil compared to mineral-based oil. It is believed that this synthetic palm-based lubricating oil would provide better performance in terms of resistance to oxidation and hydrolysis, extended range of service temperature and reduction in engine corrosion, wear and tear.

Margosa Oil (Neem Oil):

In Indian sub-continent, the tree from which the seeds are obtained is called neem (*Melia Azadirachte*) tree. The oil obtained from the neem seeds by pressing them. The proportion of oil presents in fruit is 14.8% and in seeds is 43.3%.

Neem oil is a densed liquid. The oil is dark greenish in colour, bitter in test and unpleasant in odour. The test and odour are caused by the presence of certain sulfate containing compounds. This oil contains a large propotion of unsoponified matters.

There are a number of glyceride compounds like palmite- steric, oleic-dipalmitic, oleo-palmitic-steric, palmitic-dioleic, stearic-dioleic and thioleic etc. present in neem oil. The mixed fatty acids of neem oil are arachidic, linoilic oleic, palmitic and stearic acid.(50-53)

Neem oil finds use in the manufacture of consumer goods like toothpaste and soap. Soaps with the odour of neem oils found in the market. It has got anti-fungus activities.

2.7. Lubricant additives

Lubricants additives are chemicals that are present in small amount in base oil to improve the physical, chemical or tribological properties of the lubricant. Since the performance of lubricating oils is a functions of an additive composition they contain, it is helpful to study the major types of additives used in lubricanting oil. In general, care should be taken in selecting additives to ensure compatibility, effectiveness and environmental safety. High performance machines demand oils, which contain tailored additives packages.

Additives increase the useful life of oils and provide additional performance characteristics, such as improved flow, modified friction and resistance to oxidation, extended pressure or temperature stability. The most common types of additive are anti-wear agents, antifoams, emulsifiers, extreme pressure (EP) agents, antioxidants, ashless detergents, dispersants, viscosity index improvers, rust inhibitors, corrosion inhibitors, frictions modifiers and pour point depresser (37, 40).

Some lubricant additives are briefly discussed in the following sub-section (39,40,54) and a list of lubricant additives with their chemical structure and functions are shown in table 2.1 and 2.2.

2.7.1. Anti-wear Agents

Anti-wear agents are used for the reduction of wear and friction in tribological systems. They assist the protective film formation due to chemical reaction, physical adsorption and chemisorption between the substrate and inorganic elements, and their antiwear capability depends upon the shear strength of the protective film formed. Surface protection is maintained by the inorganic compounds (such as Zn phosphides, Fe phosphides), zinc diaryl (dialkyl) dithiophosphate (ZDDP), tri-cresyl phosphate (TCP) and other phosphorus compound. Dithiophosphates (ZDDP) may be classified into two different types primary alkyl ZDDP and secondary alkyl ZDDO(2).

2.7.2. Detergents and Dispersants

Detergents and dispersants are used to keep insoluble combustion and oxidation products and other contaminants off machinery surface in dispersed condition within the oil. Suspended debris is removed from the system by periodic oil trains. Both additives have long chain hydrocarbons (oleophilic group) tails for oil solubility and a polar head which renders combustion products and other contaminants harmless. Detergents have polar (sulphonate, phenates, salicylate, phosphonate) heads containing metal cations. The metal is typically calcium, magnesium and/or sodium. In dispersants, the polar end is oxygen or nitrogen containing groups rather than metal cations(1).

Detergents, there are used as oil additives are similar to household detergents but are oil-soluble rather than water-soluble. These compounds provides an alkaline reserve to neutralized acidic by-products of combustion. Detergents react with oxidations products to reduce the formation of insoluble products and provide some measure of corrosion protection. This minimizes carbon sludge deposits that would otherwise clog oil lines and reduce flow. In addition, detergents provide a cleaning action and minimize high temperature varnish and lacquer deposits which may occurs in engine parts(2).

Detergents also help to keep engines clean by suspending carbon and other low temperature precursors of sludge deposits more uniformly in the oil. Antisludge agents have the ability to prevent the formation of sludge on the hot surfaces of engines and to prevent the burning of piston rings. They have the characteristics of both detergents and dispersants.

2.7.3. Anti-Oxidants

Oxidation stability is one of the key requirements of a lubricant due to oxidative degradation products (e. g. acids) which are formed during lubricant use. In engine oils, anti-oxidants help to prevent formation of by-products of combustion. A list of different antioxidants is given in Table 2.1. These by-products are acidic and corrode equipments parts, thicken the oil, and reduce its lubricating properties. For many years antioxidants have been lubricating oils to supplement antioxidants naturally occurring in the oil. These artificial antioxidants are added to base oil either alone or in synergistic combinations, which extend the operating life of the oil by improving its oxidation stability (42).

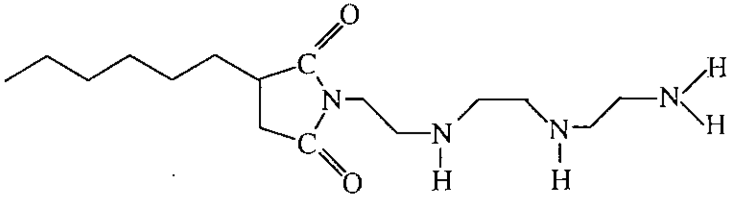
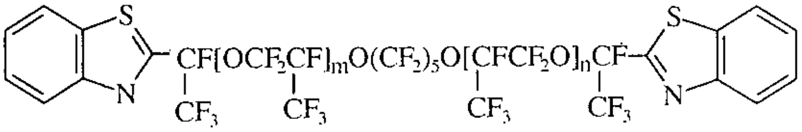
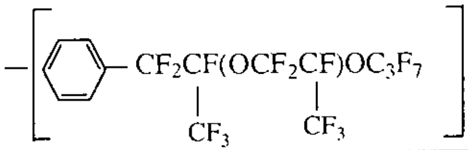
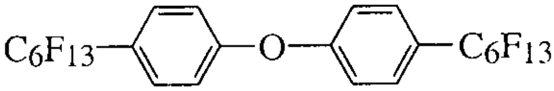
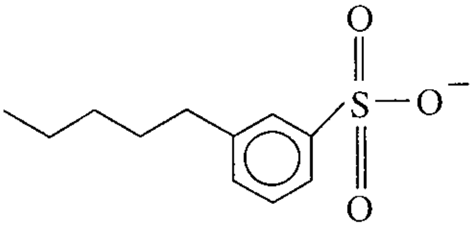
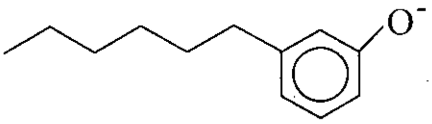
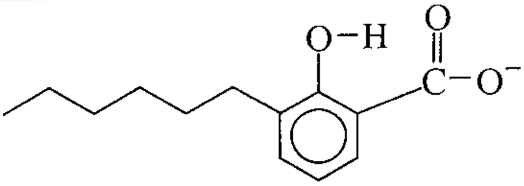
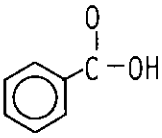
TYPE OF LUBRICANTS ADDITIVES

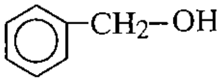
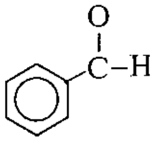
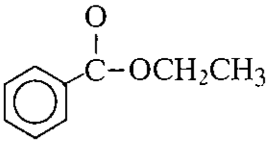
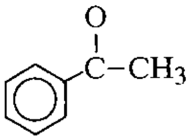
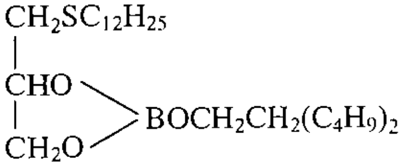
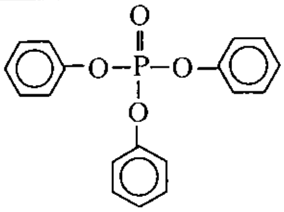
Table 2.1: Surface Protective Additives (54)

Additive type	Purpose	Typical Compounds	Function
Anti-wear and EP Agent	to reduce friction and wear and prevent scoring and seizure	Zinc dithiophosphates, organic phophates, acid phosphates, organic sulfur and chlorine compounds, sulfurizeds fats, sulphides and disulphides	Chemical reaction with metal surface to form a film with lower shear strength than the metal preventing metal-to-metal contact
Detergent	to keep surface free of deposits	Organic-metallic compounds such as sodium, calcium and magnesium phenolates, phosphonates and sulfonates etc.	Chemical reaction with sludge and varnish present to neutralize them and keep them soluble
Dispersants	to keep insoluble contaminants dispersed in the lubricant	Alkylsuccinimides, alkylsuccinic esters, and Mannich reaction products	Contaminants are bonded to dispersant molecules, by polar attraction preventing from agglomerat on and kept in suspension due to solubility of dispersant
Friction Modifier	to alter coefficient of friction	Organic fatty acids and amides, lard oil, high molecular weight organic phosphorus and phosphoric acids esters	Preferential adsorption of surface-active materials
Corrosion and Rust inhibitors	to prevent corrosion and rusting of metal parts in contact with the lubricant	Zinc dithiophosphates, metal phenolets, basic metal sulfonates, fatty acids and amines.	Preferential adsorption of polar constituent on metal surface to provide protective film, or to neutralize corrosive acids
Pour Point Improver	to enable lubricant to flow at low temperatures	Alkylated naphthalene and phenolic polymers, polymethacrylates, maleate/fumerates copolymers esters	Modify wax crystal formation to reduce interlocking
Viscosity Modifier	to reduce the rate of viscosity change with temperature	Polymers and copolymers of olefins, methacrylates, dienes or alkylated styrenes	Expand polymers with increasing temperature to counteract oil thinning
Anti-oxidant	to retard oxidative decomposition	Zinc dithiophosphates, hindered phenols, aromatic amines, sulfurized phenols	Decompose peroxides and terminate free-radical reactions

CHEMICAL STRUCTURE

Table- 2.2 Main types of additives and their chemical structure (41,121)

No	Additives Type	Chemical Structure
1	ZDDP	$[(RO)_2 P(S)S]_2 Zn$
2	TCP	$(RO)_3P = O$
3	PIBS	
4	Dibenzothiazole	 m + n = 3
5	Phosphine	
6	Bipheynel ether	
7	Sulfonate	
8	Phenate	
9	Salicylate	
10	Benzoic acid	

No	Additives Type	Chemical Structure
11	Benzoic alcohol	
12	Benzaldehyde	
13	Ether benzoate	
14.	Acetophenon	
15	DBN	$(C_{12}H_{25}O)_2\ BOCH_2CH_2(C_4H_9)_2$
16	N, N-di-n-butylamino ethyl-3-(1-mercaptododecyl)-1,2-propyl borate (SBN)	
17	Phosphazene (X-1P)	
18	Phosphazene (X-100)	
19	Thiophosphate	
20	Phosphate ester	
21	Triglyceride	
22	Alkyl ester	R — O — CO — R

2.7.4. Extreme pressure (EP) Agents

Extreme pressure (EP) can be classified in to two categories, mild, and full. Mild EP agents are also known as oiliness agents and are used to protect the metal surface from wear. Generally, they are polar molecules. They form a strong bond to the metal surface, which is difficult to remove. Full EP agents are used to prevent welding, galling and scuffing of the metal surface. The EP additives normally contain sulfur, phosphorus, chlorine or boron. Forbes et al., (55) have proposed a mechanism where hydrolysis of phosphates produces an inorganic phosporous-containing species adsorbed on iron.

2.7.5. Corrosion and Rust Inhibitors

Corrosion and rust Inhibitors are generally substances that prevent or minimize corrosion, wear, oxidation, rust and foaming. Examples of inhibitors are amine compounds, metal dithiophosphates (antioxidant), long chain polar compounds (amides, phosphites etc.), high base additives (sulfnates, organic acids or ester (etc). The chemical structure of some inhibitors has been given in table 2.1 and 2.2. Corrosion inhibitors create physical barriers to corrosion in the form of a hydrophobic layer (chemisorbed monolayer) to prevent access of water and oxygen to the metal surface(1,2).

Rust inhibitors prevent metal surface from rusting by the formation of a surface film or by neutralizing the acids. In general, antirust agents can be classified into three categories: neutral, acidic and basic.

2.7.6. Viscosity Index (VI) Improver and Pour Point (PP) Improver

Viscosity index improvers reduce the tendency of oil to change viscosity with temperature. They are high molecular weight polymers or copolymers e.g. polyisobutylene, olifin copolymers, styrene, esters and polymethacrylate. Some viscosity index improvers may function as pour point improver and also as dispersants. More detailed information, including the chemical structure of these additives can be found in the literature (39,56,57).

Pour point (PP) improvers are low molecular weight polymers, which lower the freezing points of oils, thus allowing the oils to flow at low temperatures. Examples of pour point improvers are polymethylacrylates, alkylated wax, naphthalene, vinyl ester vinyl, ether copolymers etc.

2.8. Chemistry of Additives

Adsorption on sliding surfaces and the chemical changes occurring withhin a few nanometers of the surface are the key points to the performance of lubricants and lubricant additives in the boundary lubrication regime (58). In order to control the chemistry in this important interfacial region, lubricant manufactures blend additives into the based oils (59,60). These additives either adsorb on the sliding surfaces upon contact (friction modifiers) (61,62) or react with the surfaces under extreme conditions (extreme-pressure, EP, additives) (56). In both cases form protective layers of low shear modulus which protect the underlying solid surfaces.

Polar organic compounds are widely used as friction modifying additives in lubricating oils. These compounds are adsorbed from hydrocarbon solutions on a metal surface. It is generally assumed that these adsorption layers are responsible for the improved lubricating properties of oils. Innumerable studies have demonstrated the effectiveness of Zn-dithiophosphates as lubricant additives for ferrous materials. The work by Mart. et al., (63) and Bell et al (64) have identified the formation of a 500 nm thick glassy phosphate reaction layer containing Fe^{3+} and Zn^{2+}. This layer was determined to be covered by an organic film (thickness-100 nm).

Under normal condition of speed, the mating surface temperature of the solids is significantly greater than those of the bulk surfaces. When the surfaces are relying for protection on physically adsorbed molecules, as will be the case for simple paraffinic oil, this temperature increase will result in the molecules becoming more mobile and so will tend to reduce gradually the extent of the surface coverage and thus the effectiveness of the lubricant. On the other hand, if the lubricant and the metal are capable of reacting together chemically then an increase in temperature will tend to speed up the rate of reaction. This type of behavior can be seen in fatty acids and such a reaction process can provide protection against corrosion. Once the surface temperatures reach values much over 140°C the degree of physical adsorption is likely to have fallen to a negligible value and, in addition, most metallic soaps have started to undergo thermal decomposition. This means that at service temperatures much above this sort of level there is likely to be a significant increase in frictional forces with an associated escalation in surface damage and eventually scuffing occur. In order to solve this problem extreme pressure additives are added to the lubricant to lubricate at comparatively high temperature (rather than pressure) perhaps up to as much as 300-400°C.

Satisfactory operation in this higher temperature range depends on the addition of small quantities of organic compounds usually containing chlorine, sulfur, or phosphorus. At lower temperatures these additives remain substantially inert. But they react with hot metallic surfaces to form protective flames of solid metal chloride, sulfide, or phosphate.

2.9. Lubricant Degradation

A lubricant begins to change slowly form the moment it-enters into the lubrication system of an operating machine. Generally, internal combustion engines, such as diesel engines, are the most stressful on lubricating oil .In this environment, high temperatures and stress promote thermal and mechanical degradation of the lubricant constituents. A number of researchers (65-71) have studied the various degradation characteristics of lubricants. Their work on stability of lubricant by differential scanning calorimetry (67), Volta metric methods (72), fourier transform inferred spectroscopy or FT-IR(66), statistical forecasting on the basis of physical properties (71) are significant. It has been observed that the lubricant degradation pattern for each equipment is unique (73), However, the degradation pattern of the new equipment would not remain same after it has grown considerably old. This is due to various reasons and are described in the following section.

2.9.1. Lubricant Degradation by Oxidation

Lubricant exposed to hot combustion product and other contaminants, which promote reaction with oxygen, nitrogen and sulfur, result the formation of acidic compounds. The stored alkalinity of the lubricant neutralizes these compounds. Once the reserve is consumed, however, oxidation products increase uninhibitedly. Oxidative degradation products will collect in the pump and other engine spaces, leading to the formation of scum and sludge. Engines using fuels with high sulfur content will experience incidence of acidic sulfate products in the lubrication system, and a higher potential for oxidative degradation. West et al. (74) reported that oil aging and in particular the corrosive effects of blow-by gases, increased wear. Hus et al , (75) presented data showing that the wear rate increased by about 30% owing to simple oxidation of the oil. The degree of deterioration of the lubricant is usually rated in terms of lubricant characteristics such as viscosity total acid number (TAN), total base number (TBN) and insoluble content (76).

A lubricant's ability to withstand thermal and oxidative degradation at elevated temperatures is dependent not only on introduced additives, such as antioxidants but also on it's stock characteristics. During the initial stages of oxidation a free radical reaction between the bulk lubricant and oxygen, in the presence of transition metal ions produces low-molecular weight products. This products include acids, alcohols, ketones and aldehydes, some of which are know to absorb onto metal surfaces to form a low-shear-strength film between opposing asperities. The removal rate of these adsorbed molecules is related to the temperature of the surfaces (77). Wiseman and Ah-sue (78) used FT-IR (fourier transform in frred troscopy) form onto ring oil degradation. Kaleli and

Yavasliol (69) have studied the degradation type of lubricating oil in automobiles. Added in small quantities of less than one percent by weight artificial antioxidants extend the operating life of the oil by improving its oxidation stability. In practice, three types of additives have proven successful in retarding degradation in oils, i.e. radical scavengers, metal deactivators and hydrogen per oxide. In the presence of oxygen and transition metal ions, these additives or synergistic mixtures of three additives gradually deplete eventually leading to rapid deterioration of the base oil. The result is the formation of corrosive acids, varnish and ultimately, oil insoluble sludge. The effectiveness of these antioxidants in basc oil protection is therefore crucial in minimizing equipment failure.

Over the years, a number of analytical techniques based on rapid lubricant thermal stressing have been used for oxidation stability test including antioxidant evaluation (72).Oxidation in general, is assessed by measuring the rates of oxygen gas uptake (79,80) or lubricant weight loss (81) or by measuring the rates of hydrogen peroxide (82) or acidic product formation. Laboratory tests include the oxidation characteristics of inhibited mineral oils, test (ASTM, 1943). The universal oxidation test (80), thermo gravimetric balance (81) and chemiluminescence (82) more recently, differential scanning calorimeter (DSC) has been applied to measure the stability of different antioxidants and oil formulations (68,77,83-86).

2.9.2. Lubricant degradation by additive depletion

Most lubricant and hydraulic fluids are fortified with a mix or additives, which acids in concert to protect the machine and minimizing usable life. The quality and type of additives compounds will very with the type of base stock and the performance requirements of the fluid application. In all applications, additives are normally consumed during the course of equipment operation and the fluid will require change when the key constituents decrease below acceptable limits. Detergents, dispersant, extended pressure, anti-oxidant, anti-wear and other additives in lubricating oil are often required to extend oil life, particularly in combustion engine oils. As these additives are consumed by thermal and mechanical stress, the quality of the oil is reduced and shorted usable oil life eventually reduces the margin of protection to components (corrosion and wear). When additive compounds are consumed, they undergo a molecular change, which a generally not indicated by a change in elemental concentration FT-IR provides the most economical method of routine monitoring of additive depletion, or the effect of depletion.

2.9.3 Lubricant Degradation by Contamination

Oil contamination is probably the most important cause of oil related machinery damage. Contaminants from the environment and other equipment system impair lubricant properties, promote degradation, consume additives, and cause tribological damage to machinery parts. Used oil should be routinely monitored to ensure it is free from any contamination. The following is a summary of the leading contaminant that may be encountered in a used oil analysis program.

Water usually enters into the oil system as consequence of condensation, coolant leak or free water ingress during equipment cleaning or environmental exposure. Although detergent and dispersant additives may keep small concentrations of water in suspension, thus providing some measure of protection, water will increase wear and promote oxidation and corrosion. In combustion engines, abnormal operating temperatures, most free water contamination will tend to evaporate. However , any free water that encounters a hot surface will flash into steam, remove the load carrying lubricant film, and cause localized wear. In extreme cases, wear damage can lead to catastrophic failure of the component.

2.10. Research on Vegetable-Based Lubricants and Additives

Investigations over the past six decades on mineral oil-based lubricants have improved the oil properties and diversified their applications in all fields of lubrication, especially for all sorts of rotating and sliding parts of vehicles machinery. However, the public awareness in environmental issues has been constantly growing (87). Since lubricants are used in many diverse areas, therefore, research on biodegradable functional lubricants (vegetable-based oil) is emerging as on the top priorities in lubricating system. Vegetable-based oil can offer significant environmental advantages with respect to resource renewability, biodegrability, as well as at the same time displaying satisfactory performance in a variety of applications De Gee et al., (88) have investigated the lubricating action of polyalphalefin (PAO) polypropylene glycol (PPG) and mineral oils to characterize their wear and frication reducing performance under boundary lubrication conditions It was found that the wear reducing action of PAO-based lubricant was significantly better than that of mineral oils. The lubricating action of PPG fluid was equally well or slightly better than PAOs. The PAO lubricant, either straight or doped with additives such as adsorbing polar species or ZDDP, reduces wear via a number of mechanisms. These include the formation of oxides (89), physisorbed or chemisorbed films (90,91). Rewolinski (92) has conducted lubricated wear experiments using blended diesel lubricating oil with sunflower oil. Savasankaran et al., (93) have studied jojoba oil-based gasoline engine lubricant. The results obtained from this oil showed that jojoba oil has a good potential to replace the mineral oil-based stock.

Organic straight chain compounds with polar end groups, such as oleic acid amide, are widely used as friction-modifying additives in lubricating oils. These compounds are adsorbed from hydrocarbon solutions on a metal surface. It is generally assumed that these adsorption layers are responsible for the improved lubricating properties of oils constraining these substances (62). Daniel (10) and kipling (94) have postulated that long chain fatty acids and alcohols form monomolecular layers on metals. The molecules are adsorbed with the major axis perpendicular to the surface. Recently, research has been done on vegetable-based metal working lubricant additives (fatty acids) on the grinding performance of the various types of carboxylic acids (95). The fatty acid has shown the best grinding performance of all oiliness agents friction of defer and EP agents. There have been many investigations concerning the chain length of the carbon atom of fatty acids on lubricating properties (96-98). Nakayama et al., (9) have explained the influence of temperature on the adsorption of stearic acid from hydrocarbon solutions on iron powder. They found that the structure of the monolayer was not changed at or slightly above melting point (70° C) of stearic acid. However, the limiting value of adsorption of stearic acid at 120° C is lower than that at room temperature and structure of the monolayer had changed at this temperature.

The presence of long-chain fatty acid in vegetable oil, especially methyl ester has increased the research interest into the use of vegetable oil as lubricating oil, and as an alternative source to present commercial lubricants (99). Technological development through research have made in possible for palm oil based lubricating oil to be used in a host of applications (PORIM, 1983). Palm oil contains 50%-70% palmitic acid, $C_{15}H_{31}COOH$, which is a from of glycerin. Masjuki et. al., (100) have performed experiment using palm oil methyl ester (POME) blended lubricant in a two-stroke engine and found that (POME) acts as a lubricating oil additive.

There has been a growing awareness for the use of vegetable oils, which have an excellent biodegradability and also improved chemical stability by antiwear additive formulation (43,46,101). Research on biodegradable functional lubricants (11) is emerging as one of the top priorities in lubrication and hence environmentally friendly lubricants are available in the market (102). Vegetable oils, especially rapeseed (103) and Canola (104) are really biodegradable and less costly than synthetic base stocks and show quite acceptable performance as lubricants (105). Asadauska's. et al., (106) have investigated some lubrication properties viz viscosity oxidative stability deposit formation and lubricity of biodegradable lubricants . The experijmental results showed that the viseosity index of vegetable oil (castor oil) is greater than mineral oil. Ohkawa et al, (7) had studied the oxidation stability and corrosion characteristics of vegetable-based biodegradable hydraulic oils (vegetable hydraulic oil) and they described the test results from a high pressure axial piston pump. Nakayama and Studs (107) have done research work on additive interaction and lubricating oil performance in a Polar Quadratic System. They found that polar additive binnry system showed lower lubrication performance compared to individual fatty acid additive.

The new trend towards the use of environmentally acceptable(EA) fluids appears to have emerged for hydraulic application in the construction ,mining, marine, government fleets and agricultural industries (108). Mobil corporation in USA. has already developed their own rapeseed oil-based hydraulic oil .It varies widely in biodegradability toxicity and performance. The trimethylolpropone esters were tested as biodegrabable hydraulic fluids and compared with commercially available hydraulic oils (109). They found that the hydraulic fluid based ontrimetylolpropane esters of rapeseed oil had good cold stability friction and wear characteristics and better oxidation stability at elevated temperatures. The new synthetic type metalworking lubricants have been introduced in the market in compliance with environmental and technical considerations. These lubricants are slowly gaining acceptance over the traditional oil-based formulas, which have proven in effective in dissipating heat. Mud additives that were formulated earlier on form water-soluble substances combinations of Si.P.Al and B have replaced by thinner sunflower lubricating agents in Russian drilling operations (110). These environmentally safes additives have been found to both thin the mud and improve the mud inhibition level. Common industrial wastes, such as used sunflower oil and organic acids from the food processing industry, have also found in Russia an applications a base martial for lubricating additives

Chapter-3

EXPERIMENTAL DESIGN
&
PROCEDURE

EXPERIMENTAL DESIGN AND PROCEDURE

3.1 Introduction

The experimental part of this thesis divided in to three sections. Firstly, Analysis of oils (physical and chemical properties) secondly, determination of composition of metal and, finally the study of corrosion behavior of three different metals studied in different base oils medium.

3.2 Analysis of oils

Lubricating oil of mineral origin is used extensively in automobile engine. Universally viscosity is the main property of lubrication oil. Higher faction obtained in the refining of mineral oils are used as lubricating oils. Among different physico-chemical properties density, viscosity and their related properties along with flash point and fire point are very important for a good quality of lubricating oil. The chemical composition of a oil is also very important. The oil analysis test can be divided into two categories:

(i) Test for physical properties analysis

(ii) Test for chemical properties analysis

3.2.1 Test for physical properties analysis of oil:

(i) Viscosity:

Viscosity and it changes with temperature is very important properties of lubricating oils. Because viscosity is measure of internal friction in the liquid, which is considered as the inherent principle of lubricating of fluid(1,2).

In this study Saybolt Universal Viscometer (S.U.V fig-3.1) is used to determine the lubricants viscosity. In this method determination of the viscosity of an oil by measuring the time for a definite volume of oil to flow under gravitational force through a standard vertical oil tube, which is located centrally in a

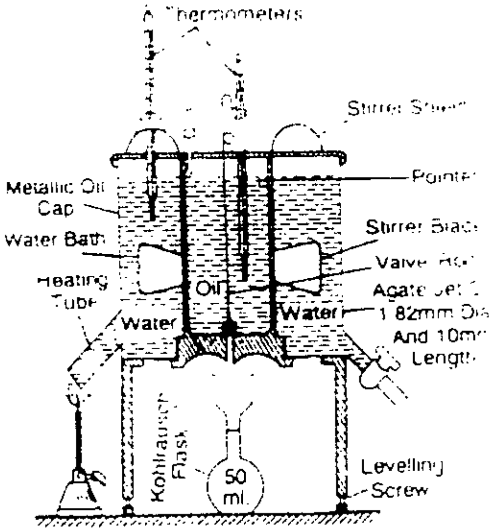


Fig: 3.1Saybolt Universal Viscometer.

temperature controlled oil bath. The vartical tube has an outlet orifice through which the oil flows into a receiving flask, the capacity of which filled to the mark on its neck is 60 cm^3.

The viscosity estimated by the formula:

Viscosity (centistokes)= .22t-180/t [t=time in second]

(ii) Density:

In this study, density of each lubricating oil was measured at different temperature (30, 40, 60, 80 and 100°C). For this measurement, the apparatus used was designed and made in the laboratory. Hydrostatic method was followed by using a glass made plumate of 2 cm^3. Both the plumate and the apparatus were first thoroughly cleansed with cleaning) mixture (chloroform and hexane and then with enough distilled water. These were then dried by rubbing with tissue paper. The weight of the plumate in air, in distilled water and in the solution under investigation were taken at different temperature. A polish made U.10 ultrathermostat was used to control the temperature with in ± 1°C. The density of different solution were calculated by using the formula:

$$\textbf{Density} = \frac{\text{Weight of the plumate in air} - \text{Weight of the plumate in solution}}{\text{Volume of the plumate } (2\text{cm}^3)}$$

The apparatus for density measurement was calibrated with redistilled water. The density values of different solution at different temperature under investigation are presented in experimental data.

(iii) Flash point and fire point(1,2)

Flash point is the minimum temperature of the liquid fuel at which the oil will produce vapor which will give flash of flame when a flame is run over the vapour. It is important because, if the working temperature of the oil is above its flash point, then there is a possibility of getting fire through the oil. Flash point is a signal of fire that may take place within the oil. Fire point may be defined as the minimum temperature of the oil at which the oil vapour will burn with continuous flame at least for few second. It is always higher than the flash point.

To determine flash and fire point an amount of oil was taken in a crucible and a thermometer was placed in to the oil. Heat was applied by using a gas burner. Every after 2^0C rise in temperature flame in plays over the vapor of oil using the gas nozzle of the apparatus. The flash point is that temperature when the oil vapor is sufficient to give a flash of flame over it and extinguish. Fire point will be that temperature at which the flame of fire will persists and least for 5 seconds.

3.2.2 Chemical analysis of oil

(i) Oxidation test of oils:

In order to assess the oxidation stability of palm and margosa Oil added lubricants, static oxidation test was conducted for 24 hours. The sample oil was put into a glass beaker and placed on a hot-plate heater. The oxidation temperature was set at 120^0C. The aeration was kept constant throughout the test. At every four (4) hour time interval, the oil sample was analyzed for degradation characteristics. The degradation characteristics were measured using TAN determination and IR Spectroscopy.

(a) Total acid number analysis[1,2]

To determine the total acid number, 1 gm sample oil is dissolved in 20 mL of alcohol in a conical flask. 1 mL of phenolphthalein indicator is added into this. It is taken titrated quickly with 1N potassium hydroxide solution. The total number of acid (TAN) is determine by the equation:

$$\text{Total acid number (TAN)} = \frac{56.1 \times S \times V}{W}$$

Where, W = weight in gm.

S = Strength of KOH in (N)

V = Volume of KOH solution (mL).

(b) Infrared (IR) Spectroscopy Analysis.

IR spectroscopy analysis is the study of the interaction of infrared light with matter. The fundamental measurement obtained in infrared spectroscopy is a infrared spectrum which is a plot of observed infrared intensity versus wave length (or wave number) of light (111). This technique is widely used in oil analysis because of its capabilities to extract lubricant degradation and contamination parameter from the spectrum of the used oil sample with in a very short time. The spectrum of fresh oil and used oils were generally very similar, and by subtracting the spectrum of fresh oil from used oil, the differences can be obtained. Differences of spectrum represent the products formed by oxidation of base oil, contamination in the oil, and depletion of the additives. The IR spectra of lubricating oil investigated in this study were recorded at the Department of Chemistry, University of Dhaka.

3.3 Chemical composition test of materials

(i) Steel analysis:(112)

Plain carbon steel contains a certain amount of carbon, silicon, sulphur, phosphorus, and manganese. For special purposes, amounts of other elements, such as chromium, vanadium, molybdenum, tungsten, titanium, nickel, cobalt, zirconium and copper are added. Iron itself is rarely determined. In steel only the subsidiary elements are determined, because of their great practical importance. Generally a number of methods are available for the determination of these elements.

Gravimetric methods are being replaced by titrimetric procedures. For the determination of elements present in small quantities, colormetric, spectrophotometric, spectrographic, and ploarographic techniques are widely used. In this work above mentioned technique are used to analysis steel.

Carbon: The total carbon in steel is determined by combustion at 1000-1200 ^{O}C in a atmosphere of pure oxygen. The gases produced from the combustion (CO_2, SO_2, and SO_3) are passed through selective reagents which absorb everything except oxygen and carbon dioxide. The carbon dioxide gas is finally absorbed in a U-tube containting solid reagent.

Phosphorus: This element usually occurs as phosphide, and must be oxidised to orthophosphate before it can be determined. About 3.0g of the steel was weighted and taken into a 250ml conical flask. 75ml. of 6N (3:8) nitric acid was added into it then and warm gently on a hot plate until the solid steel is dissolved. 10 ml. of 2 per cent potassium permanganate solution was added, and boiled for a few minutes in order to precipitate the manganese dioxide. The precipitate was dissolved by adding a freshly prepared solution of sodium sulfite drop wise. The solution was boiled for a few minutes to expel out sulphur dioxide and oxides of nitrogen. Partially nitric acid was neutralized by the addition of 20-25 ml. of 6 N ammonia solution and then 75ml of ammonium molybdate reagent was introduced. The flask was stoppered with a rubber bung, and shaked for 5-10 minutes. The solution was allowed to stand for overnight. The precipitate of ammonium phosphomolybadate was filtered of and then washed. The precipitate was dissolved in 20 ml. of 6N ammonia solution containing 2g of citric acid, and collected the filtrate in a 250ml beaker. Filter paper was washed two to three times with 1:20 ammonia solution, and finally with 1:20 hydrochloric acid. A few drops of methyl red indicator was added into solution, and the solution is acidified with dilute hydrochloric acid. 25 ml. of magnesia mixture was then added. Phosphor was weighted as magnestium ammonium phosphate, $MgNH_4$ PO_4 $6H_2O$ or as magnesium pyrophosphate, $Mg_2P_2O_7$.

Sulphur: About 5.0g. of the steel taken into a covered 250ml conical flash or beaker. 50 ml of pure concentrated nitric acid was added into it. When the sample was dissolved then added 1 g AR sodium chloride. It was evaporate to dryness, and baked gently on a hot plate for about 10 minutes. 25 ml of concentrated hydrochloric acid was added after cooling, and evaporated the solution almost to dryness. 5ml of concentrated hydrochloric acid 25ml of water, and 5g. of A.R, zinc granules added into it. Then it was warmed on the steam bath until all the ferric iron had been reduced and evolution of hydrogen ceased. The solution through a small was filtered and collected the filtrate in a 250-400ml beaker. The residue was washed with small volumes of 1:50 hydrochloric acid. The filtrate was warmed and washings to 70^0C, and precipitated the sulphate by the slow addition of 10ml of hot 10 per cent barium chloride solution. It was allowed to stand overnight, and was filtered through a Whitman No. 40 or 540 filter paper. The precipitated was washed first with a solution containing 10 ml of concentrated hydrochloric acid and 1 g of barium chloride per liter, then with cold water to remove chlorides. The precipitate was ignited and weighed as barium sulfate according to the procedure. A blank determination was also run. The weight difference between two experiment was the weight of sulphur.

Silicon: About 5.0g of the steel taken into a porcelain dish, and covered it with a clock glass. 55ml of a mixture of 2 volumes of nitric acid (sp g. 1.20) and 1 volume of dilute sulphuric acid (1:1) was added and heated until the steel was dissolved. When the reaction was over, then the clock glass was removed and evaporated the solution until dense fumes of sulphur trioxide were evolved for 2-3 minutes. Since insoluble sulfates was formed, then it was cooled to 50-60^0 C, and added 5ml of dilute hydrochloric acid (1:1) and 50 ml. of water. This solution was heated to boiling and stired until all salts dissolved. It was then filtered through a Whatman No. 40 or 540 paper; and used a rubber-tipped glass road to dissolved any precipitate adhering to the sides of the vessel. The precipitate was washed with hot hydrochloric acid until all iron salts removed, and finally washed with a little hot water. The paper and precipitate was placed in a weighted platinum crucible, then heated slowly to char the paper and burned off the carbon, and then applied the full heat. This ash was cooled in a desecrator and weighed. The loss in weight represents silicon.

Manganese: From the different method in work titrimetric method was used. About 0.4g steel was taken and dissolved into concentrated nitric acid and then added concentrated HCl acid. Then it was evaporated to small volume in a water bath. This was diluted with water and filtered 25ml of the solution pipetted into a 500ml conical flask and 5ml of 10% aqueous hydroxyl ammonium chloride solution , 10mL of 20 % triethanolamine solution , 10-35 ml of ammonia solution and about 100ml water, and 6/7 drops of thymolphathlexone indicator solution. This solution was titrated with standard 0.05 M EDTA until the color changes from blue to color less.

(ii) Brass analysis:[(112)] The chief components of the alloy brass are copper and zinc, but small quantities of tin, lead, and iron and sometimes very small quantities of other elements as well, are usually present. The percentages of the important constituents rarely fall outside the following values:

Cu	Zn	Sn	Pb	Fe
50-905	20-40%	0-6%	0-2%	0-1%

The analysis involves, therefore, the separation and determination of tin, lead copper, iron, and zinc.

The sample was treated with nitric acid to precipitate the hydrated tin oxide SnO_2H_2O and to bring copper, zinc, iron, and lead into solution: the insoluble stannic acid was filtered off, ignited, and weighed as stannic oxide, SnO_2. The filtrate from the tin precipitate was evaporated with an excess of sulfuric acid to fumes of sulfur trioxide in order to expel nitric acid. The residual liquid was treated with water and the insoluble lead sulfate was filtered off and weighed as PbSO4 after ignition at a about 500^{0}C The copper in the filtrate from the lead sulphate was determined as cuprous thicoyanate, CuSCN. The solution from which the copper had been separated was treated with bromine water or with nitric acid to oxidize iron to the ferrite state, and this metal was separated from the zinc by double precipitation with ammonia solution; the ferric hydroxide is ignited and weighed as Fe_2O_3. Finally the zinc was precipitated as zinc ammonium phosphate and weighed either as zinc pyrophosphate, $Zn_2P_2O_7$.

3.4 Corrosion characteristics study: (122)

Corrosion of metal is usually occurred by can occur of electrochemical or chemical interactions with the environment. Electrochemical corrosion (EC) tests are normally used to test specimens. The EC test where the test time is few minutes is used to rank specimen that corrodes by electrochemical means. These tests are useful during early stage development.

Electrochemical corrosion is a chemical reaction accompanied by the passage of an electric current and for this to occur, a potential difference must exist between two regions. The region at low potential is known as an anode and the region at high potential is known as a cathode. Electrochemical corrosion is influenced by the relative electropotential. Electrochemical corrosion may accelerate in a corrosive environment because corrosive fluids may provide a conductive medium necessary for electrochemical corrosion to occur on the rubbing surfaces.

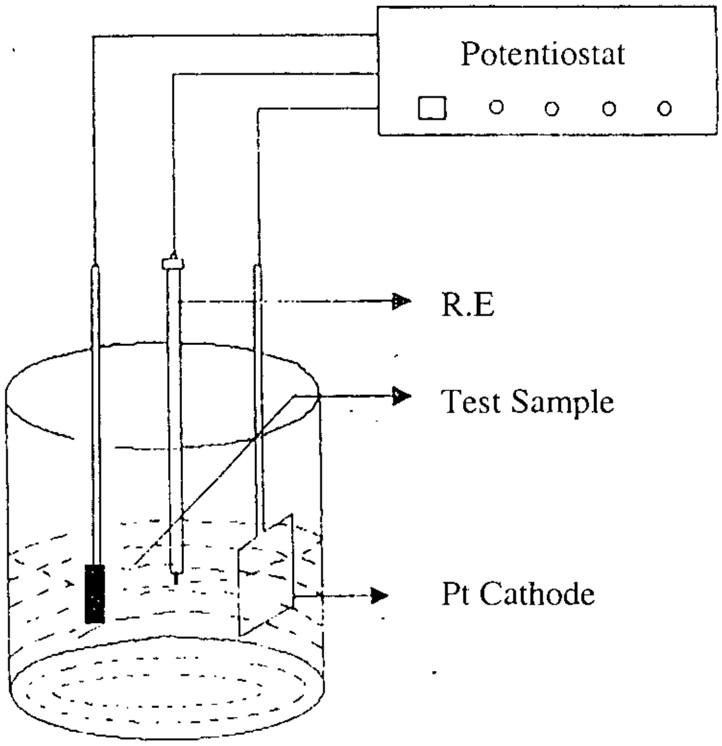


Fig: 3.2 Three Electrodes system for electrochemical corrosion measurement.

The standard technique used to run the corrosion test is electrochemical polarization analysis. The influence of blended lubricating oil on electrochemical corrosion (EC) phenomenon was carried out using A Hokuto Denko (HABE-501) electrochemical measurement system. The system works in conjunction with a saturated calomel electrode, counter electrode, working electrode and a beaker. The schematic diagram of the experimental set-up is shown in Fig. 3.2 The setup of the experimental procedure are as follows:

Rod specimens were prepared by cleaning with silica paper until scratches are removed. All dirt, oil and other contaminates on the specimens were remove by cleaning distilled water and acetone and dried by air jet from a pressure gun.

The specimen was mounted on the electrode holder and blended lubricant (acts as an electrolytic solution) was poured into the beaker. The reference electrode was inserted into the beaker and all cables were connected accordingly. The potentiosatic polarization test method was chosen for the test. Finally the current *Vs* potential is plotted after each examination.

Chapter-4

Result & Discussion

Result and Discussion

4.1. Introduction:

In this study an investigation on physico-chemical properties of palm and Margosa oil added lubricants has bee carried out. The results of physical and chemical properties of palm and Margosa oil blended lubricants are discussed here. The physical properties of different blended lubricants like viscosity and density over a wide range of temperature such as 30,40,60,80 and 100°C have been present in this chapter. The obtained results on chemical degradation of palm and Margosa oil blended lubricants are also bee presented in this section. The most important part of this thesis is the study of electrochemical corrosion, which has been carried out at three different temperatures. The corrosion rate is also discussed in two different temperatures i.e., room temperature and 60°C temperature in this study.

4.2. Effect of Temperature on Viscosity and Density of Lubricants:

The viscosity and density of a liquid are intercalated properties. If viscosity is less then density is also less. These two properties varies with temperature. Viscosity and viscosity coefficient are of very important properties of lubricating oils. Viscosity is a measure of internal friction in the liquid, which is considered as the inherent principle of lubricating fluid. A good lubricating oil must have an optimum viscosity, neither too high to shear the force nor too low which is unable to bear the load. The density of a liquid may be defined as the mass per unit volume of the liquid, the unit volume being cubic centimeter (cm^3) or milliliter (ml). Since the milliliter is defined to be the volume occupied by one gram of water at temperature of maximum density (4°C), the density of water in this C.G.S system is unity. Since the density of a liquid at different temperature is solely dependent on the volume of the liquid at the corresponding temperature, the volumetric study is fully based on density measurement.

4.2.1.Viscosity:

The viscosity of palm oil added lubricants was determined at different temperatures using Saybolt Universal Viscometer. The results of viscosity coefficient of palm oil blended lubricants at different temperatures are presented in figures 4.1 and 4.2. It is observed from the figure 4.1 that viscosity coefficient of lubricating oil decrease with the increase of temperature for all types of palm oil blended lubricants. This is the natural characteristic behavior of all liquid substances including lubricating oil. Fig 4.2 shows the effect of percentages of palm oil on the viscosity of palm oil blended lubricants at different temperatures. From the figure 4.2 it is found that viscosity increases with the increase of palm oil at all temperature. This significant character of palm oil described elsewhere(3).

The results on viscosity coefficients of Margosa oil blended lubricants at different temperatures are presented in figures 4.3 and 4.4. It is evident from the figure 4.3 that like palm oil blended lubricating oil the viscosity of Margosa oil blended lubricants also decrease with the increase of temperature. It is also evident from the figure 4.4 that the viscosity coefficient of Margosa oil added lubricant increases with the increase of percentage of Margosa oil in the blended lubricants. Although the curves of 4.4 shows upward trend than 4.2.

The increase of viscosity coefficient of blended lubricating oil may be due to positive interaction of palm or Margosa oil with lubricating mineral oil. This indicates the positive additive effects of palm and Margosa oil on lubricating mineral oil.

4.2.2.Density:

The density of palm and Margosa oil blended lubricating oil was determined by hydrostatic method at different temperatures using Archimidus principle. The results are presented in figure 4.5 to 4.8. It is observed from the figures 4.5 and

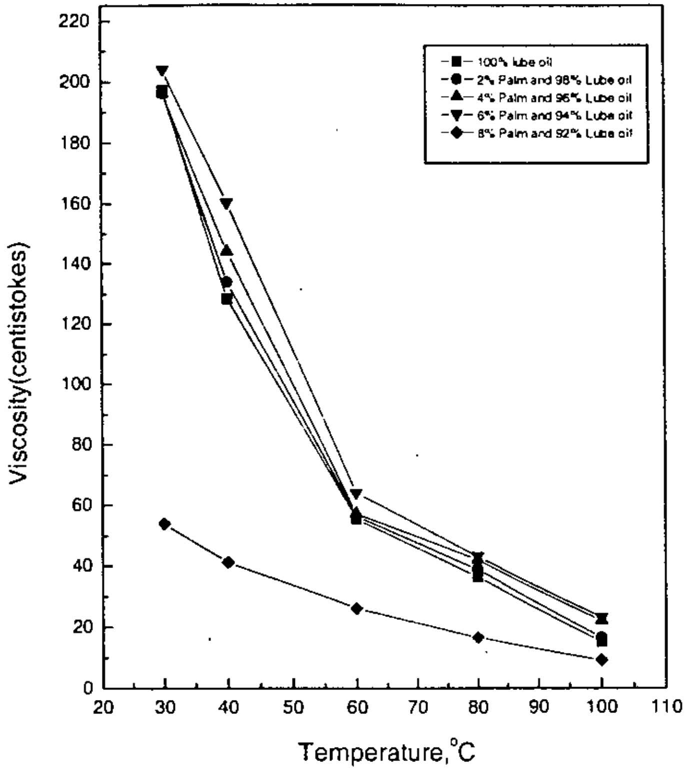


Fig. 4.1: Effect of temperature on vicosity at different Palm oil blendeed Lubricants.

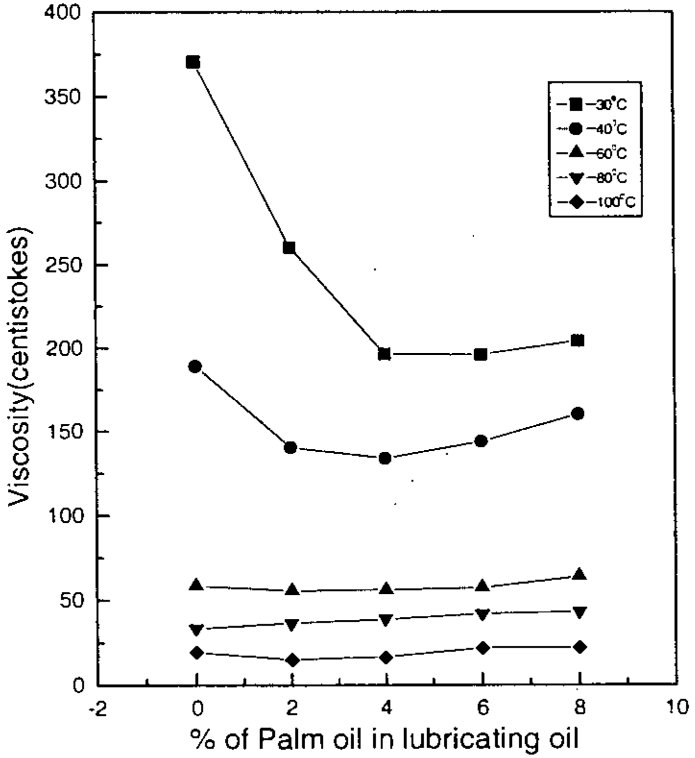


Fig. 4.2: Effectof different palm blended lubricants on vicosity at different temperature.

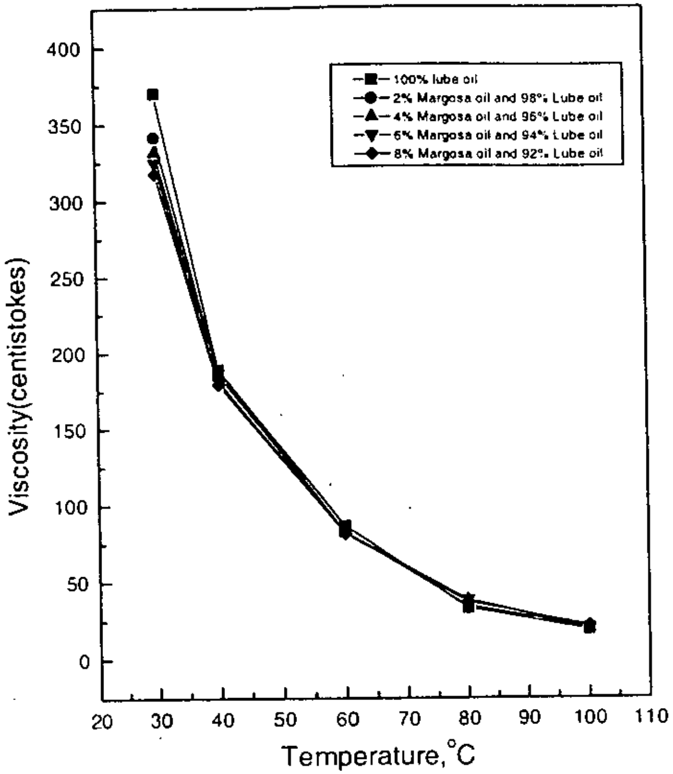


Fig. 4.3: Effect of temperature on vicosity at different Margosa oil blendeed Lubricants.

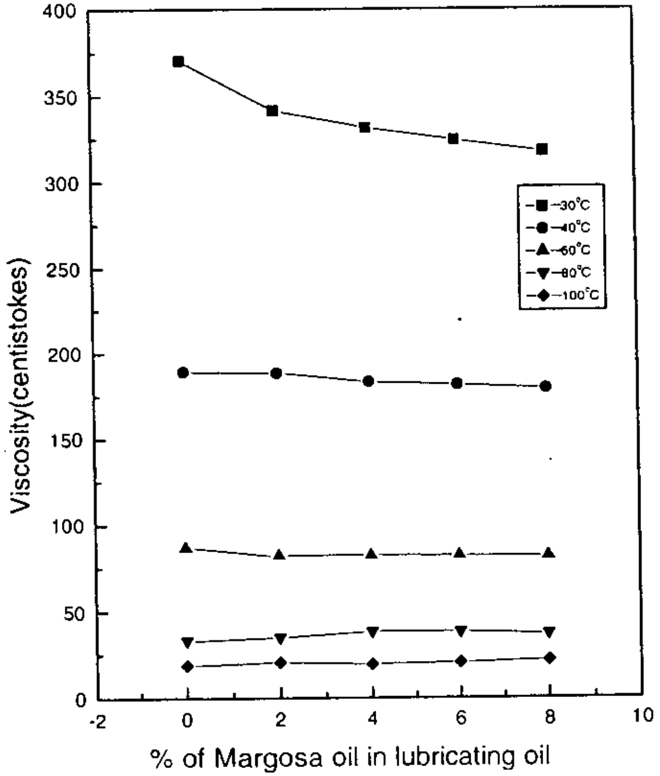


Fig. 4.4:- Effectof different margosa oil blended lubricants on vicosity at different temperature.

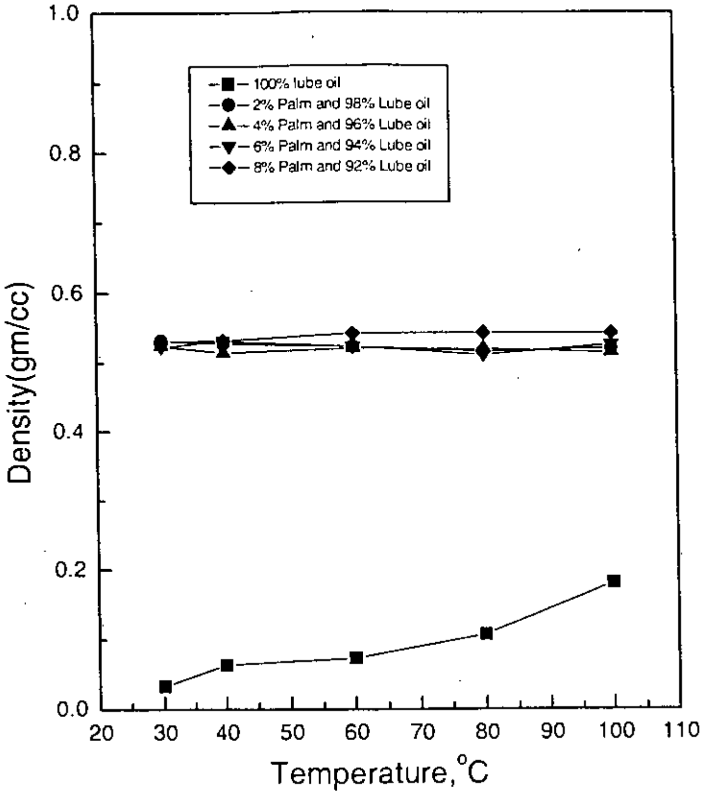


Fig. 4.5: Effect of temperature on density at different palm oil blended Lubricants.

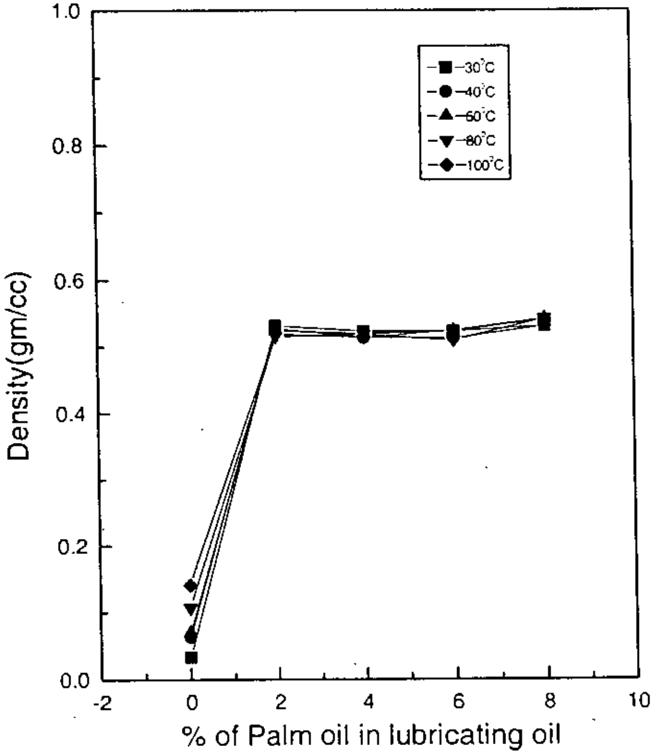


Fig. 4.6: Effect of different palm blended lubricants on density at different temperature.

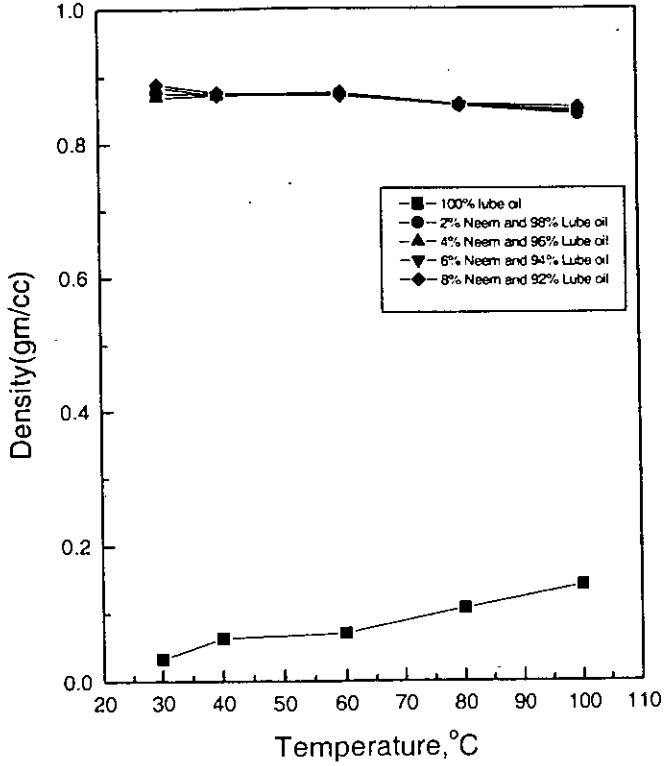


Fig. 4.7: Effect of temperature on density at different Margosa oil blendeed Lubricants.

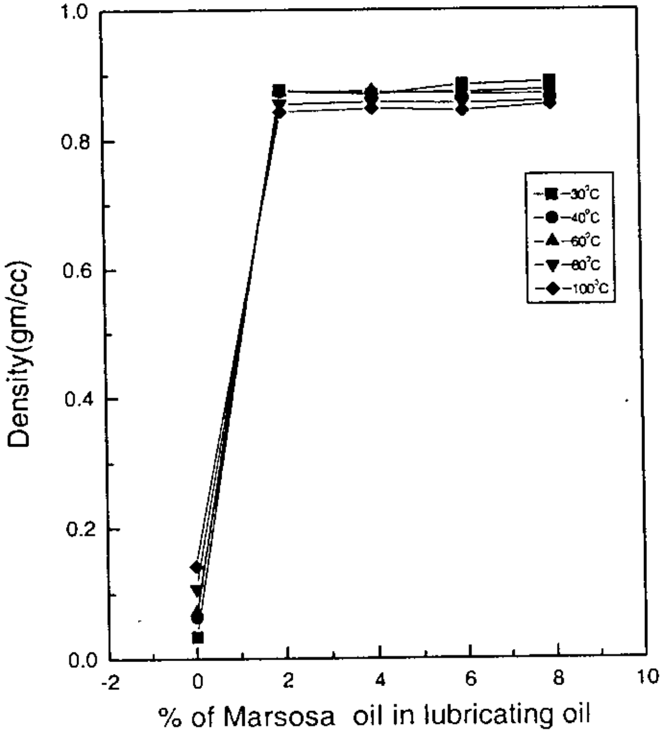


Fig. 4.8: Effect of different margosa blended lubricants on density at different temperature.

4.7 that density of different lubricating oil under investigation decreases with increase of temperature. The highest and lowest density is found at room temperature and 100^{0}C temperature respectively. A careful examination of the data presented in figure. 4.6 and 4.8 that the density of blended lubricating oils increase with the increase of palm and Margosa oil concentration at all temperature. In this case the highest and lowest density is found in the presence of 8% and 2% palm and Margosa oil respectively at all temperature.

It is also observed from the results presented in this section that the viscosity and density of blended lubricants are found to be higher than the fresh lubricating oil at higher temperature. Asadauskas et al.(106), have studied the lubrication properties of vegetable-based castor oil and found reasonably high viscosity at high temperature. According to their explanation conventional vegetable oils provide their high inherent viscosity index (VI) at high temperature.

The highest viscosity found at 8% palm and 2% Margosa oil blended lubricant is due to the fact that the carbonyl group in the vegetable oil that induces stronger hydrogen bonding among the try glyceride molecules causing the intermolecular attraction. Konishi et al. (116) performed oxidation test on vegetable-based hydraulic oil and found that viscosity increases at higher temperature. Similar effect is also found in this experiment.

4.3. Flash and Fire point analysis of Palm and Margosa oil blended Lubricants:

These points represent the volatility and tendency of the oil to be burned in an automobile while functioning. The flash point and fire points of different lubricating oils under investigation were determined. The results are presented in table 4.1 and 4.2. It is evident from the results presented in table 4.1 that there are no significant effects of palm oil on the flash and fire point of the palm oil blended lubricants.

Table: 4.1 The effect of palm oil concentration on Flash and Fire point.

Oil	Flash	Fire
Pure lubricating oil	253	261
Pure palm oil	253	263
2% palm-98% lubricating oil	253	261
4% palm+96% lubricating oil	253	261
6% palm+94% lubricating	253	261
8% palm+92% lubricating	160, 253	261

Table: 4.2 Effect of Margosa oil concentration on Flash and Fire point

Oil	Flash Point	Fire Point
100% Lubricating	253	261
Margosa oil	253	261
2% Margosa oil+98% lubricating oil	253	261
4% Margosa+96% lubricating oil	253	261
6% Margosa+94% lubricating	254	261
8% Margosa oil +92% lubricating	254	262

The results presented in table 4.2 show that there are no dominating effects of Margosa oil concentration on flash and fire point. From the data of two tables the dominating character of lubricating oil is observed particularly in the case of fire point and flash point. This may be due to the high quantitative volume of lubricating oil.

In fact fire point and flash point of oil do not correlate any way to the lubricating properties of the oil. These properties just serve as a guideline of using lubricants in machine functioning at high temperature.

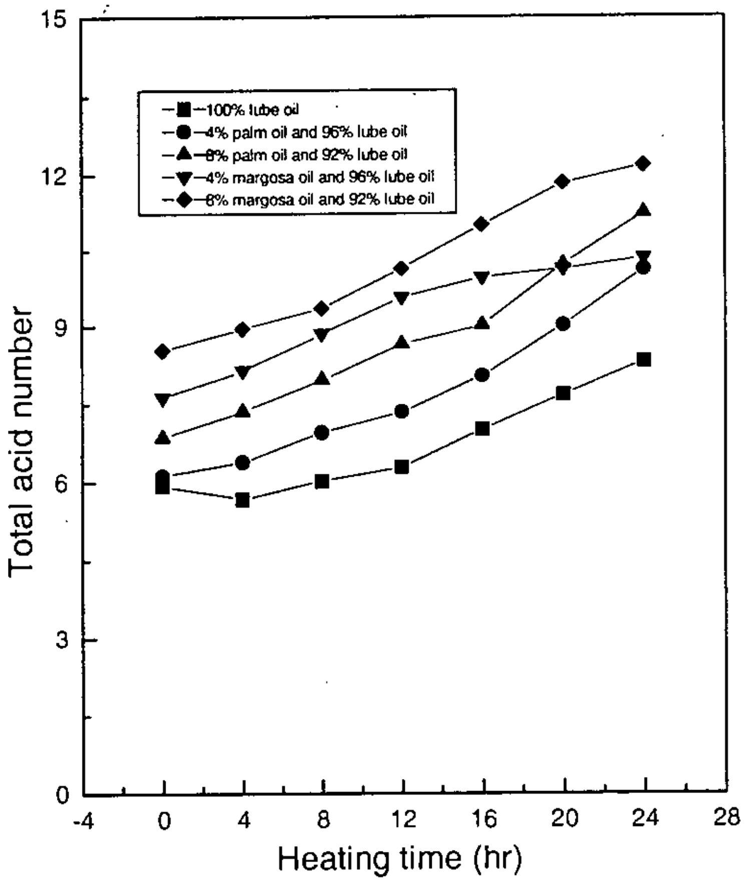


Fig. 4.9. Effect of heating time on total acid number on 0%,4%, and 8% palm and margosa oil blended lubricants at 120^{0}C temperature.

4.4 Oxidation test of Palm and Margosa oil blended Lubricants:

The main objective of this test is to find out the thermal oxidation of palm and Margosa oil blended lubricating oils due to high temperature. In general the degradation product of palm and Margosa oil blended lubricants are fatty acids. For this reason, the total acid number (TAN) and IR-spectroscopic analysis is performed after and before heating of the lubricating oil.

4.4.1 Effect of temperature on Total Acid Number (TAN):

Total acid number is a measure of oil acidity, which is an indication of the corrosive effect of lubricants due to oxidation. The lesser is the acidity, the better is the performance of the lubricating oil. TAN has been considered to be an important indicator of quality, specifically in terms of defining oxidative status (114). Total acid number of different lubricating oils under investigation were determined by using the standard method (113). The obtained results are presented in tables 4.3 and 4.4. Table 4.3 shows the effect of heating time on total oxidation number of 0%, 4% and 8% palm oil blended lubricating oil. It is observed from the table that total acid number (TAN) increases with the increase of heating time. Maximum TAN is found at 8% palm oil blended lubricant at 24 hours heating time. It is to be mentioned here that thermal oxidation of lubricating oil may be correlated with the heating time. Higher is the heating higher is the thermal oxidation.

Table: 4.3 Effect of heating time on total acid number (TAN) of (0%, 4% and 8% palm oil blended lubricants.

Oxidation time (Heating time in hrs.)	Increase of Total Acid Number (TAN)		
	0% Palm Oil	4% Palm Oil	8% Palm Oil
Initial	5.95	6.12	6.85
4	5.69	6.39	7.35
8	6.03	6.95	7.95
12	6.30	7.34	8.65
16	7.00	8.03	9.01
20	7.66	9.01	10.21
24	8.30	10.11	11.23

Table 4.4 Shows the effect of heating time on total acid number of 0% Margosa, 4% Margosa and 8% Margosa blended lubricating oil. It is evident from the results presented in table 4.4 that like palm oil added lubricants similar effects are also observed in the case of Margosa oil blended lubricating oil. Fig. 4.9 Shows the effect of heating time on total acid number of 0%, 4% and 8% palm and Margosa oil blended lubricating oil. From the figure it is evident that palm is more stable at high temperature than Margosa oil. The reason may be that oxygen reacts with the hydrocarbon of lubricating oil on heating and form carbonyl containing products (primary oxidation products), which subsequently undergo further oxidation (as the oxidation time was increased) and finally form carboxylic acids (secondary oxidation product). Similar effects have also been found by other workers(114).

Table: 4.4 Effect of heating on 4% and 8% Margosa oil blended lubricants oil oxidation on total acid number (TAN)

Oxidation time (Heating time in hrs.)	Increase of Total Acid Number (TAN)		
	0% Margosa Oil	4% Margosa Oil	8% Margosa Oil
Initial	5.95	7.63	8.53
4	5.69	8.12	8.95
8	6.03	8.85	9.35
12	6.30	9.57	10.13
16	7.00	9.95	11.01
20	7.66	10.12	11.83
24	8.36	10.34	12.17

4.4.2 IR Spectroscopic Analysis of Degraded Palm and Margosa oil:

IR spectroscopic analysis was performed on degraded oils after static oxidation test. The IR spectra of palm and Margosa oil blended lubricants are presented in Figures 4.10-4.13.

The infrared spectrum is in general considered to be a kind of fingerprint of the structure of molecules. When infrared radiation is passed through a substance an absorbance peak is obtained. The pattern of a peak in a particular region is very specific. Comparison with a reference peak can identify the functional group of the compound. The intensity of infrared absorbance quantify the concentration of the functional group in the compound. In this study, two different oil samples have been used to monitor the degradation properties. These samples (8% palm and Margosa oil blended lubricants) are analyzed before and after the thermal oxidation.

From the IR-spectra obtained in this study it evident that significant changes have been taken place during the oxidation of the oil. From the IR-spectra presented in Figures 4.11 and Fig 4.13. it can be seen that the evidences for oxidation products appear in six regions as indicated by 1,2,3,4,5 & 6 in the figures 4.11 and 4.13. The hydroxyl stretching frequency (1), the carbonyl stretching frequency (2), nitrogen compounds and ester stretching frequency (3), and carbon-oxygen stretching frequency (4) indicate hydroxyl, carbonyl and ether groups present in the samples. The changes absorbance peak in the oxidized oil and fresh oil are apparent in around bands 2800-2900 cm^{-1}, 1800 cm^{-1}, 1500cm^{-1}, 1400 cm^{-1} 1200 cm^{-1} etc. The band positions of the peaks indicate that changes have taken place on bands around 2850, 2900, 1740, 1450, and 1360 cm^{-1}etc as the wave numbers of the peaks are almost same for all spectrum. This means that there is a possibility of loss of additives caused by the oxidation of the palm and Margosa oil blended lubricants. Almost similar observation was obtained by Mukherjee et. al.(118) where they tested heavy duty earth moving machinery oil. The characteristic group frequencies are identified as follows (111,119):

Wave number range (cm^{-1})	Characteristics
2700.2800	Presence of aliphatic, aromatic compounds formation of carboxylates groups.
1700-1800	This feature is due to the presence of carbonyl in degradation (carbon oxidation) products of the lubricating oil. The strong peak in the carbonyl region is usually

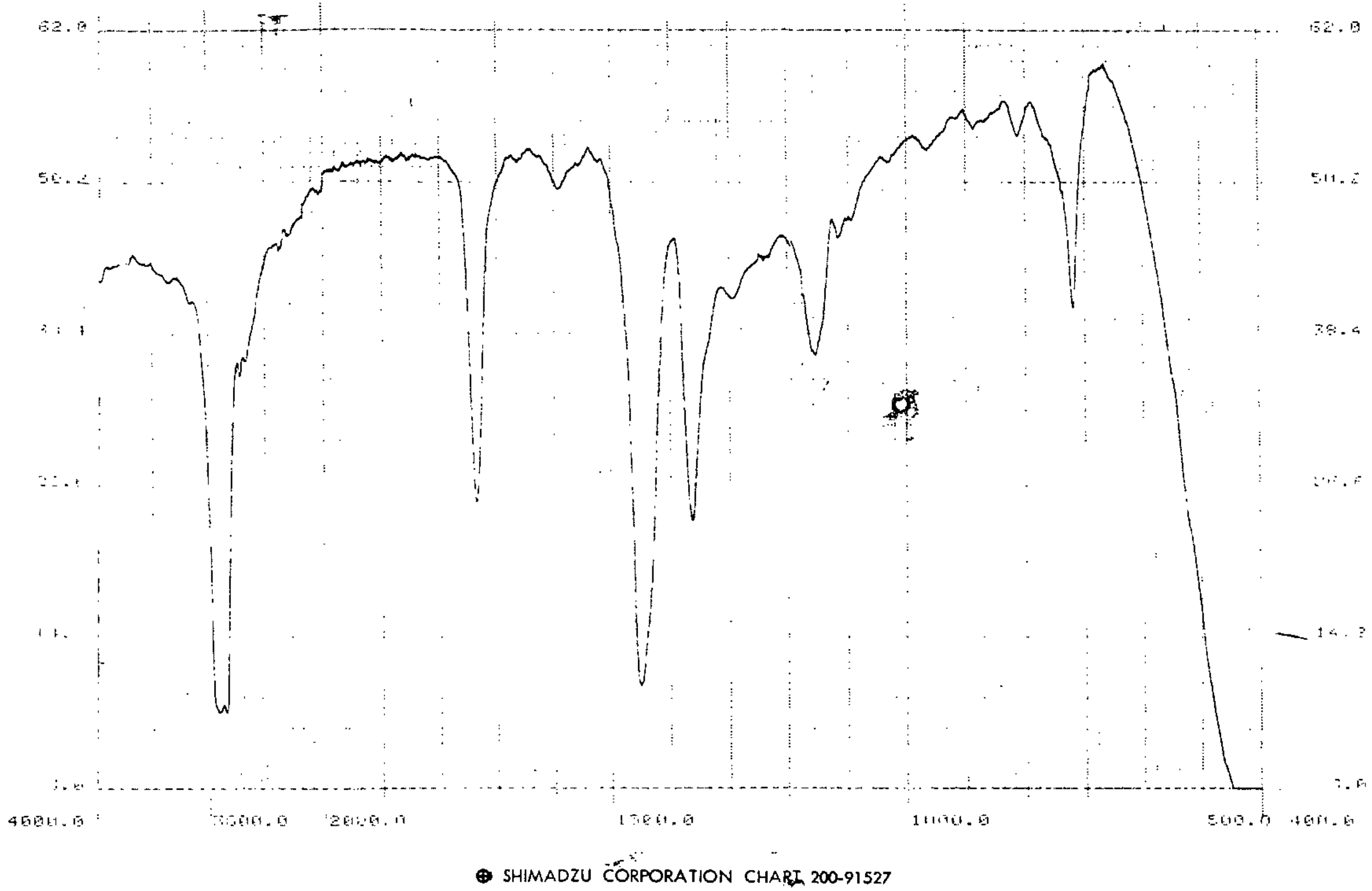


Fig 4.10: The infraed spectrum of fresh 8% palm oil blended lubcriants before oxidation.

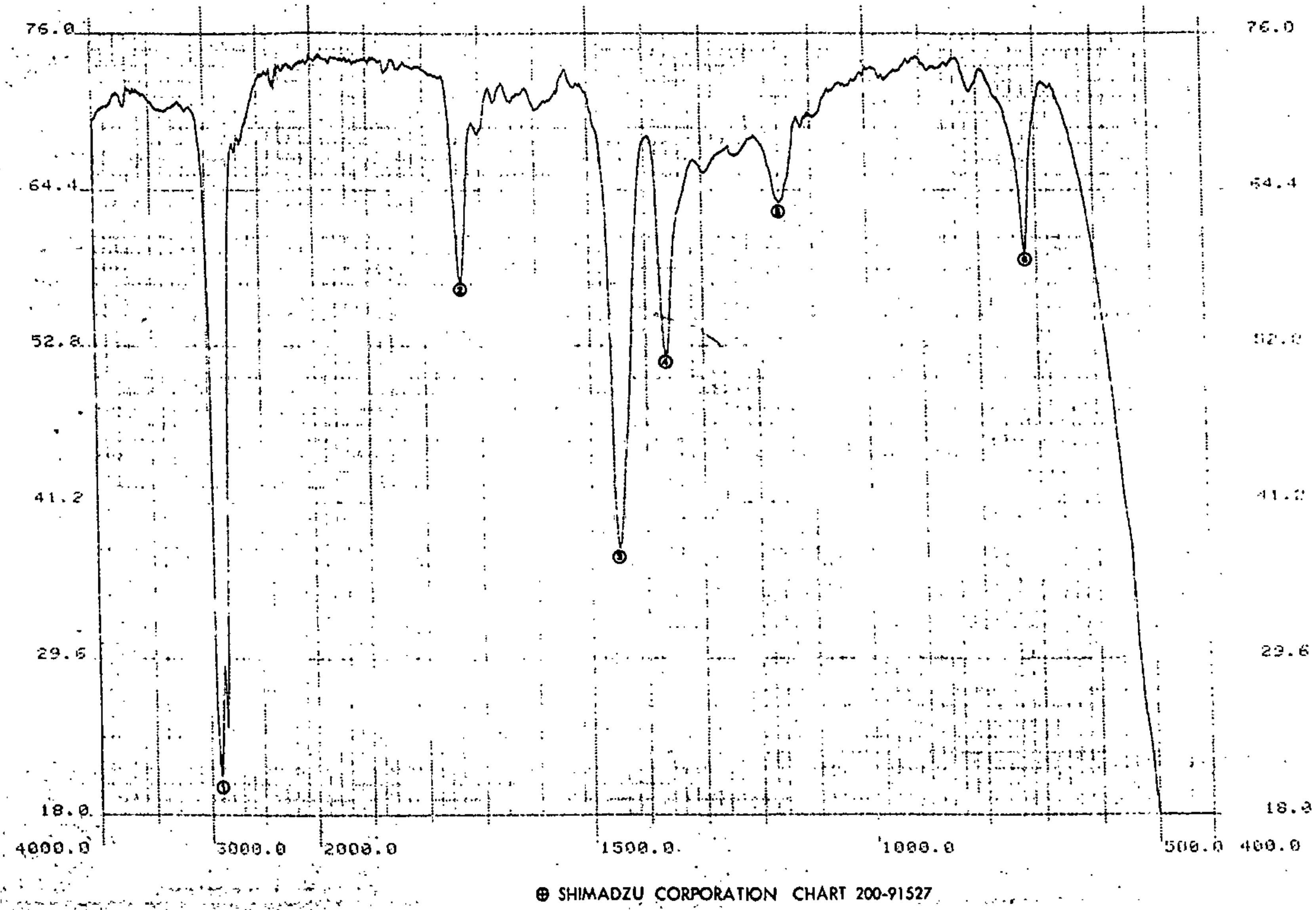


Fig 4.11: The infraed spectrum of 8% palm oil blended lubcriants after oxidation.

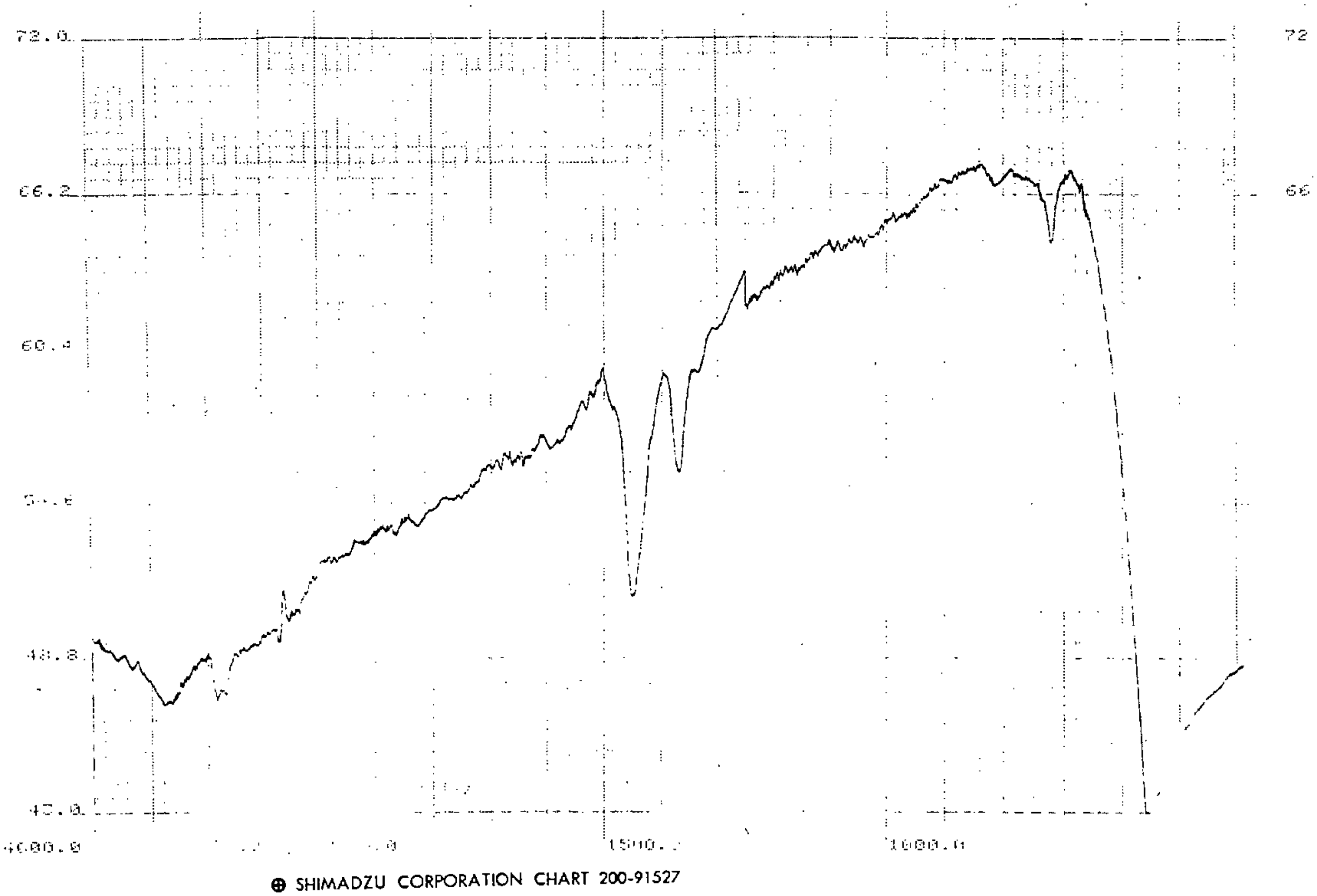


Fig 4.12: The infraed spectrum of fresh 8% margosa oil blended lubcriants before oxidation.

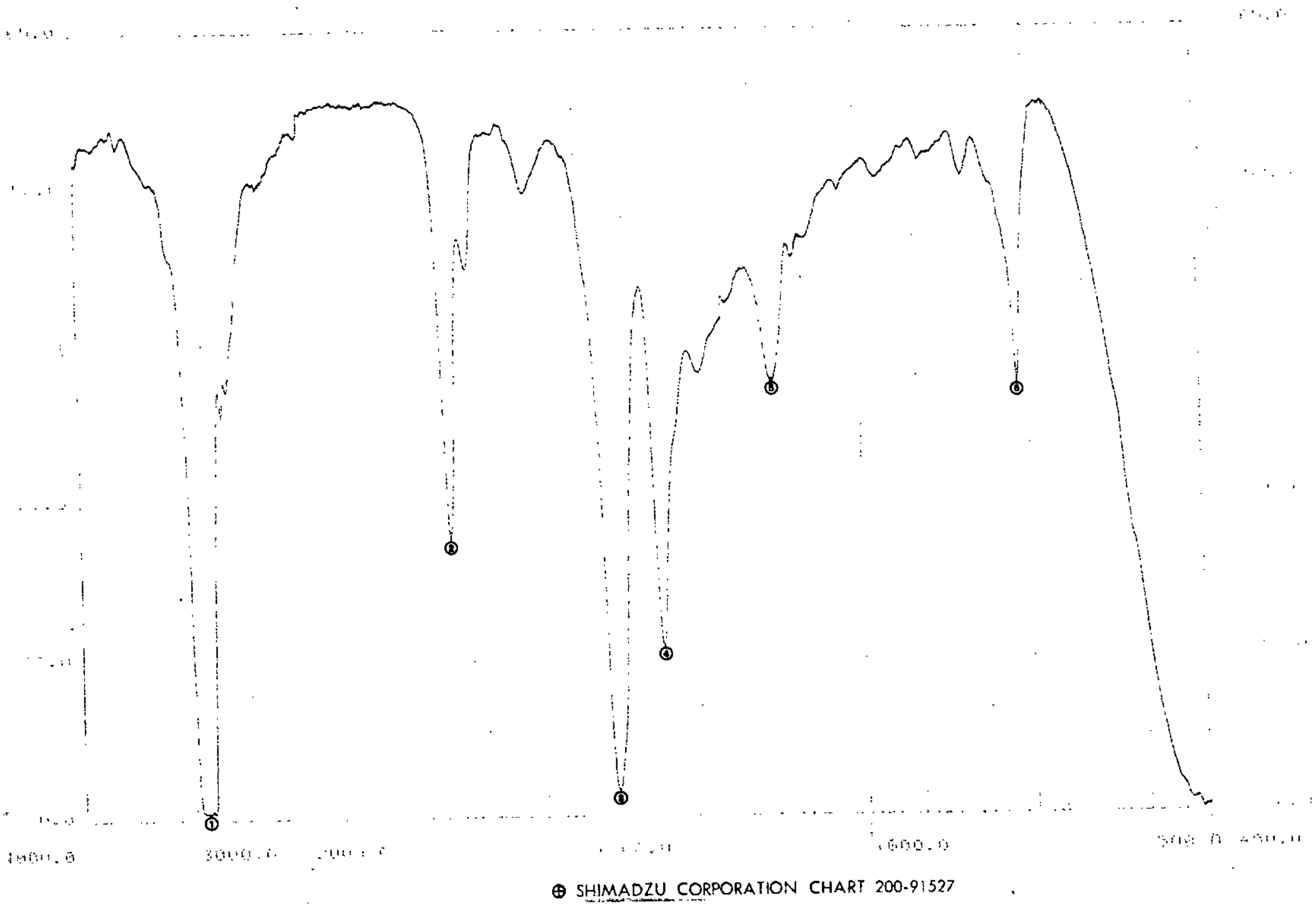


Fig 4.13 The infraed spectrum of 8% margosa oil blended lubcriants after oxidation.

	associated with the presence or formation of saturated lactones, acids, ketones, aldehydes etc.
Around 1600	The absorption around this wave number indicates the present of alkanes, ceyeloalkanes, amides, alcohols, decomposition of nitrogen compounds. Presence of conjugated carbonyl species double bonds are also indicated by this absorption band.
1100-1200	Absorption peak at this wave number indicates the formation of sulfide productsa and presence of esters including double band (C-C) stretching.
Around 830	Absorption peak at this wave number indicates the presence of two adjacent hydrogen atoms.

From spectra presented in Figures 4.11 and 4.13 it can be seen that the presence of new compounds in the region of carbonyl stretching (1760-1710 cm^{-1}) was usually associated with the presence of ketones (1715 cm^{-1}) or carboxylic acids (1710 cm^{-1}) while palm and Margosa oil added lubricants were oxidized. Another peak at 1740 which was obtained from palm and Margosa oil blended lubricant with oxidation (Fig-4.11 & 4.13) indicates the possible formation of five member ring lactones. These acids, with peaks in the carbonyl vibration region, exhibit the ability to of physical absorption of oil onto the metal surfaces and form protective films. But under 8% palm and Margosa oil added lubricant especially when oxidized, the broad feature centered around 1740 cm-^{1} wave number was due to the presence of carbonyl containing degradation products of the lubricant. This has been identified as ketones or aldehydes(113). Ketones, although found in straight chain lengths carbon atoms, are having low polarity and as such do not absorb readily onto metal surfaces. This is supported by Bowman and Stachowiak(77) observation.

Bowman and Stachowiak(77) studied the effect of oxidation base oil on scuffing and observed the oil degradation products after 25,50 and 100 hrs of oxidation test by FT-IR. They explained that the strong peak (1713) was usually for the presence of ketones and the weaker peak (1767) for the formation of a 5-membered ring lactone. This has also been confirmed by others(120). The absorption band around 1600 wave number was associated with the presence of long chain alcohols, amides, conjugated carbonyl species (68) which are formed through the oxidation of lubricants and is known as surfactants. A study on POME added lubricants of oxidation for automotive tribo-matrieals is also supported this phenomena (3,5,7).

4.5. Materials Analysis for Corrosion test:

Corrosion characteristic of a material largely depends on the composition of materials and also on the composition of environment. In this work two steels and one brass samples are taken used to study their corrosion behaviour in palm and Margosa oil blended lubricants medium. In this study 1.1cm diameter of these three metallic samples are used. The chemical composition of the tested specimens are shown in table 4.5 and 4.6.

Table- 4.5: Chemical Composition of Steels

Materials	Chemical Composition, Wt%					
	C	Si	Mn	S	P	Fe
Steel	0.16	0.18	0.82	0.02	0.036	Rest
Steel	0.79	0.21	0.63	0.02	0.02	Rest

Table- 4.6: Chemical Composition of Brass

Materials	Chemical Composition, Wt%				
	Cu	Zn	Pb	Sn	Fe
Brass	76	22	1.5	-	.5

4.6. Corrosion Characteristics of Metallic Alloys in Lubricants :

4.6.1.Introduction:

Corrosion characteristics of palm and Margosa oil blended lubricants studied at three different temperature viz. room temperature (30±1), 40 and 60°C. Steels bearing 0.16% and 0.79% carbon and brass alloy were used in this experiment as the samples tribo-materials. Corrosion rate was determined in both pure and blended lubricants.

The experiments were carried out to study the anodic polarization behavior of tribo-materials in lubricating oil media. In this study a wide range of potential (500-7500mV) was applied. At different specific interval of potential the corresponding flow of current was recorded. The current flow was recorded after each five minutes interval at a specific potential. The results of this study were presented in the diagrams of potentials VS current flow. The flow of current through these oil media showed that metals were corroding. When current passed through the oil media, metals lost their electrons and went into solution. So oxidation took place at anode. At the same time, hydrogen is absorbed or evolved at cathode by the reduction reaction i.e. gaining electron in the process. The rate of current flow indicates the corrosion of the metal. The higher rate of flow of current at a specific potential indicates the higher corrosion of the metal.

In this section the corrosion behavior of metals in pure lubricants, in pure palm oil, in palm oil blended lubricants, in Margosa oil and in Margosa oil added lubricant have been discussed. A comparative study on corrosion rate of these sample metals in different lubricating oils under study has also been discussed.

4.6.2. Corrosion of Metallic Alloys in Lubricating Oil :

The corrosion behavior of tribo-materials in lubricating oil was investigated at different temperatures viz.30, 40 and 60°C. The characteristic of corrosion rate

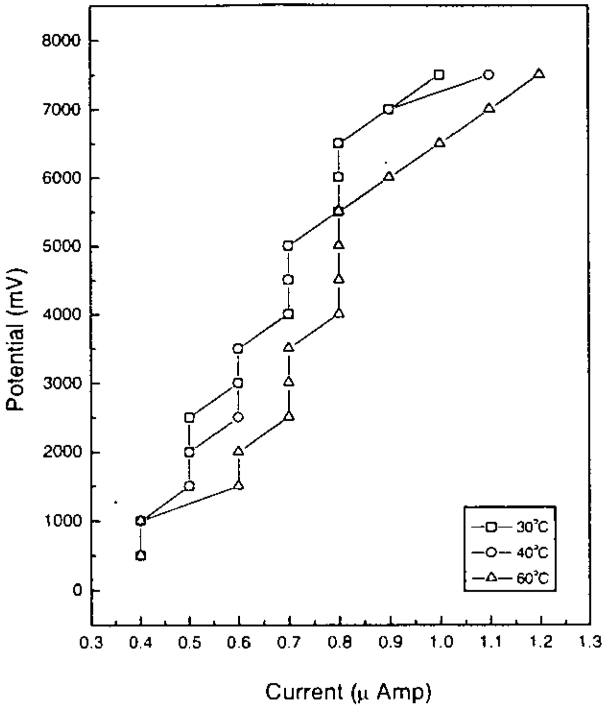


Fig. 4.14: The corrosion behavior of 0.16% carbon steel in 100% lubricating oil at different temperature.

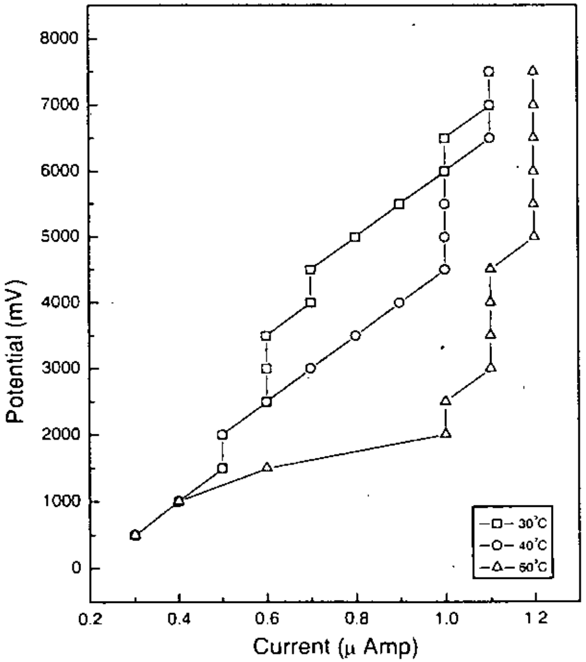


Fig. 4.15: The corrosion behavior of 0.79% carbon steel in 100% lubricating oil at different temperature.

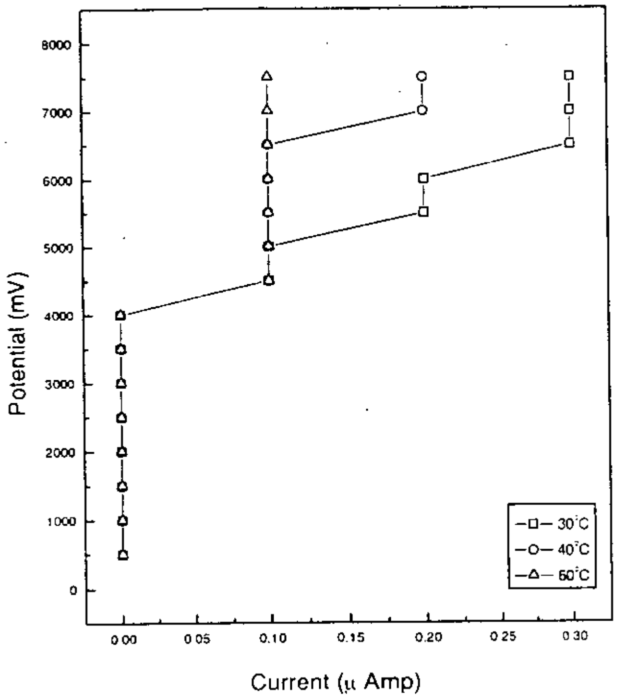


Fig. 4.16: The corrosion behavior of brass alloy in 100% lubricating oil at different temperature.

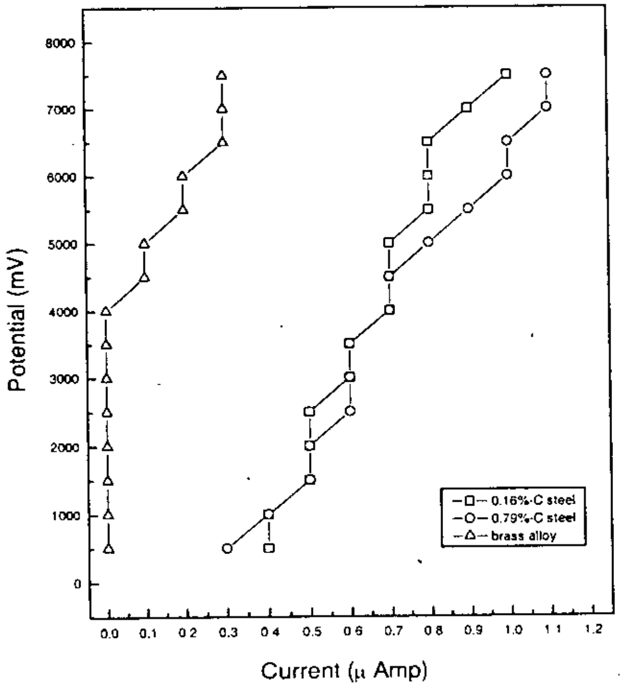


Fig. 4.17: The corrosion behavior of defferent metal at 30°C temperature in 100% lubricating oil.

is presented in the diagram by plotting potential VS current. The diagrams are presented in figures 4.14 to 4.16.

Fig 4.14 shows the corrosion behavior of 0.16% carbon steel in pure lubricating oil at three different working temperatures. From the figure, it is evident that the corrosion rate increases with the increase of potential at room temperature. The highest and lowest corrosion rate are observed at 7500 and 500 mV respectively. The corrosion rate of 0.16% carbon steel is similar at all temperatures, although the higher corrosion current is found at the potential from 6500 mV and above at 60°C temperature. This high corrosion rate at high temperature may be due to the presence of sulfur, H_2S, Poly sulfide compound in the lubricating oil (1,2) which normally activate at aggressive condition.

Fig 4.15 represents the corrosion behavior of 0.79% carbon steel in pure lubricating oil at the different temperatures. Fig. 4.15 shows that corrosion rate on 0.79% carbon steel increases with the increase of potential at all temperatures. The lowest and highest corrosion rate is observed at 500 and 7500 mV respectively. At 60°C temperature the higher corrosion is observed than room and 40°C temperature. The causes of higher corrosion rate may also due to the presence of corrosive agents (S, H_2S, polysulfied compounds). in the lubricating oil as described above.

Fig. 4.16 represents the corrosion behavior of brass in pure lubricating oil at different temperatures. The figure shows that at low potential there is no current flow observed. The corrosion current is found to flow at around 4500 mV at all temperatures. The highest corrosion rate is found at room temperature. Brass is an alloy of Zinc and Copper. From the electrochemical point of view Zn is more reactive than Cu. When potential applied Zn reacts with organic acid of lubricant and produces organometallic compounds. In lubrication system organometallic compounds are used to inhibit corrosion (1,2). This may be cause that brass does not show any corrosion reaction at low voltage and at all temperatures.

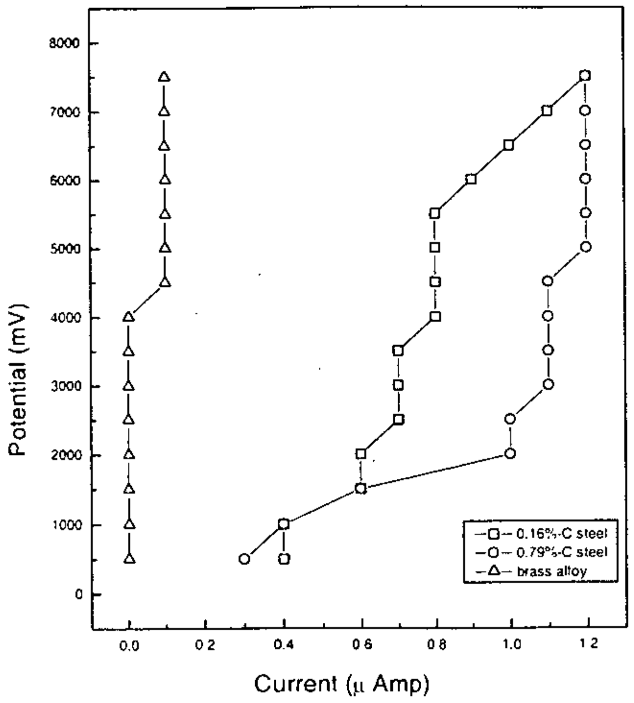


Fig. 4.18: The corrosion behavior of defferent metal at 60°C temperature in 100% lubricating oil.

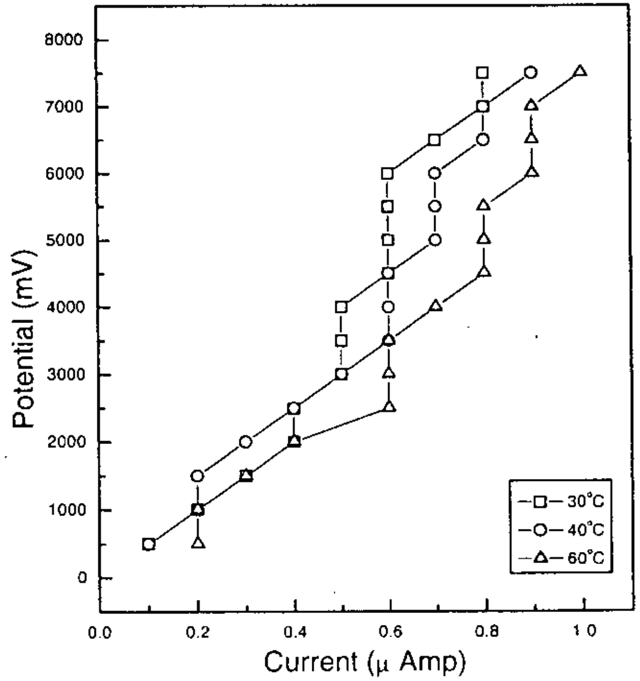


Fig. 4.19: The corrosion behavior of 0.16% carbon steel in Mobil oil at different temperature.

A comparative study of corrosion behavior of three sample (viz. 0.16% carbon steel, 0.79% carbon steel and brass alloy) tribomaterials in lubricating oil at 30 and 60°C temperatures has been investigated by plotting potential Vs current flow. The diagrams are shown in figures 4.18 and 4.19. From the figure 4.18 it is found that 0.16% and 0.79% carbon steel corrodes more or less at the equal rates at 30^0C. But in brass the corrosion reaction started at around 4500 mV. The highest corrosion current in brass is found to be around 3μA at 7500 mV. At 60^0C higher corrosion current is observed for 0.79% carbon steel than 0.16% carbon steel. The highest corrosion current of these two metals are almost equal at 7500 mV. At 60^0C the rate of corrosion reaction on brass is almost negligible. The may be due to the quick reaction of Zn metal of brass with fatty acids of lubricating oil thereby formation of corrosion inhibiting organic metallic compounds.

4.6.3 Corrosion of Metallic Alloys in Mobil (Commercially used Lubricants)

The corrosion behavior of tribomaterials in Mobil oil was studied at different temperatures. The characteristics of corrosion behavior have been investigated by plotting potential Vs current. The diagrams are presented in fig 4.19 to 4.21.

Fig 4.19 shows the corrosion behavior of 0.16% carbon steel in Mobil oil at different temperature. From the figure it is found that at all temperature the corrosion rate increases with the increase of temperature. This increase of corrosion rate may be due to the presence of different additives like viscosity improver, dispersant and detergent etc. The additives in general contain corrosive agent. The highest corrosion rate is observed at 60^0 C and at 7500 mV. The lowest corrosion rate is observed at 500 mV and at 30 and 40^0C temperature for 0.16% and 0.79% carbon steel receptively.

At all temperature corrosion rate increases with the increase potential.

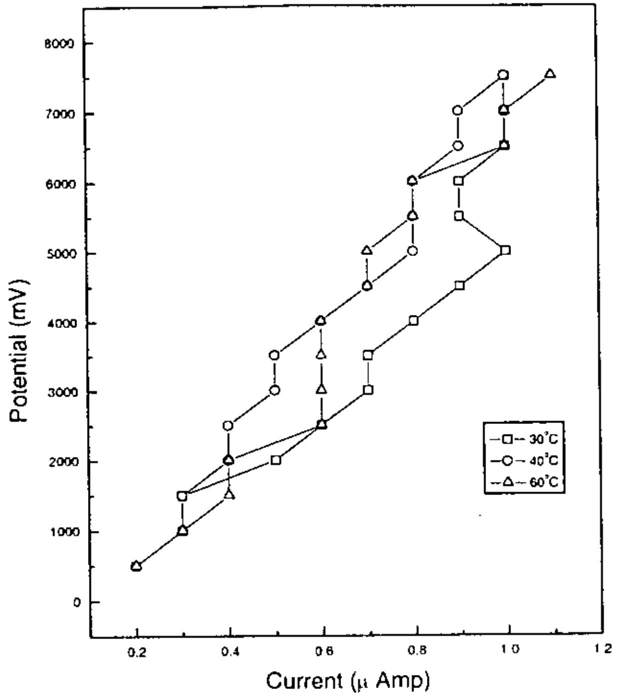


Fig. 4.20: The corrosion behavior of 0.79% carbon steel in Mobil oil at different temperature.

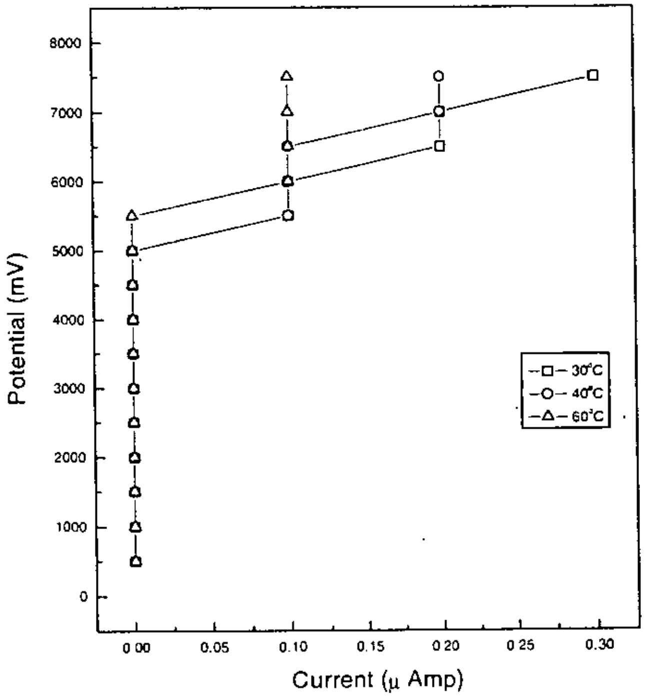


Fig. 4.21: The corrosion behavior of brass alloy in Mobil oil at different temperature.

From Fig 4.20 it is found that higher corrosion of 0.79 % carbon steel is found in Mobil oil at all temperatures. The higher corrosion is rate also found at 30^{0}C and at low potential in Mobil oil. The causes of high corrosion rate has been described in section 4.6.2.

Fig. 4.21 represents the corrosion behavior of brass in Mobil oil at different temperature. In this figure no corrosion reaction is observed at 500 to 5000 mV and at all temperatures. From 5500 mV and above corrosion is found to start. The highest corrosion rate of brass in Mobil oil is observed at 7500mV and at 30^{0}C. The corrosion inhibition mechanism in Mobil oil is similar to that of lubricating oil which has been described in the previous section.

A comparative study of corrosion behavior of tribomaterials in Mobil oil has also been carried out at 30°C and 60°C temperatures by plotting potential VS current. This diagrams are presented in figures 4.22 and 4.23. From these two figures it is found that 0.79% caborn steel corrodes at higher rate than the other steels at 30^{0}C temperature. A negligible corrosion is found for brass alloy at 30^{0}C temperature. At 60^{0}C temperature, corrosion rates of 0.16% and 0.79% carbon steel are almost similar. However in the case of brass the corrosion rate is found to be negligible.

4.6.4. Corrosion of metallic alloys in palm oil:

The corrosion behavior of tribomaterials in 100% palm oil was studied at different temperatures. The characteristics of corrosion behavior have been investigated by plotting potential VS current. The diagrams are presented in fig 4.24 to 4.26.

Fig 4.24 shows the corrosion behavior of 0.16% carbon steel in 100% palm oil at different temperature. From the figure a negligible corrosion is found to occur on the alloy in pure palm oil at all temperatures. However, at and above 3,000 mV potential the corrosion reaction is found to occur. No effect of temperature is found in this system.

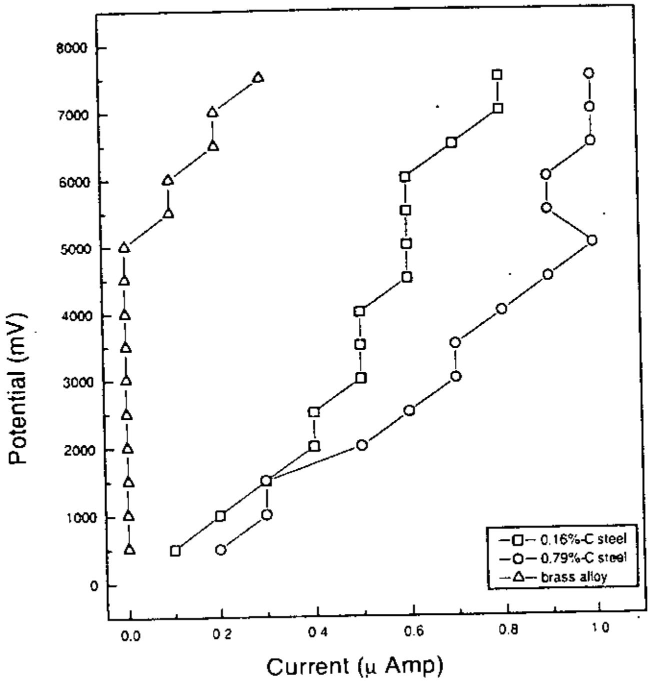


Fig. 4.22: The corrosion behavior of defferent metal in Mobil oil at 30°C temperature.

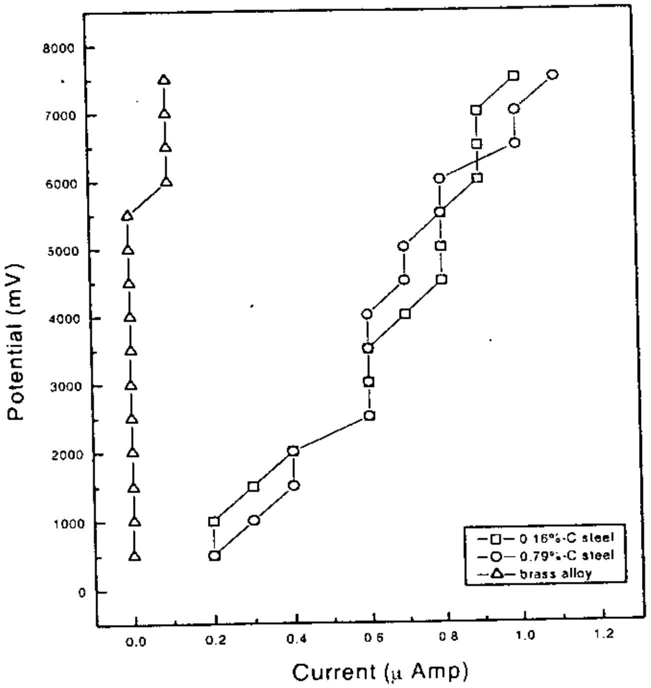


Fig. 4.23: The corrosion behavior of defferent metal in Mobil oil at 60°C temperature.

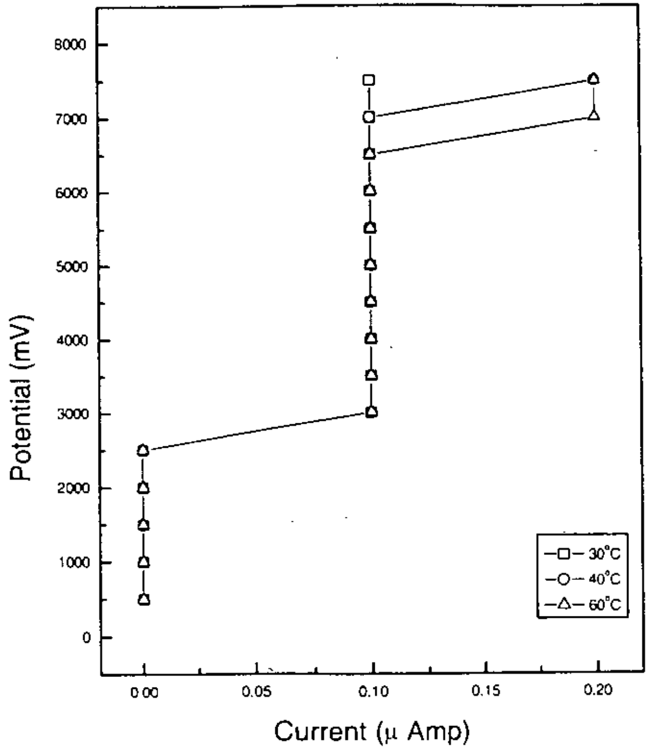


Fig. 4.24: The corrosion behavior of 0.16% carbon steel in 100% palm oil at different temperature.

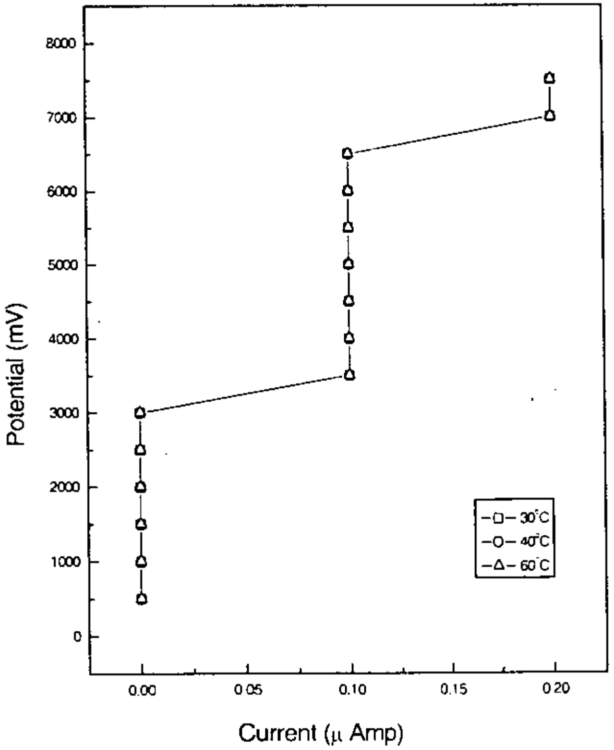


Fig. 4.25: The corrosion behavior of 0.79% carbon steel in 100% palm oil at different temperature.

Fig. 4.25 and 4.26 represent the corrosion behavior of 0.79% carbon steel and brass in palm oil at different temperatures. It is observed form the figures that the corrosion behavior of 0.79% carbon steel and brass are almost similar to that found in 0.16% carbon steel as presented above.

A comparison of corrosion behavior of these three tribomaterials in 100% palm oil has been investigated at 30°C and 60°C temperatures by plotting potential VS current. These diagrams are presented in figures 4.27 and 4.28. Fig 4.27 shows the corrosion behavior of three metals in 100% palm oil at room temperature (30±1)°C. It is evident from the figure that pure palm oil is more corrosive for 0.16% carbon steel particularly at lower potential. However at higher potential it is found to be more corrosive for 0.79% carbon steel. Fig 4.28 shows the corrosion behavior of three sample materials in 100% palm oil at 60°C temperature. It is evident from the figure that at this temperature the corrosion behavior is quite similar to that at 30°C which has been presented in fig. 4.27.

A careful observation of the results presented in figures 4.24-4.28 in 100% palm oil reveals that there is little corrosion on the three sample materials at all temperatures. Below 3000 mV for all the three metarials there is no current flow at all. However, above 3000 mV very small current (0.1 mA) is found to low at both 30°C and 60°C. This effect may be explained as in palm oil there is no sulfur compounds, H_2S or polysulfied compounds. But it contains low percentage of fatty acid which reacts with tarbo materials and forms a barrier against corrosion. So a little corrosion is found.

4.6.5. Corrosion Metallic alloys in palm oil blended lubricants:

(i) Corrosion behavior of 0.16% carbon steel in different percentage of palm oil blended lubricating oil at different temperatures:

The corrosion behavior of .016% carbon steel in different percentage palm oil blended lubricating oil is investigated at different temperatures. The characteristic behavior of corrosion is studied by plotting potential VS current. The diagrams are presented in figs 4.29 - 4.32.

Fig. 4.29 shows the corrosion behavior of 0.16% carbon steel in 2% palm oil and 98% lubricating oil mixture at different temperatures. At room temperature a little corrosion is observed even at high potential (6500-7500 mV). At 40 and 60°C similar effect on corrosion is found in this system. Actually in this mixture the rate of corrosion is negligible at all temperatures.

Fig. 4.30, 4.31 and 4.32 show the corrosion behavior of 0.16% carbon steel in 4%, 6% and 8% palm oil blended lubricants. at different temperatures. It is observed from the figs. that in these palm oil blended lubricants the corrosion reaction on alloy is found occur at 5500, 3000 and 3500 mV respectively at all temperature. From the figures it is also evident that there is no effect temperature of temperature on the rate of corrosion in 8% palm oil added lubricants. However, at around 3500 mV. 0.1 mA current is found to flow. which indicates that under this system small corrosion takes at 3500 mV potential.

(ii) Corrosion behavior of 0.79% carbon steel in different palm oil blended lubricants at different temperature:

The corrosion behavior of 0.79% carbon steel in different palm oil blended lubricating oil was investigated at different temperature by plotting potential VS current flow. The diagrams are presented in fig 4.33 to 4.36.

Fig 4.33 shows the corrosion behavior of 0.79% carbon steel in 2% palm oil and 98% lubricating oil mixture at different temperatures. At the potential range with in 500 to 3000 mV there is no corrosion at all at any temperature. But a little corrosion is observed at around 3500 mV and above. Higher corrosion current (0.2μA) is found to flow at 7000 and 7500 mV.

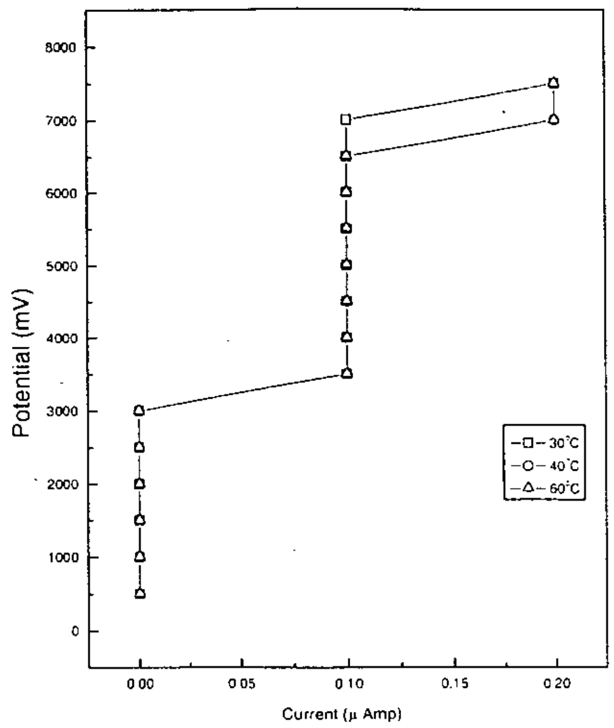


Fig. 4.26: The corrosion behavior of brass alloy in 100% palm oil at different temperature.

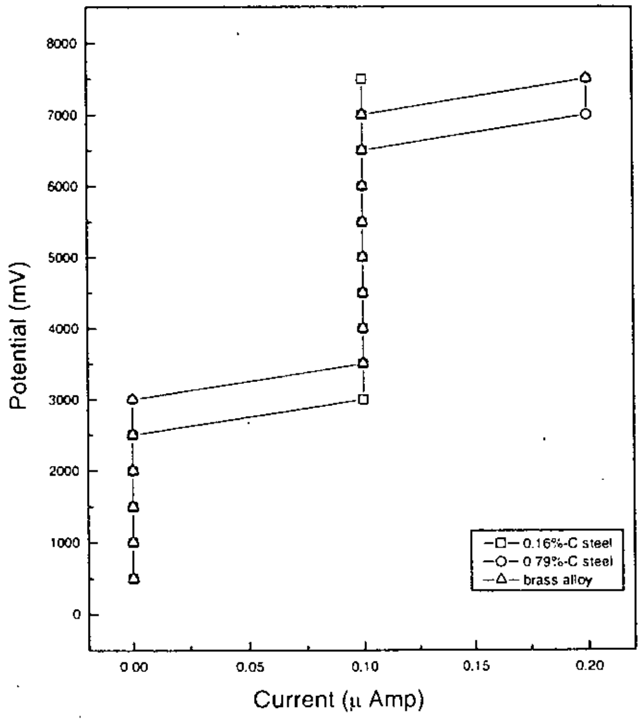


Fig. 4.27: The corrosion behavior of defferent metal in 100% palm oil at 30°C temperature.

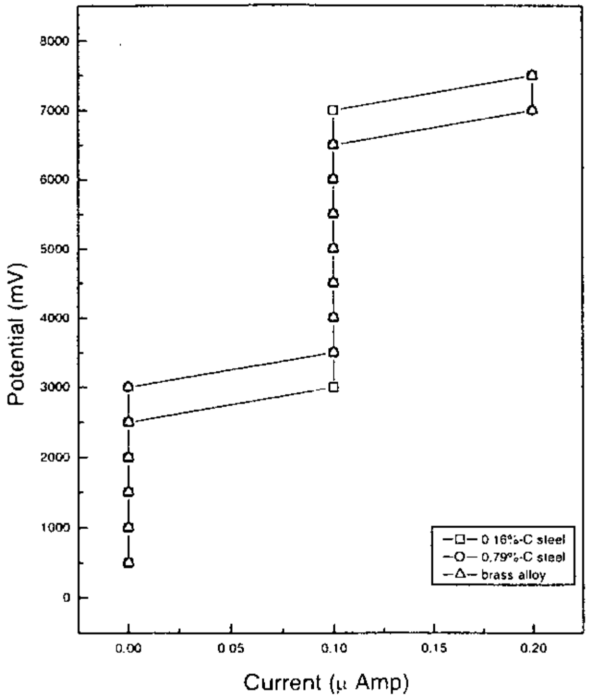


Fig. 4.28: The corrosion behavior of defferent metal in 100% palm oil at 60°C temperature.

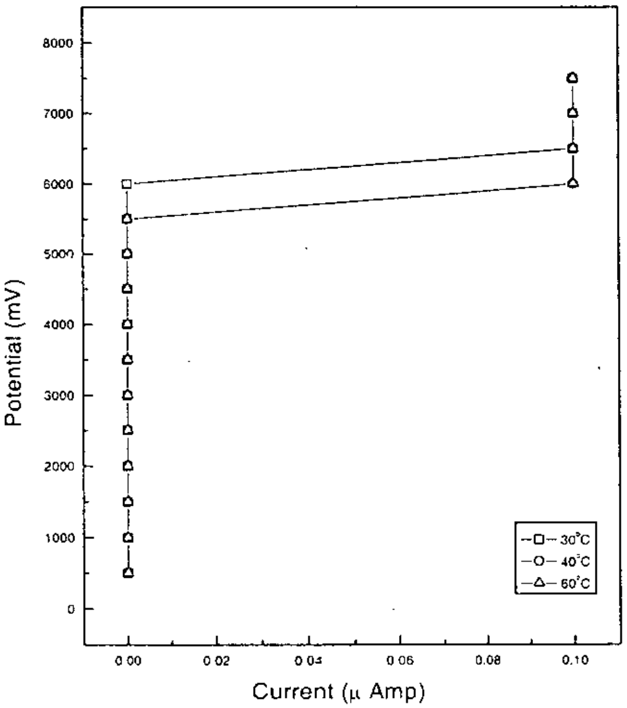


Fig. 4.29: The corrosion behavior of 0.16% carbon steel in 2% palm and 98% lubricating oil at different temperature.

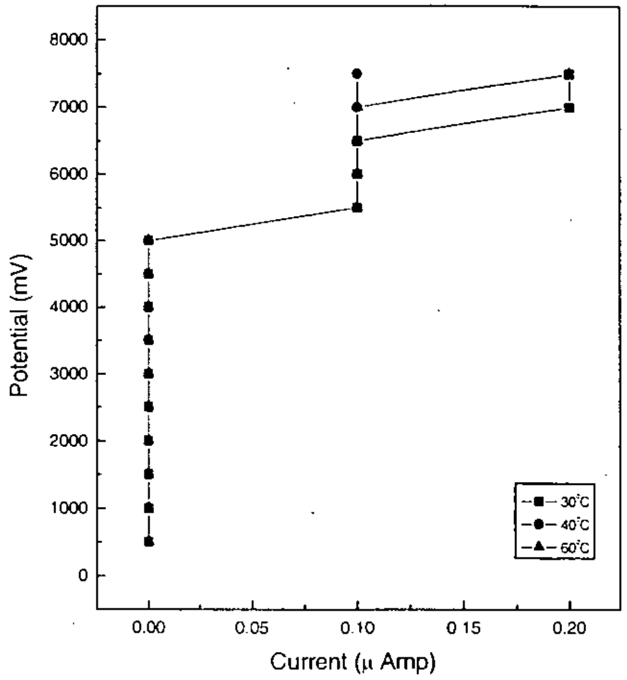


Fig. 4.30: The corrosion behavior of 0.16% carbon steel in 4% palm and 96% lubricating oil at different temperature.

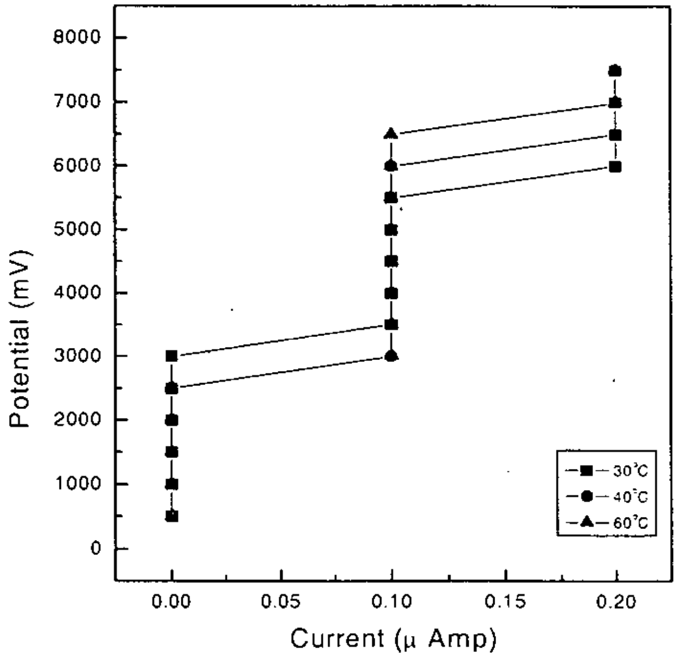


Fig. 4.31: The corrosion behavior of 0.16% carbon steel in 6% palm and 94% luricating oil at different temperature.

Fig. 4.34, 4.35 and 4.36 show the corrosion behavior of 0.79% carbon steel in 4%, 6% and 8% palm oil blended lubricating oil mixture at different temperatures respectively. In these figures it is evident that no current flow is observe below 3500 mV potential. Current is found to flow from 3500 mV and a steady corrosion rate is found in these lubrication systems. A higher corrosion rate is observed at 7000 and 7500 mV at all temperature.

(iii)Corrosion behavior of brass in different palm oil blended lubricants at different temperature:

The corrosion behavior of brass alloy in different palm oil blended lubricating oil was studied at different temperature. The characteristic of corrosion behavior was investigated in diagram by plotting potential VS current. The diagrams are presented in fig 4.37 to 4.40.

Fig 4.37 represents the corrosion behavior of brass in 2% palm oil and 98% lubricating oil mixture at different temperatures. From the figure it is found that brass corrode to a little extent at all temperatures. Corrosion current first visible at 3500 mV, 0.2 mA is found as the highest current flow in this system. at 7500 mV potential at all temperature.

Fig 4.38, 4.39 and 4.40 represent the corrosion behavior of brass in 4%, 6% and 8% palm oil blended lubricating oil mixture at different temperatures respectively. There is no corrosion on brass bellow 3500 mV potential in these systems. Corrosion starts from 3500 mV and a steady corrosion rate is found in these lubrication systems. Some times a higher corrosion rate is visible at 7000 and 7500 mV at all temperature.

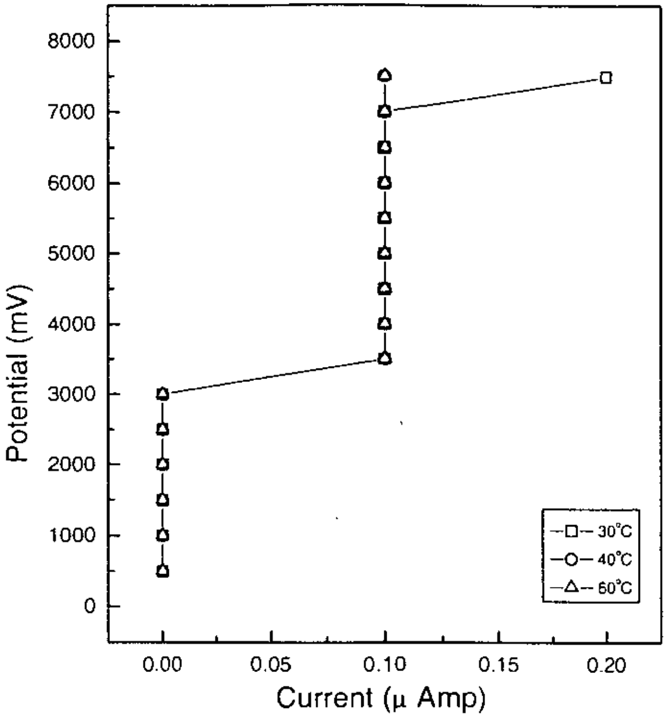


Fig. 4.32: The corrosion behavior of 0.16% carbon steel in 8% palm and 92% luricating oil at different temperature.

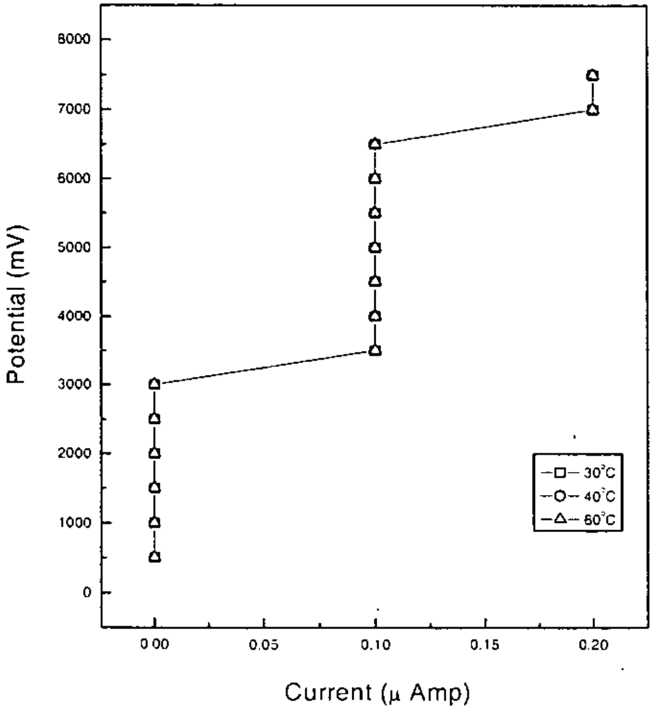


Fig. 4.33: The corrosion behavior of 0.79% carbon steel in 2% palm and 98% lubricating oil at different temperature.

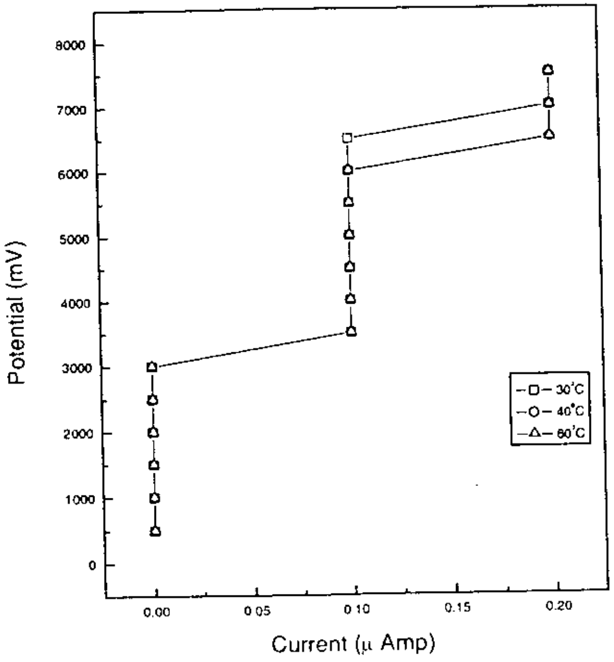


Fig. 4.34: The corrosion behavior of 0.79% carbon steel in 4% palm and 96% lubricating oil at different temperature.

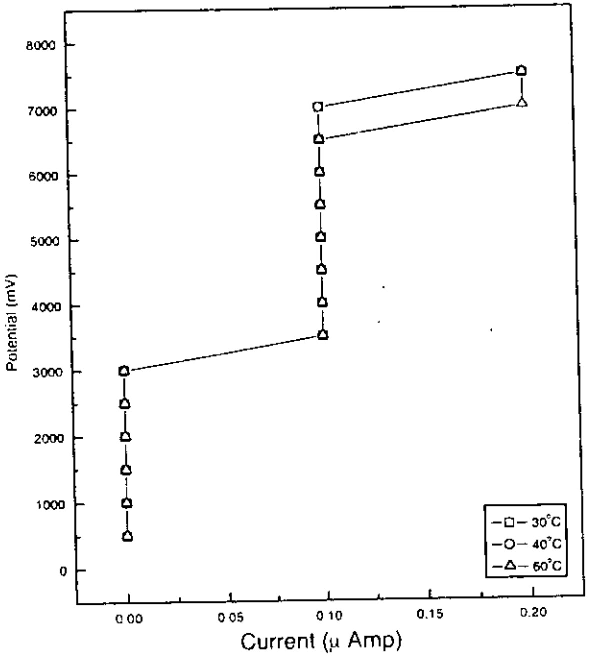


Fig. 4.35: The corrosion behavior of 0.79% carbon steel in 6% palm and 94% lubricating oil at different temperature.

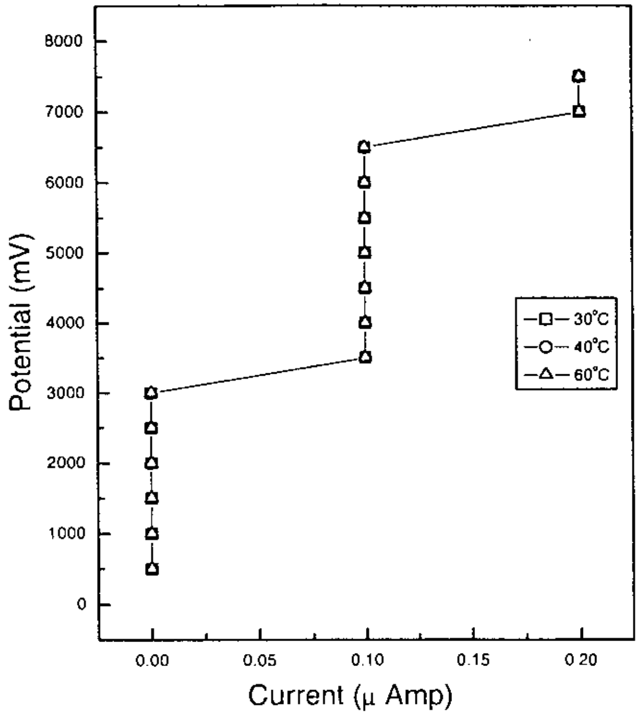


Fig. 4.36: The corrosion behavior of 0.79% carbon steel in 8% palm and 92% lubricating oil at different temperature.

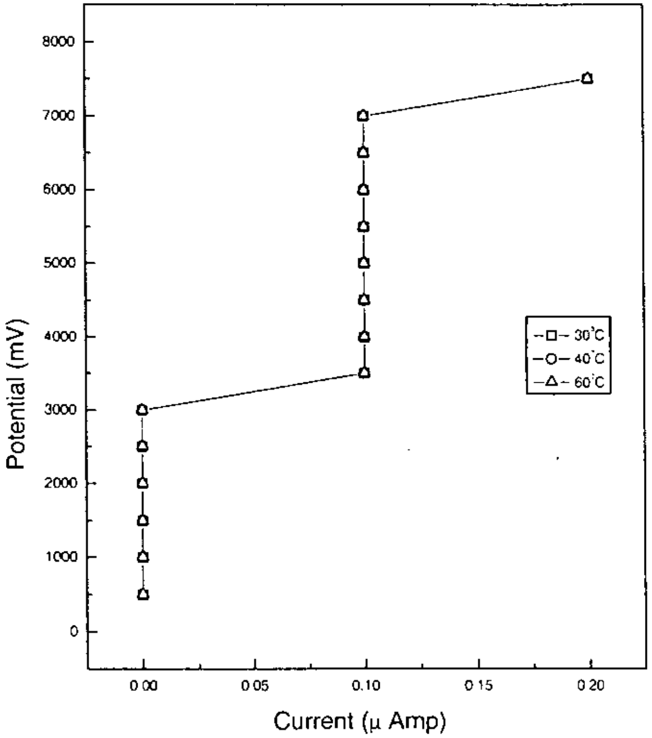


Fig. 4.37: The corrosion behavior of brass alloy in 2% palm and 98% lubricating oil at different temperature.

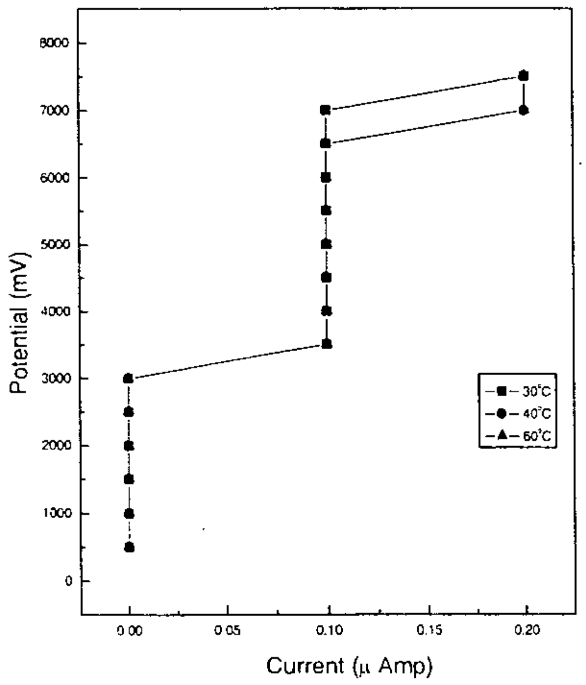


Fig. 4.38: The corrosion behavior of brass alloy in 4% palm and 96% lubricating oil at different temperature.

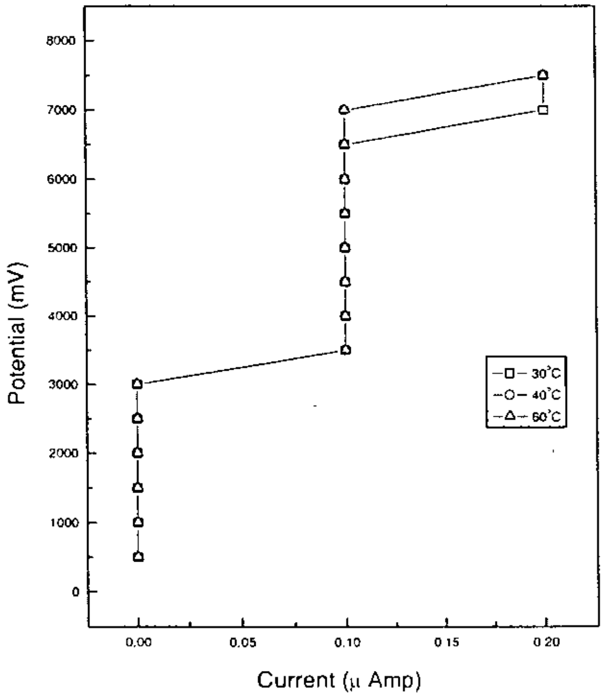


Fig. 4.39: The corrosion behavior of brass alloy in 6% palm and 94% lubricating oil at different temperature.

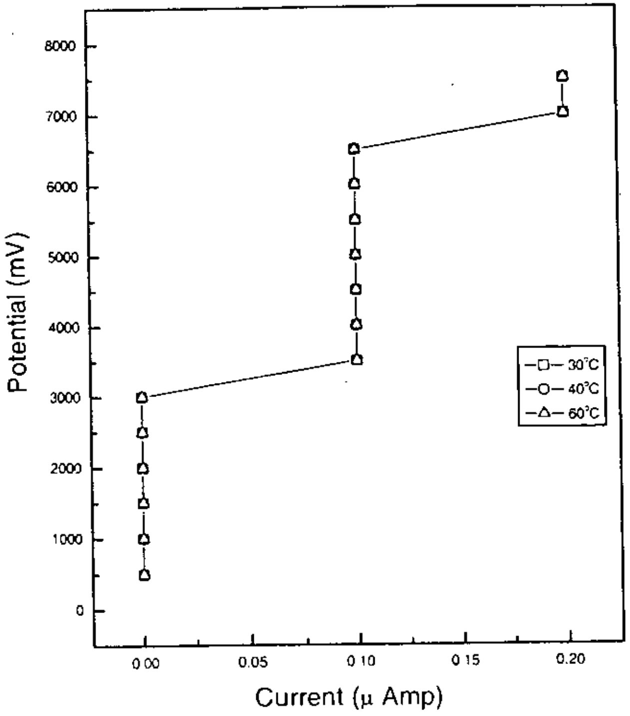


Fig. 4.40: The corrosion behavior of brass alloy in 8% palm and 92% lubricating oil at different temperature.

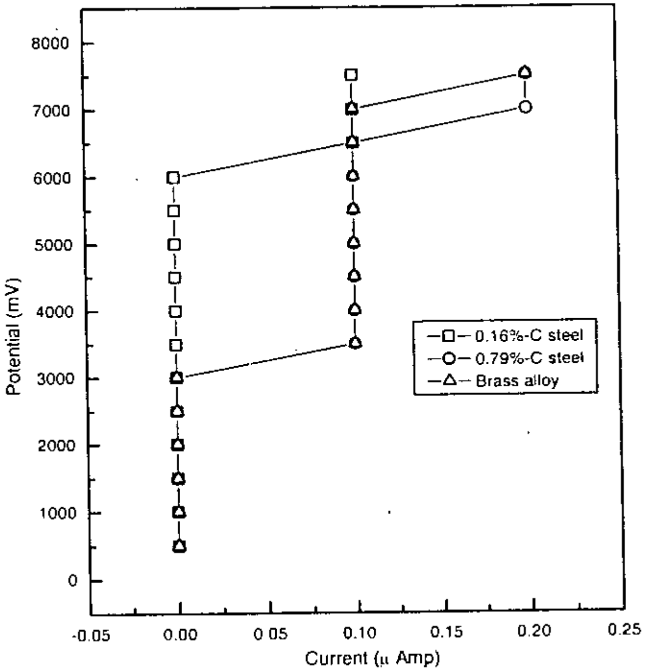


Fig. 4.41: The corrosion behavior of different metals in 2% palm and 98% lubricating oil at 30°C temperature.

(iv) Comparison of corrosion rate of different metals in palm oil blended lubricants:

A comparison of corrosion behavior of tribomaterials in diffferent palm oil blended lubricating oil was also investigated at 30°C and 60°C temperatures. It was carried out by plotting potential VS current. This diagrams are presented in figures 4.41- 4.48.

Fig 4.41 represents the corrosion behavior of three metals in 2% palm and 98% lubricating oil at 30°C temperature. From the figure it is found that this base oil medium is apparently noble for 0.16% carbon steel. This is evident from the figure that the corrosion current is found to flow at 6500 mV. But in the case of 0.79% carbon steel and brass it is found to flow corrosion current at 3500 mV.

Fig 4.42 represents the corrosion behavior of three metals in 4% palm and 96% lubricating oil blended lubricant at 30°C temperature. It is observed in figure that corrosion current found to flow at 5500 mV in this case of 0.16% carbon steel. But in the case of 0.79% carbon steel and brass alloys it is observed in fig 4.41 that corrosion current is found to flow at the same voltage as that of 2.0% palm and 98.0% lubricating oil.

Fig 4.43 and Fig. 4.44 represent the corrosion behavior of three metals in 6% and 8% palm oil blended lubricants respectively. From these two figures it is found that the corrosion current is found to flow at 3500 mV for all metals at 30°C.The highest corrosion current (.2 μA) is found at 7500 mV at this temperature.

Fig. 4.45 to fig 4.48 represents the corrosion behavior of three metals in 2%, 4%, 6% and 8% palm oil blended lubricating oils at 60°C temperature. The experimental results are found to similar as described above.

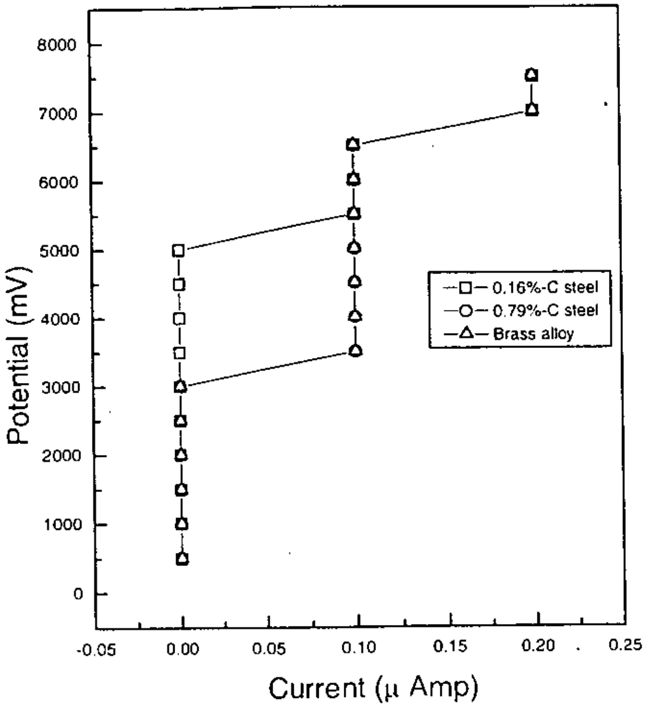


Fig. 4.42: The corrosion behavior of different metals in 4% palm and 96% lubricating oil at 30°C temperature.

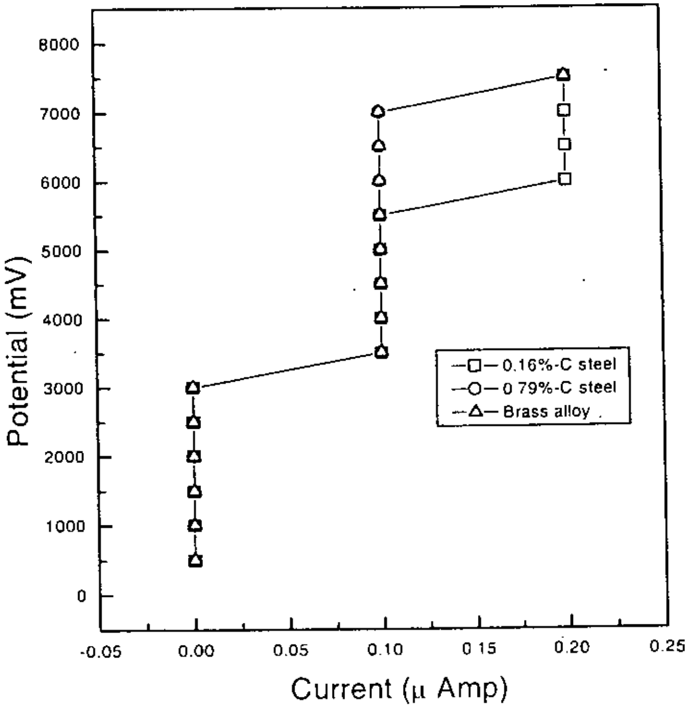


Fig. 4.43: The corrosion behavior of different metals in 6% palm and 94% lubricating oil at 30°C temperature.

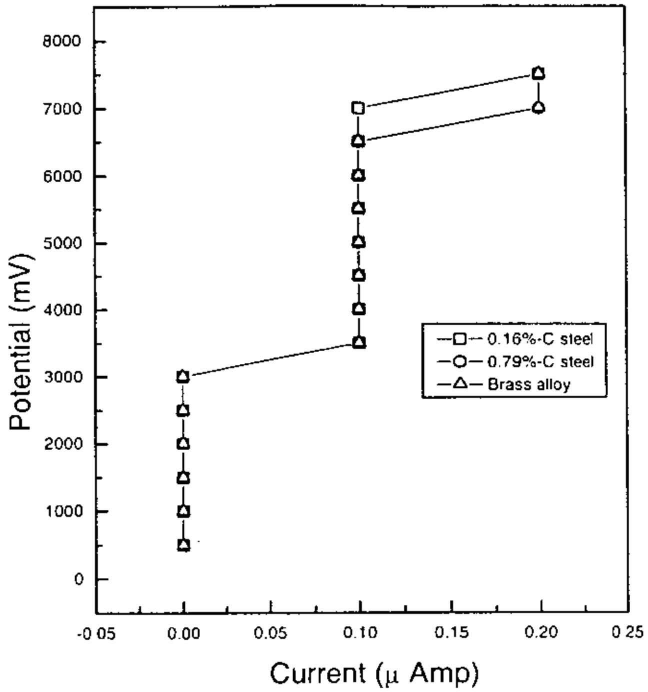


Fig. 4.44: The corrosion behavior of different metals in 8% palm and 92% lubricating oil at 30°C temperature.

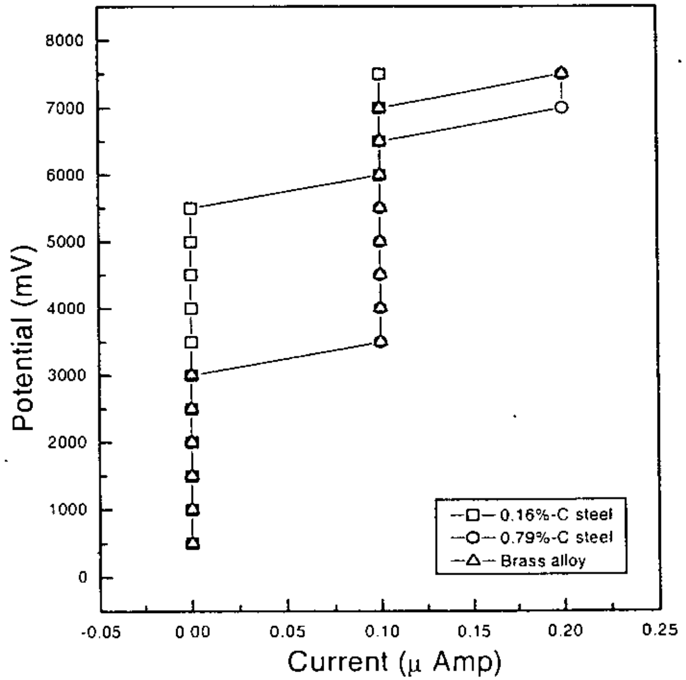


Fig. 4.45: The corrosion behavior of different metals in 2% palm and 98% lubricating oil at 60°C temperature.

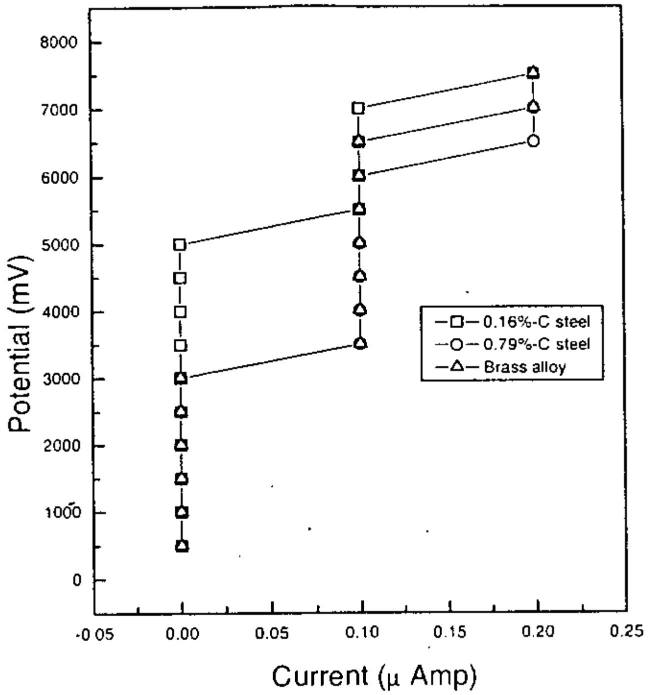


Fig. 4.46: The corrosion behavior of different metals in 4% palm and 96% lubricating oil at 60°C temperature.

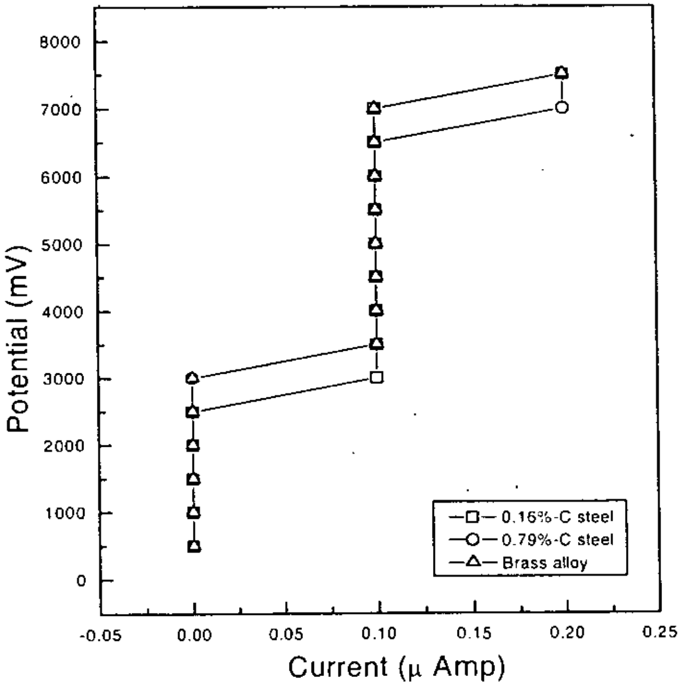


Fig. 4.47: The corrosion behavior of different metals in 6% palm and 94% lubricating oil at 60°C temperature.

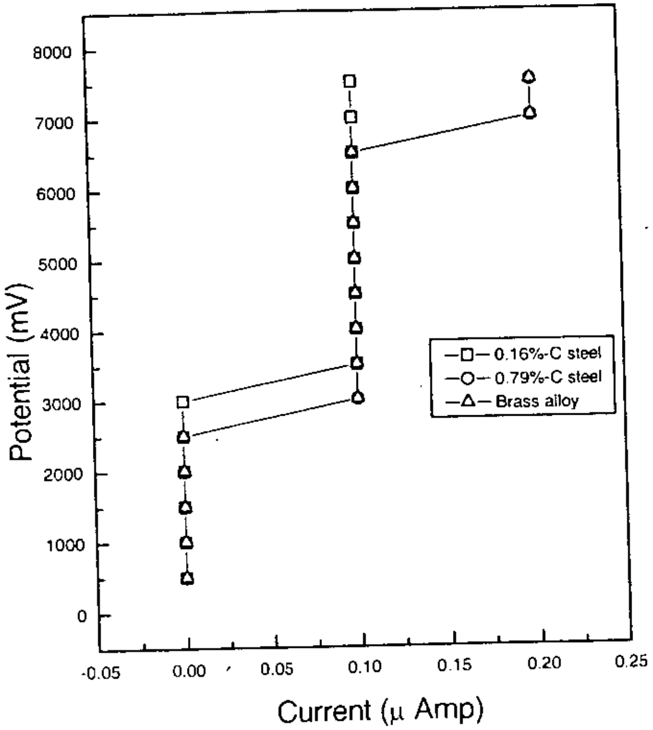


Fig. 4.48: The corrosion behavior of different metals in 8% palm and 92% lubricating oil at 60°C temperature.

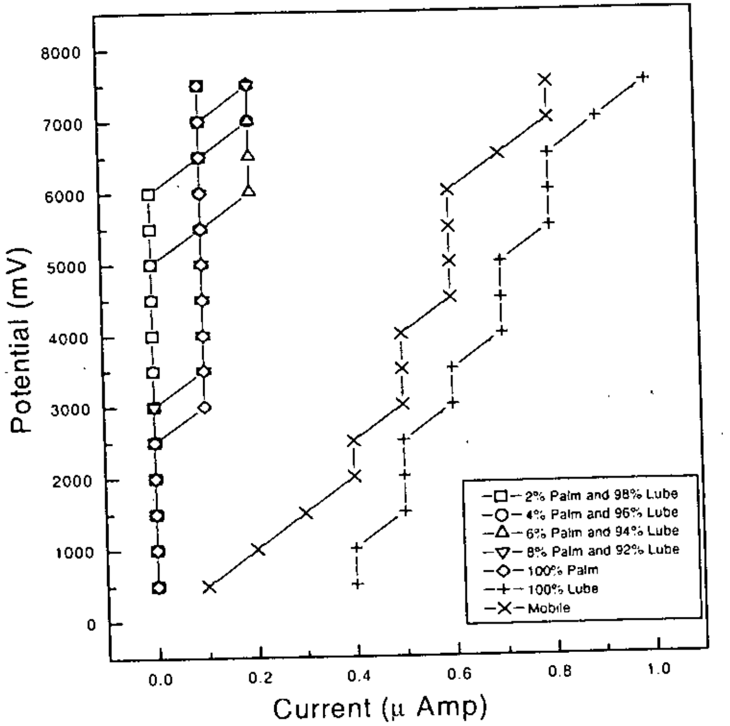


Fig. 4.49: The corrosion behavior of 0.16% carbon steel in different palm blended lubricating oil at 30°C temperature.

From these four figures it may be said that the presence of palm oil in lubricating oil shows inhibiting behavior. Small volume of palm oil acts as a good inhibitor for the 0.16% carbon steel at 30°C. But increase of palm oil in the lubricating oil corrosion current found to flow at low mV. So increasing the percentage of palm oil in the lubricating oil decreases the corrosion potential. But no significant effects of palm oil on 0.79%. carbon steel and brass alloy are found. The corrosion rate of 0.79% carbon steel and brass alloy is almost same for all types of blended lubricants.

4.6.6 Comparative study of corrosion behavior of different materials under study in different percentage of palm oil blended lubricants:

Corrosion behavior of a metal in 2%, 4%, 6%, and 8% palm oil blended lubricating oil, 100% palm oil, 100% lubricating oil, and Mobil was also investigated at 30°C and 60°C temperature. The investigation was carried out by plotting potential VS current. These diagrams are presented in figures 4.49-4.54. The result presented in this figures give us a clear view about inhibiting property of palm oil in lubricating oil as discussed below.

(i) Corrosion behavior of 0.16% carbon steel in palm oil blended and other lubricants:

The corrosion behavior of 0.16% carbon steel in 2%, 4%, 6%, and 8% palm oil blended lubricating oil, 100% palm oil, 100% lubricating oil, and Mobil at 30°C temperatures is presented in figure 4.49. From the figure it is evident that a little corrosion is observed in pure palm oil and palm oil blended lubricant. The lowest corrosion is observed at 2% palm oil blended lubricant at this temperature. The increase of palm oil in the lubricating oil increase the corrosion rate. From the figure 4.49 it is clear that pure lube oil has significant corrosion character. Mobil has also enough corrosion property. But in the presence of 2% palm oil in lubricating oil shows negligible corrosion at 30°C. At 60°C temperature, corrosion behavior of 0.16% carbon steel in 2%, 4%, 6%, and 8% palm oil blended lubricating oil, 100% palm oil, 100% lubricating oil, and Mobil is presented in figure 4.50. It is evident form the figure that similar inhibiting character of palm oil is observed at 60^0C. However, lubricating oil and mobil show higher corrosion rate at 60^0C that at 30^0C.

(ii) Corrosion behavior of 0.79% carbon steel in palm oil blended and other lubricant.

The corrosion behavior of 0.79% carbon steel in 2%, 4%, 6%, and 8% palm oil blended lubricating oil, 100% palm oil, 100% lubricating oil, and Mobil at 30 and 60^0C are presented in figures 4.51 and 4.52 respectively. From the figure 4.51 it is found that this alloy starts to corrode at 3500 mV in pure palm oil and all palm oil blended at 30^0 C. The rate of lubricants corrosion is also very low (0.1mA). At 30^0C any percentage of palm oil in lubricating oil acts as a good inhibitor for 0.79% carbon steel. However, in pure lubricating oil and Mobil the rate of corrosion on 0.79% carbon steel is quite high at 30^0C temperature. It is evident from the figure 4.52 that the corrosion character shown by these systems at 60^0C is quite similar to that at 30^0C as discussed above.

(iii) Corrosion behavior of brass alloys in different palm oil blended and other lubricants:

The corrosion behavior of brass alloy in 2%, 4%, 6%, and 8% palm oil blended lubricating oil, 100% palm oil, 100% lubricating oil, and Mobil at 30 and 60^0C are presented in figures 4.53 and 4.54 respectively. From the figures it is found that corrosion started at 3500 mV in pure palm and palm oil blended lubricants. But in pure lubricating and Mobil corrosion started from 4500 mV and 5500 respectively. The corrosion rate also slightly high at room temperature. However, in the case of brass, corrosion started at 3500 mV at 60^0C in palm oil blended lubricants.

The experimental results presented in figures (4.29-4.54) show that the presence of palm oil in lubricating system reduces corrosion of metals significantly. However, the temperature does not show any effect on corrosion rate investigated in this system. Although the increase of palm oil percentage in lubricating oil corrosion current of metals is found at low potential. The higher corrosion current (.2μA) is found at high potential (6500-7500mV).

Laverti (117) suggested that hydrocarbons particularly in tars and oils at as corrosion inhibitor for metals. This may be due to the fatty acids present in oil physically or chemically adsorb on the metal surface. This may act as barrier against corrosion. Fatty acids of palm oil make the barrier more effective against corrosion for both steel.

In the case of brass, Zn is more reactive electro-chemically than Cu. When potential applied at the beginning Zn reacts with organic acid of lubricants produces organometalic compound. In lubrication system organometatic compounds used to inhibit corrosion (1,2). Thus brass shows the less corrosion behaviour than steel in lubricating medium at all temperature.

4.6.7. Corrosion behavior of metals in Margosa oil (Neem):

The corrosion behavior of tribomaterials (0.16% carbon steel, 0.79% carbon steel and brass alloy) in 100% Margosa oil have been investigated at different temperatures. The characteristic of corrosion behavior is presented in the diagram by plotting potential VS current. The diagrams are shown in Figures 4.55-4.57.

Fig 4.55 shows the corrosion behavior of 0.16% carbon steel in 100% Margosa oil at different temperatures. It is found from the figure that corrosion rate decreases with the increase of temperature. However, the corrosion rate increases with the increase of potential at all temperatures.

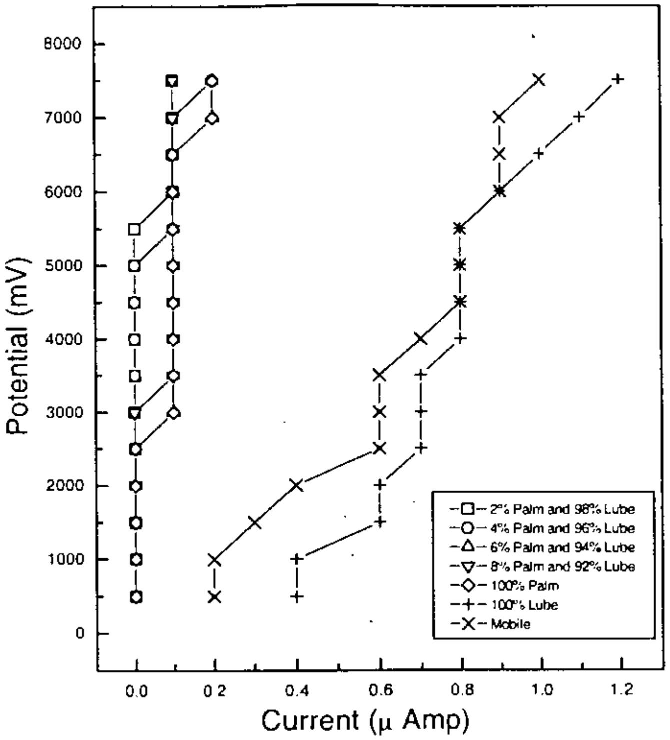


Fig. 4.50: The corrosion behavior of 0.16% carbon steel in different palm blended lubricating oil at 60°C temperature.

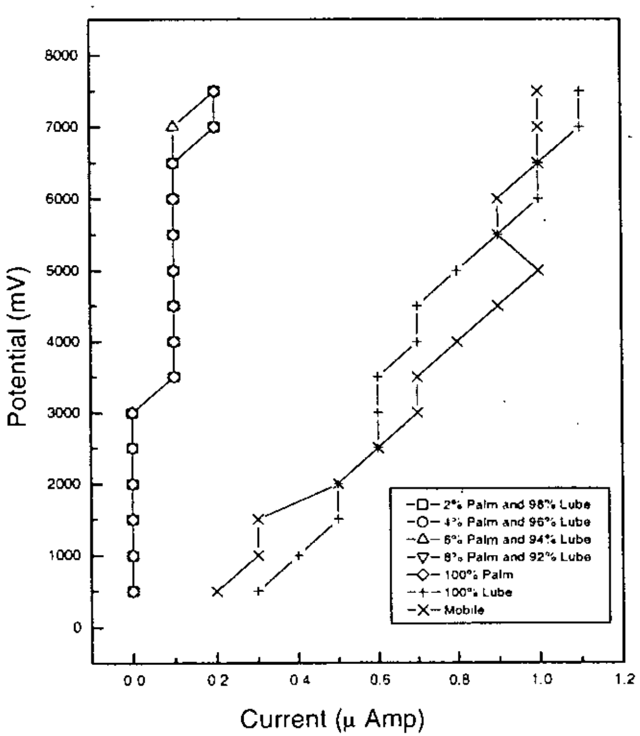


Fig. 4.51: The corrosion behavior of 0.79% carbon steel in different palm blended lubricating oil at 30°C temperature.

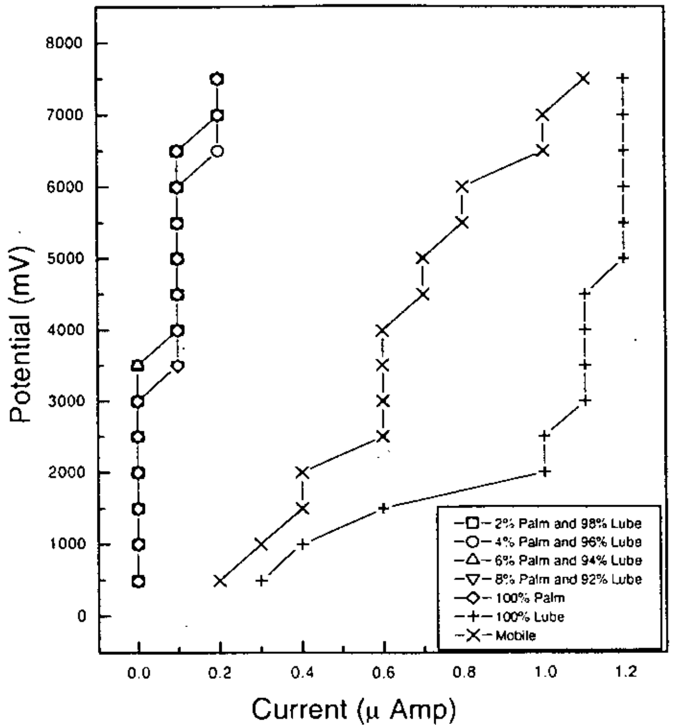


Fig. 4.52: The corrosion behavior of 0.79% carbon steel in different palm blended lubricating oil at 60°C temperature.

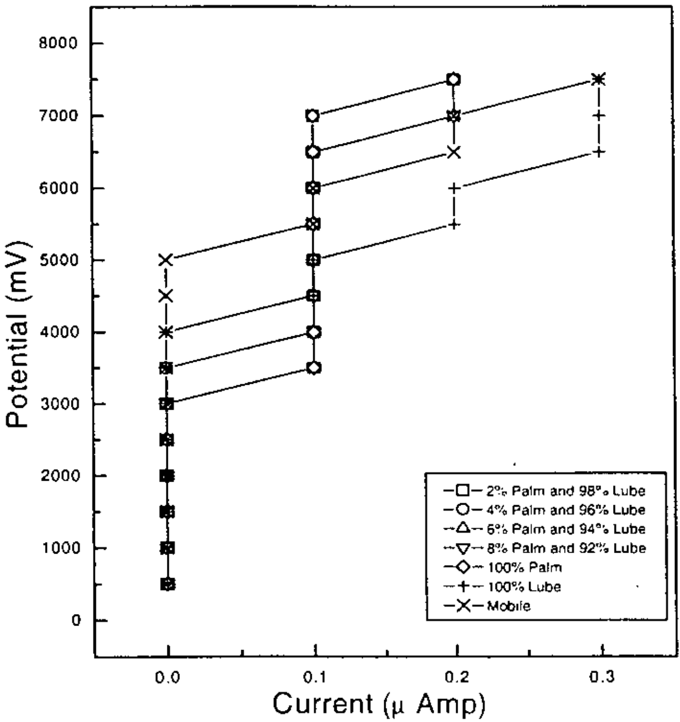


Fig. 4.53: The corrosion behavior ofbrass alloy in different palm oil blended lubricating oil at 30°C temperature.

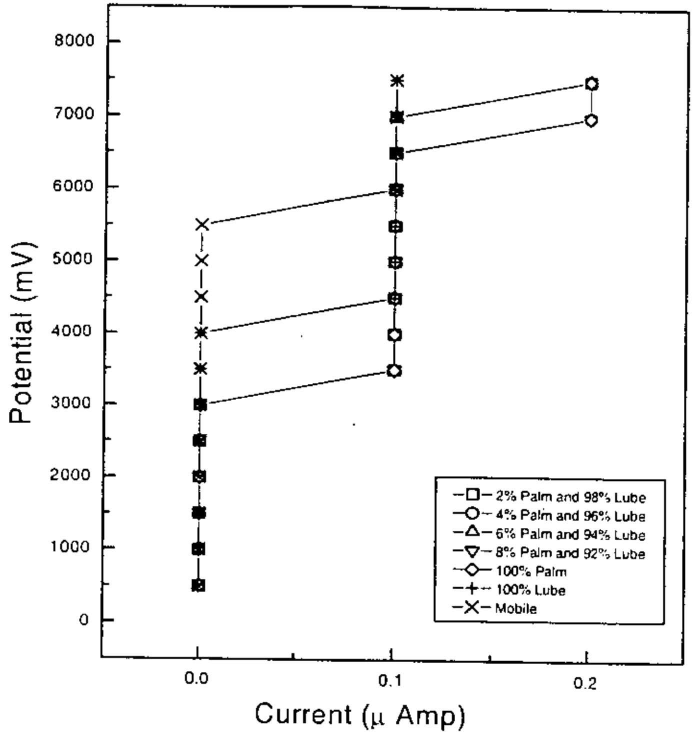


Fig. 4.54: The corrosion behavior ofbrass alloy in different palm oil blended lubricating oil at 60°C temperature.

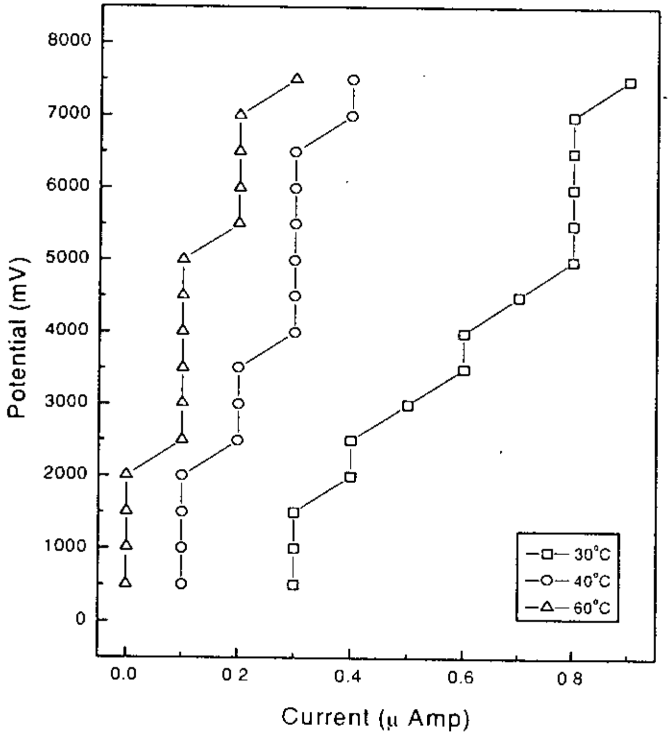


Fig. 4.55: The corrosion behavior of 0.16% carbon steel in 100% margosa oil at different temperatures.

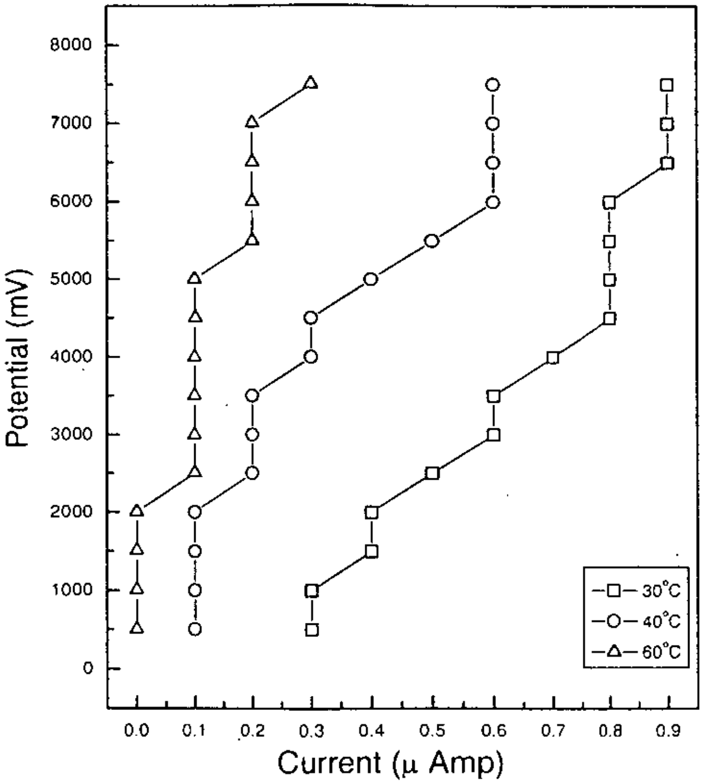


Fig. 4.56: The corrosion behavior of 0.79% carbon steel in 100% margosa oil at different temperatures.

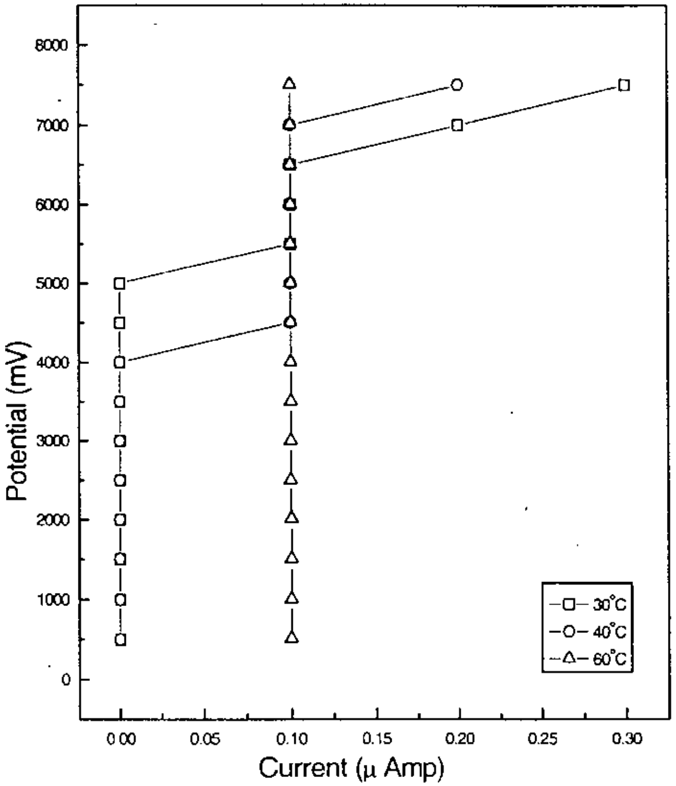


Fig. 4.57: The corrosion behavior of brass alloy in 100% margosa oil at different temperatures.

The highest and lowest corrosion rates are observed at 7500 and 500 mV respectively at all temperature.

Fig 4.56 shows the corrosion behavior of 0.79% carbon steel in 100% Margosa oil at different temperature. The highest corrosion rate is observed at 30°C temperature and at 7500 mV. Corrosion is not observed at 60°C at potential up to 2000 mV. In the case of 0.79% carbon steel the corrosion characteristics is similar to that of 0.16% carbon steel.

Fig 4.57shows the corrosion behavior of brass alloy in 100% Margosa oil at different temperatures. From the figure it is evident that at 30°C corrosion current is found to flow at 5500 mV. Below 5500 mV no corrosion on brass alloy is observed at 30°C temperature. The corrosion potential decreases with increase of temperature. At 40°C corrosion current is found to flow at 4500 mV, and at 60°C corrosion current is found to flow at 500 mV. Although the corrosion rate is steady and negligible at all potential, The corrosion characteristics on brass are opposite to that of steel.

Fig. 4.58 and 4.59 show the corrosion behavior of different metals in 100% Margosa oil at 30 and 60°C respectively. From the Figure it is evident that 0.79% carbon steel shows the highest corrosion rate at 30°C. But at 60°C, 0.16% carbon steel shows the highest corrosion current. There is a negligible corrosion rate on brass at both the temperatures.

4.6.8. Corrosion characteristics of Margosa oil blended lubricant

(i) Corrosion rate on 0.16% carbon steel in different Margosa oil blended lubricating oil at different temperatures:

The corrosion behavior of .016% carbon steeel in different Margosa oil blended lubricating oils has been investigated at different temperatures. The characteristic

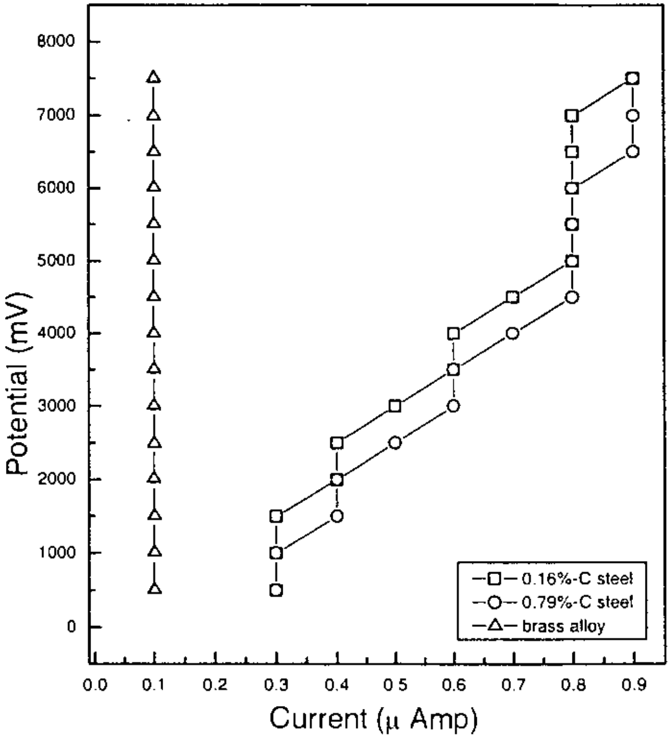


Fig. 4.58: The corrosion behavior of different metals in 100% margosa oil at 30^{0}C temperatures.

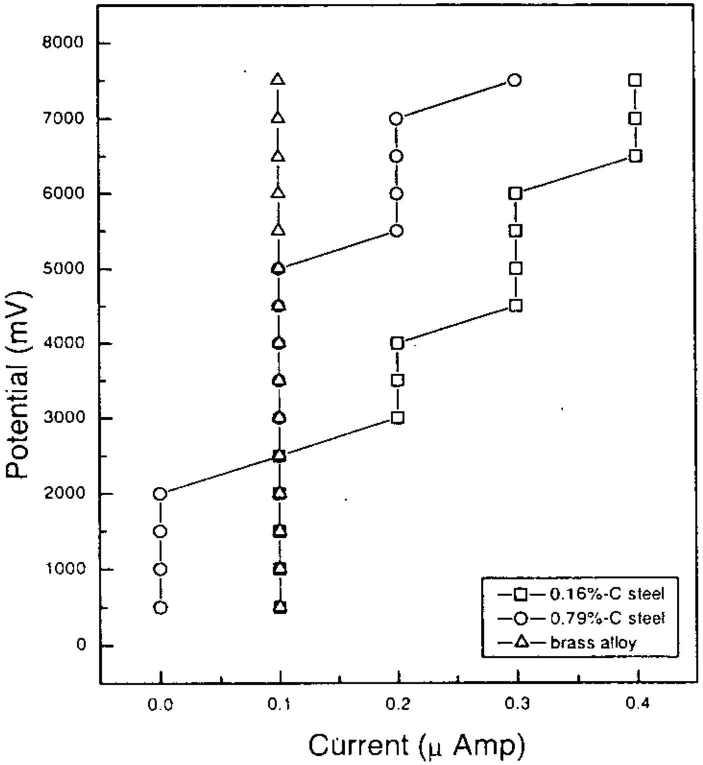


Fig. 4.59: The corrosion behavior of different metals in 100% margosa oil at 60^{0}C temperatures.

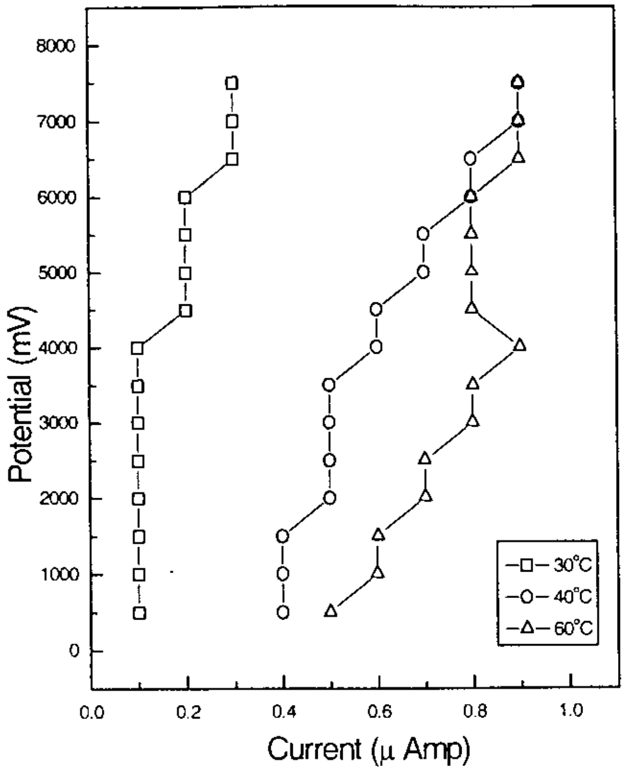


Fig.4.60: The corrosion behavior of 0.16% carbon steel in 2% margosa oil and 98% lubricating oil at different temperatures.

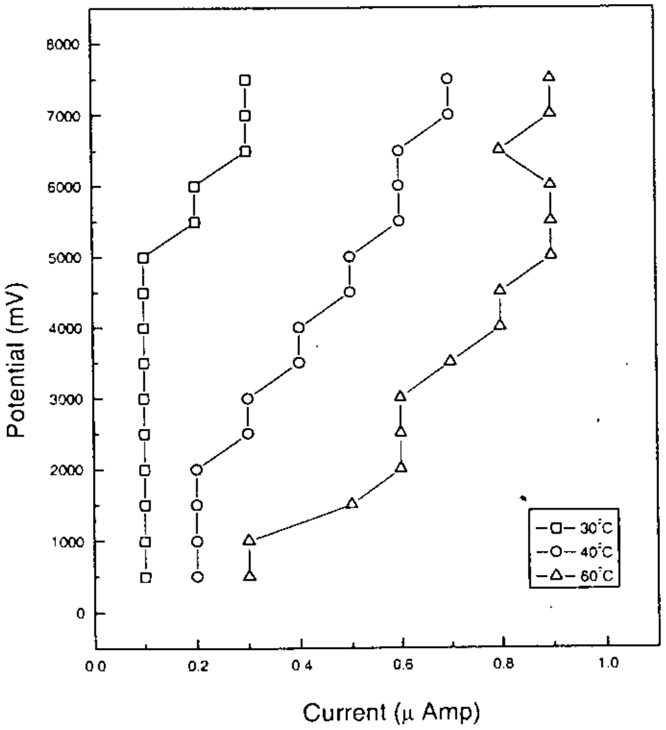


Fig.4.61: The corrosion behavior of 0.16% carbon steel in 4% margosa oil and 96% lubricating oil at different temperatures.

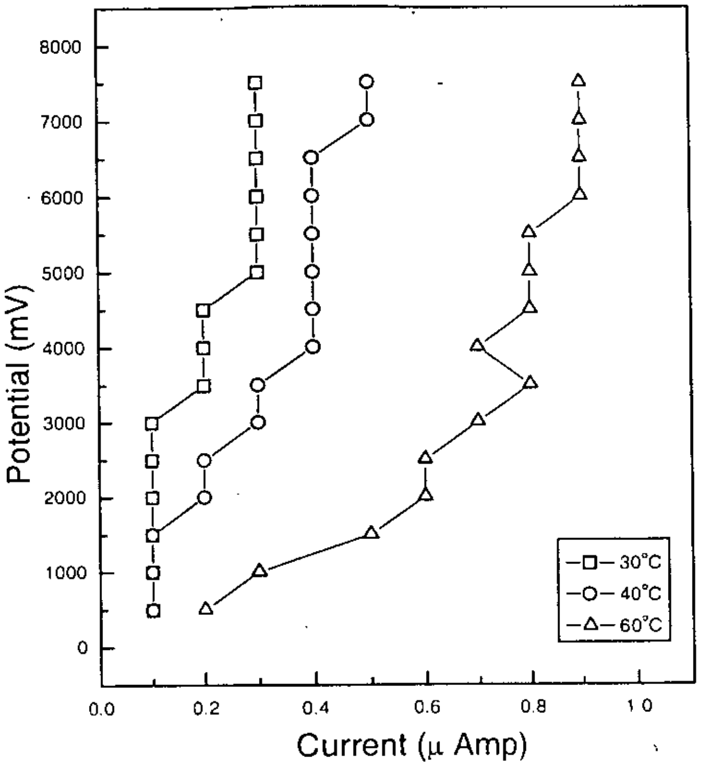


Fig.4.62: The corrosion behavior of 0.16% carbon steel in 6% margosa oil and 94% lubricating oil at different temperatures.

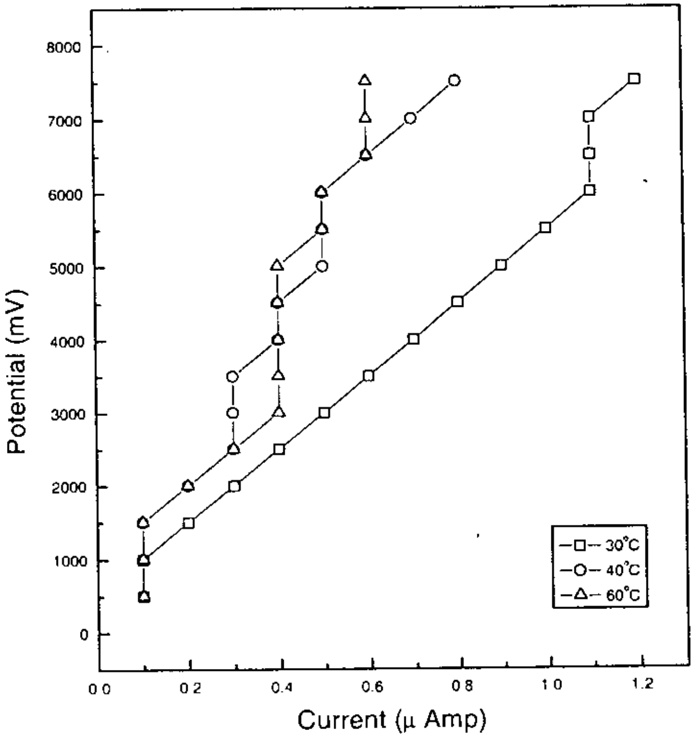


Fig.4.63: The corrosion behavior of 0.16% carbon steel in 8% margosa oil and 92% lubricating oil at different temperatures.

of corrosion is presented in the diagram by plotting potential VS current. The diagrams are shown in figures 4.60 - 4.63.

Fig. 4.60 shows, the corrosion behavior of 0.16% carbon steel in 2% Margosa oil and 98% lubricating oil mixture at different temperatures. It is found from the figure that corrosion rate increases with the increase of temperature. The highest and lowest corrosion rates are observed at 60 and 30°C temperature respectively at a potential 7500 mV and 500 to 2000 mV respectively. At 30°C, from 500 to 2000 mV potential no corrosion current is observed.

The corrosion behavior of 0.16% carbon steel in 4% and 6% Margosa oil blended lubricants at different temperature is presented in figures 4.51 and 4.62 respectively. In these two figures it is found that the corrosion rate increases with the increase of temperature. In both the figures it is observed that the corrosion rates are more or less equal in 4% and 6% Margosa oil blended lubricants at the same temperature. The highest and lowest corrosion rates are found at 60°C and 30°C on 7500 and 500 mV respectively. In fig. 4.63 the highest corrosion rate is found at room temperature in 8% Margosa oil blended lubricant. Corrosion rate decreases with the increase of temperature. The lowest corrosion rate is found at 60°C temperature.

(ii) Corrosion behavior of 0.79% carbon steel in different Margosa oil blended lubricating oil at different temperature:

The corrosion behavior of 0.79% carbon steel in 2%, 4% and 6% Margosa oil blended lubricants is presented in figures 4.64, 4.65 and 4.66 . These figures show that corrosion rate on 0.79% carbon steel increases with the increase of temperature. In 2% Margosa oil blended lubricant no corrosion is observed when 500-2000 mV is applied at 30°C. But at 2500 mV and above corrosion current is found to flow at room temperature. In Figure 4.60 and 4.66 it is observed that corrosion current is started to flow at 500 mV. The highest corrosion rate is found at 7500 mV and at 60°C in 2%, 4% and 6% Margosa oil blended lubricants.

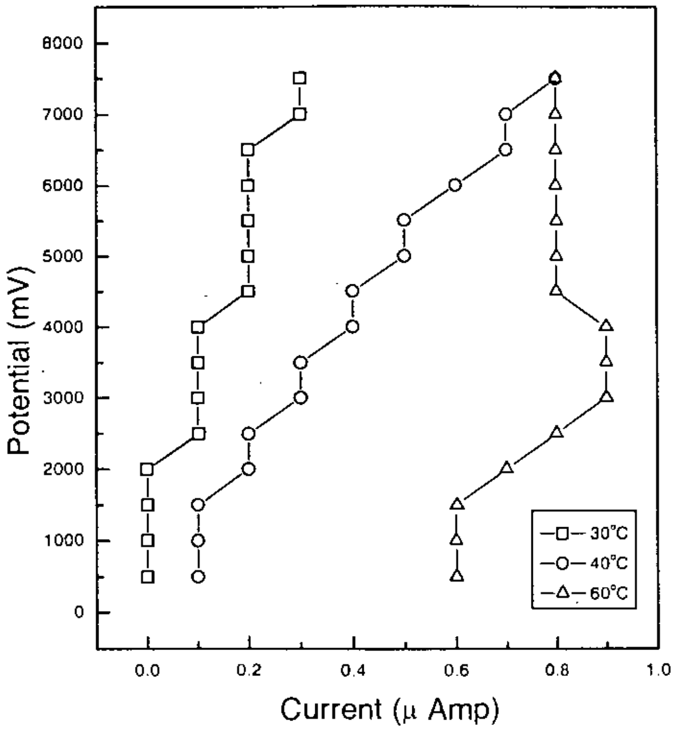


Fig.4.64: The corrosion behavior of 0.79% carbon steel in 2% margosa oil and 98% lubricating oil at different temperatures.

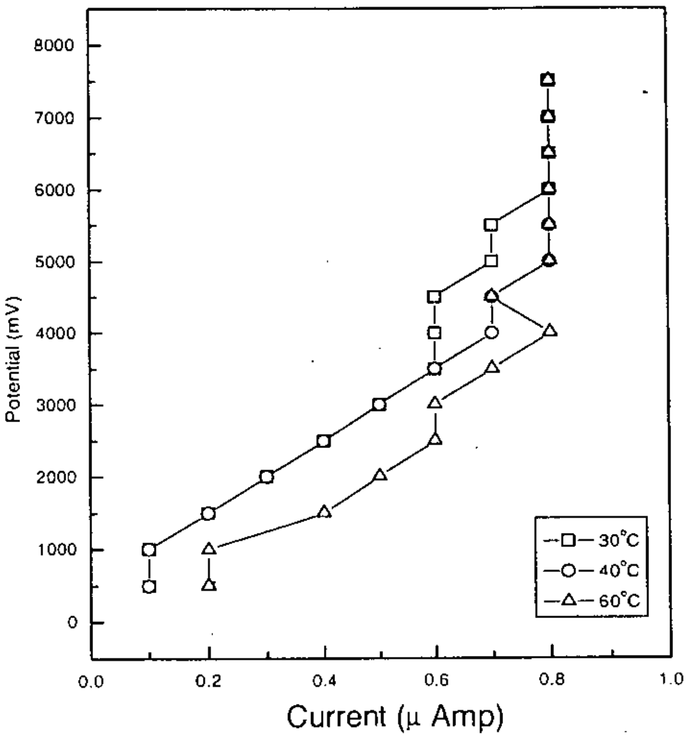


Fig.4.65: The corrosion behavior of 0.79% carbon steel in 4% margosa oil and 96% lubricating oil at different temperatures.

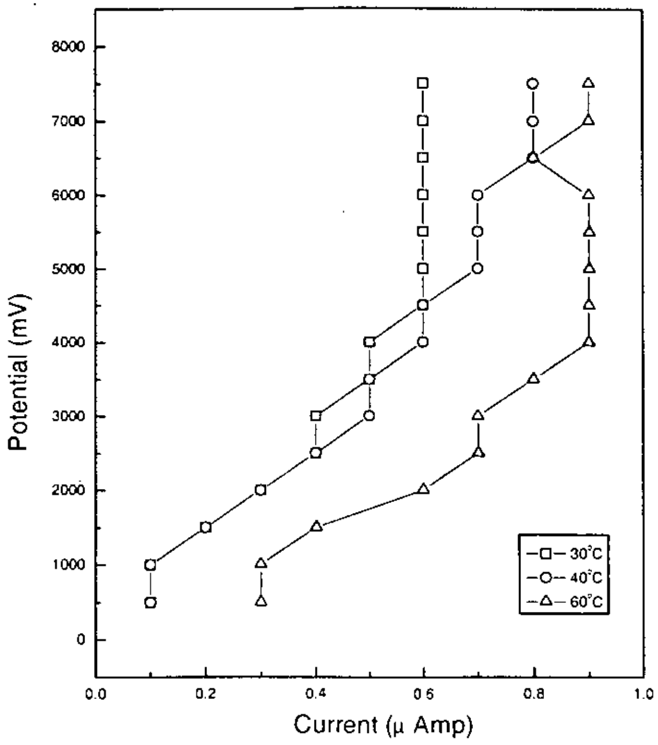


Fig.4.66: The corrosion behavior of 0.79% carbon steel in 6% margosa oil and 94% lubricating oil at different temperatures.

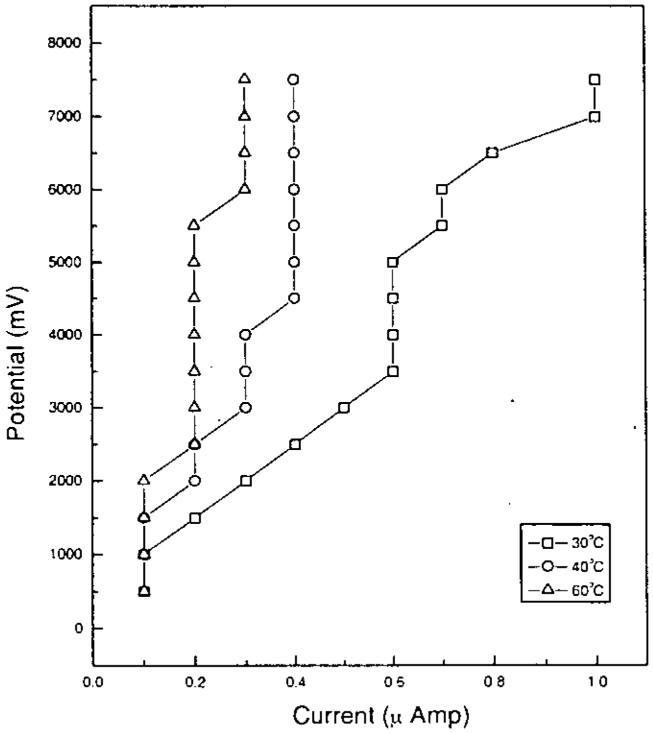


Fig.4.67: The corrosion behavior of 0.79% carbon steel in 8% margosa oil and 92% lubricating oil at different temperatures.

Figure. 4.67 shows the corrosion behavior of 0.79% carbon steel in 8% Margosa oil blended lubricant at different temperatures. Here, the corrosion rate decreases with the increase of temperature. The highest corrosion rate is found at 30°C and at 7500mV. The highest and lowest corrosion rates are observed at 7500 and 500 mV respectively at all temperatures.

(iii) Corrosion on Brass in different Margosa oil blended lubricating oil at different temperatures:

The corrosion behavior of brass in 2%, 4% and 6% Margosa oil blended lubricants at different temperatures is presented in figures 4.68. In this figure there is no fluctuation of corrosion rate is observed. At all temperatures from 500 to 7500 mV a constant but negligible corrosion current (.1μA) is found to below. The corrosion behaviour of brass in 8% Margosa oil blended lubricants at different temperatures is presented in figure 4.69. It is observed in figure 4.69 that in 8% lubricating oil at 30°C temperature brass does not corrode up to 3500 mV potential. At 4000 mV corrosion started and at 7500 mV the highest corrosion is found. At 40°C and 60°C a constant corrosion rate is observed.

(iv)Comparison of corrosion behavior of different metals in Margosa blended lubricants:

A comparison of corrosion behavior on tribomaterials in diffferent Margosa oil blended lubricating oil also investigated at 30 and 60°C. The results are presented in diagrams by plotting potential VS current. This diagrams are shown in figures 4.70 –4.77.

Fig. 4.70 shows corrosion behavior of different metals in 2% Margosa oil blended lubricant at 30°C. It is evident from the figure that the highest corrosion rate is observed at 7500 mV for hoth 0.16% and 0.79% carbon steel. But 0.79% carbon steel does not corrode below 500 mV potential.

Fig. 4.71, 4.72 and 4.73 represent the corrosion behavior of different metals in 4%, 6% and 8% Margosa blended lubricants at 30^{0}C. From the figures it observed that 0.79% carbon steel corroded at higher rate than other metals in 4%, 6% and 8% Margosa oil blended lubricants. It is also observed in the figure

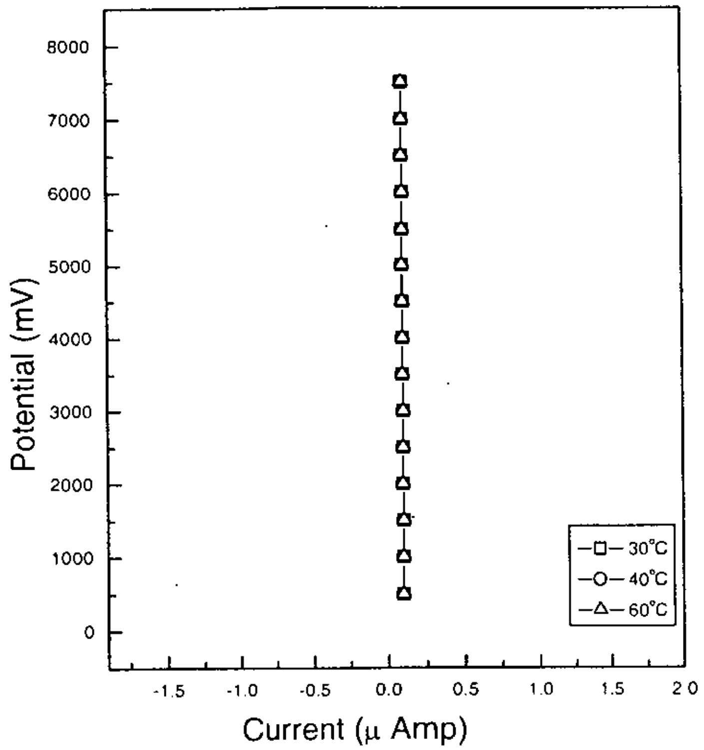


Fig.4.68: The corrosion behavior of brass alloy in 2%, 4%,and 6% margosa oil added lubricating oil at different temperatures.

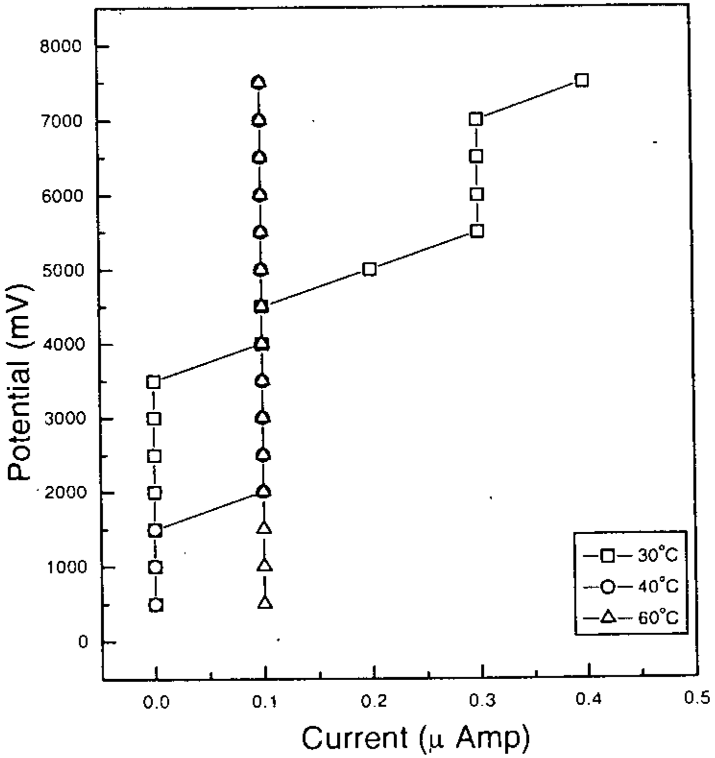


Fig.4.69: The corrosion behavior of brass alloy 8% margosa oil and 92% lubricating oil at different temperatures.

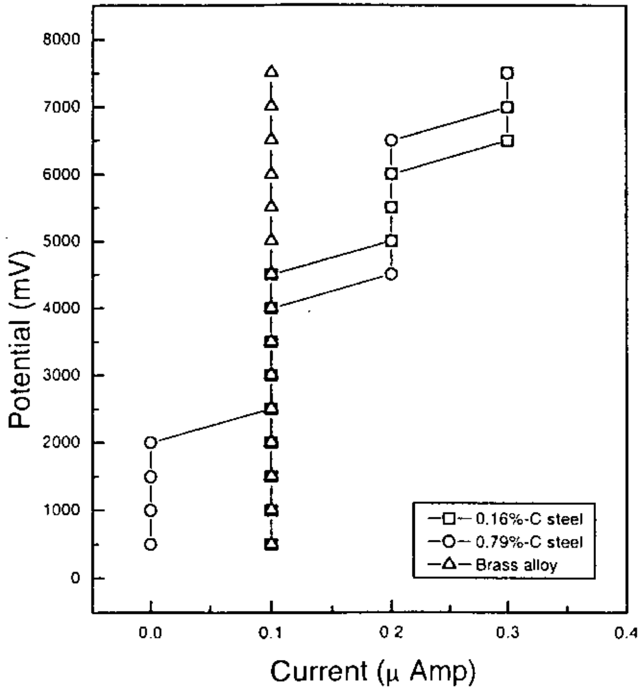


Fig. 4.70: The corrosion behavior of different metals in 2% margosa oil and 98% lubricating oil at 30°C temperature.

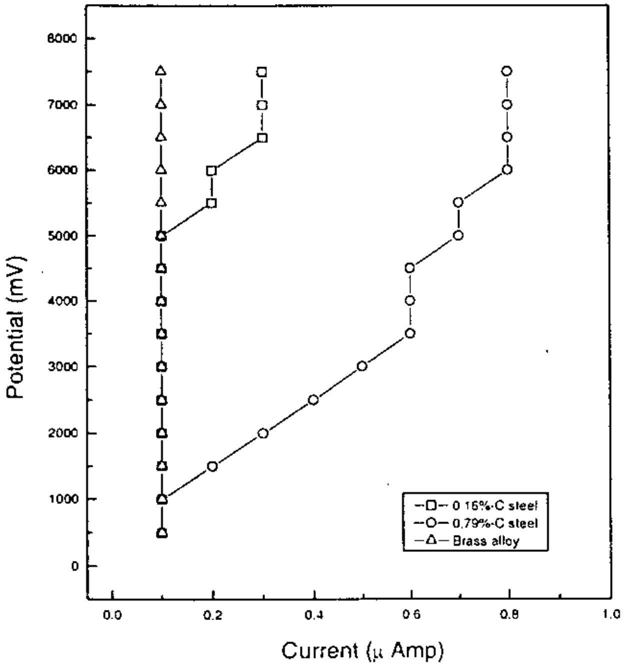


Fig. 4.71: The corrosion behavior of different metals in 4% margosa oil and 96% lubricating oil at 30°C temperature.

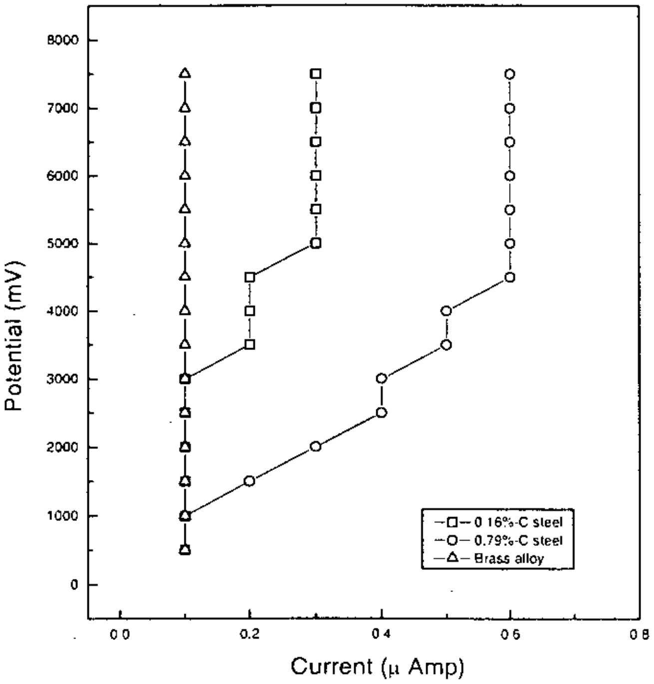


Fig. 4.72: The corrosion behavior of different metals in 6% margosa oil and 94% lubricating oil at 30°C temperature.

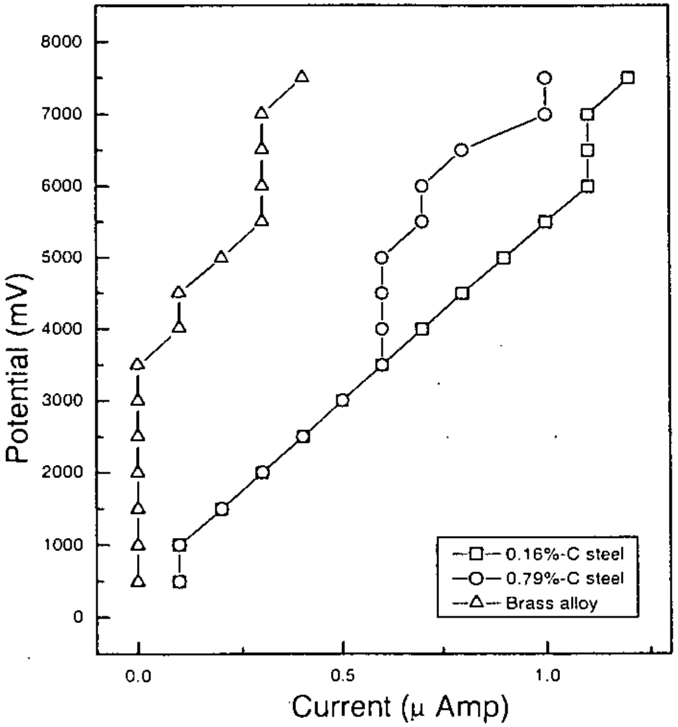


Fig. 4.73: The corrosion behavior of different metals in 8% margosa oil and 92% lubricating oil at 30°C temperature.

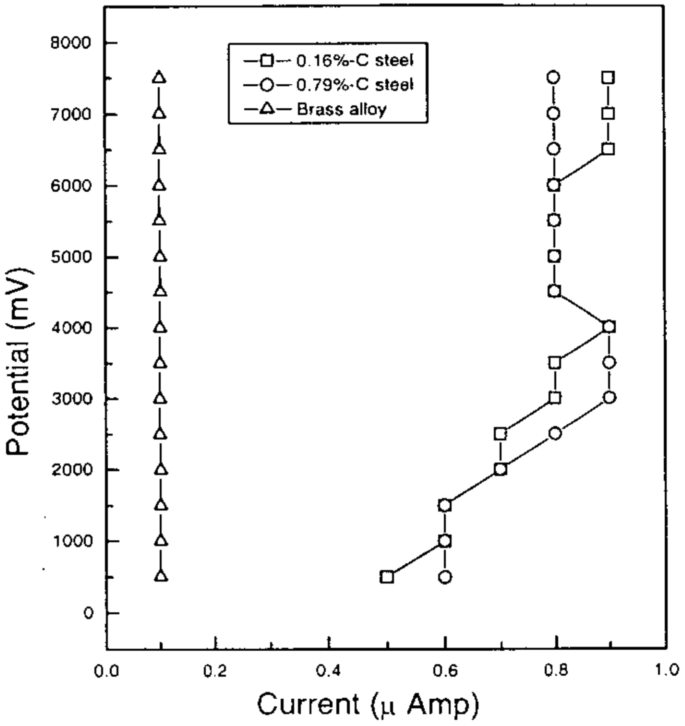


Fig. 4.74: The corrosion behavior of different metals in 2% margosa oil and 98% lubricating oil at 60°C temperature.

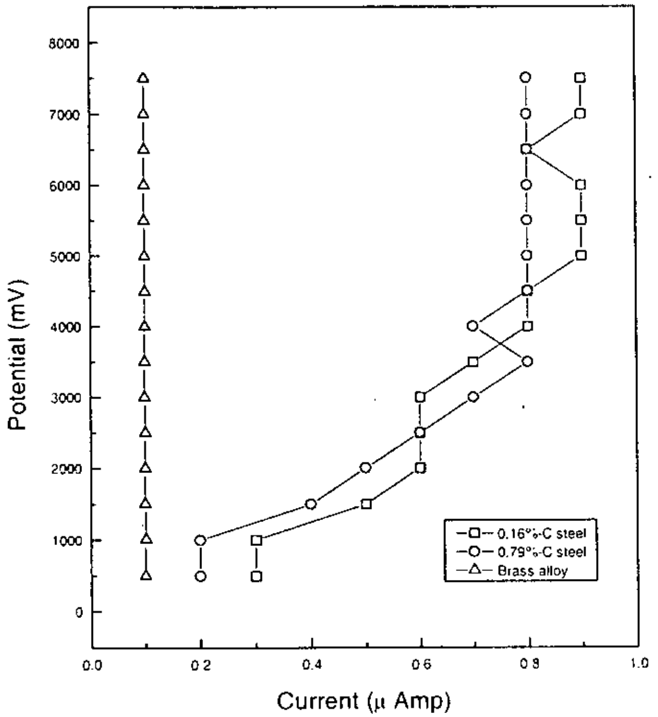


Fig. 4.75: The corrosion behavior of different metals in 4% margosa oil and 96% lubricating oil at 60°C temperature.

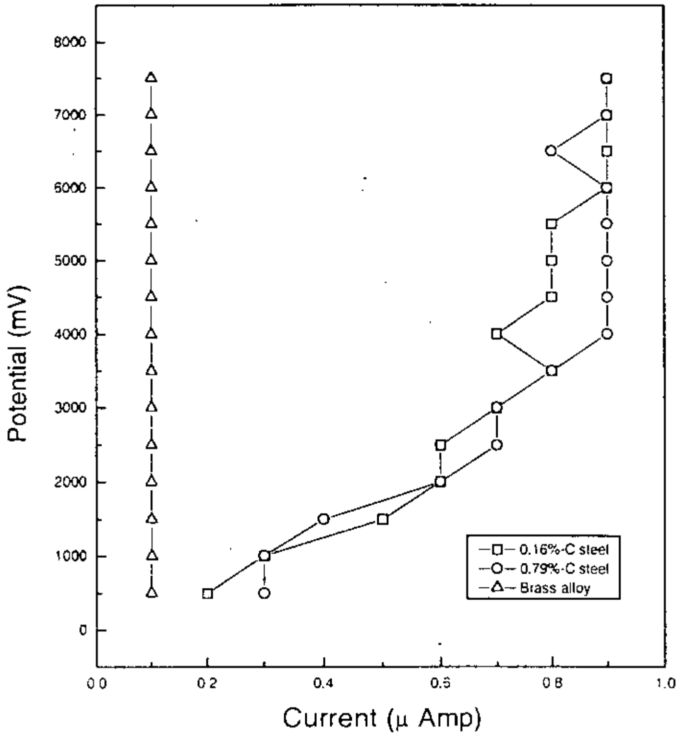


Fig. 4.76: The corrosion behavior of different metals in 6% margosa oil and 94% lubricating oil at 60°C temperature.

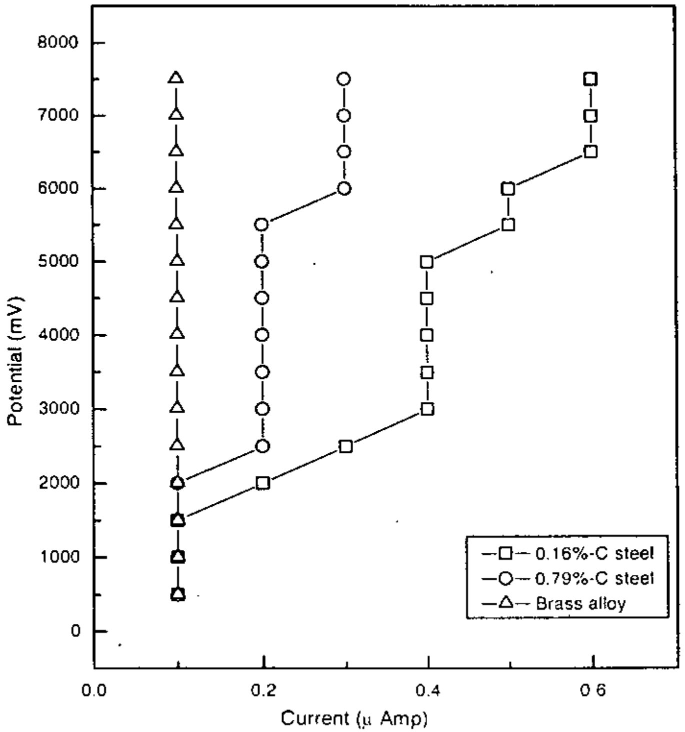


Fig. 4.77: The corrosion behavior of different metals in 8% margosa oil and 92% luricating oil at 60°C temperature.

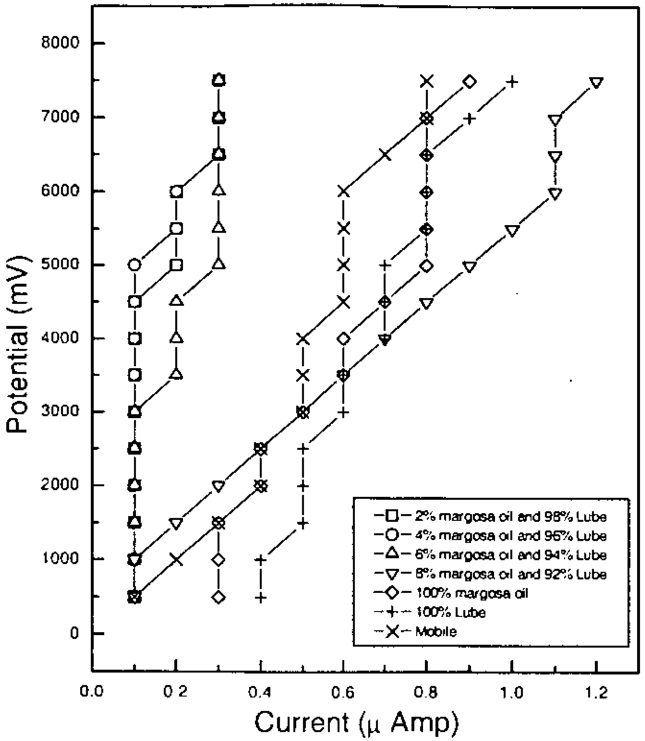


Fig. 4.78: The corrosion behavior of 0.16% carbon steel in different margosa oil blended lubricating oil at 30°C temperature.

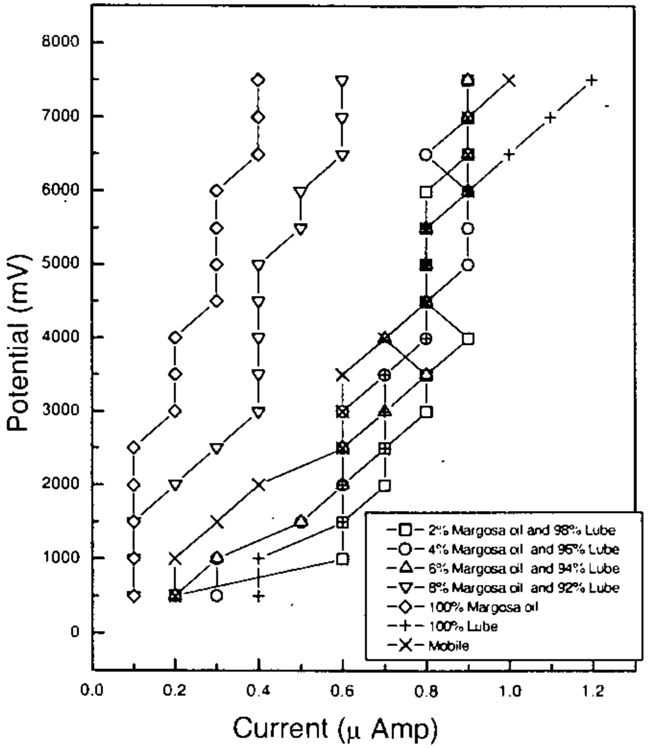


Fig. 4.79: The corrosion behavior of 0.16% carbon steel in different margosa oil blended lubricating oil at 60°C temperature.

that in the case 0.16% carbon steel the corrosion rate is comparatively high at 8% Margosa blended lubricant. However, it is evident from the figure that brass shows different polarization nature in 8% Margosa oil. Brass starts to corrode at 4000 mV up to 7500 mV. (Above 4000 mV no corrosion is observed.)

The corrosion behavior of different metals under study in 2%, 4%, 6% and 8% Margosa oil at 60°C temperature is presented in figures 4.74 to 4.77. From the figures it is found that corrosion rate on 0.16% carbon steel is high at all concentration of Margosa oil than other alloys. Corrosion on 0.16% and 0.79% carbon steels is more or less equal in all Margosa oil blended lubricants. Brass shows a constant but negligible corrosion rate in all concentration of Margosa oil blended lubricants.

4.6.9.Comparative study of corrosion behavior of alloys in different Margosa blended lubricants:

Corrosion behavior of a alloy under study in 2%, 4%, 6%, and 8% Margosa oil blended lubricating oil, 100% Margosa oil, 100% lubricating oil, and Mobil has also been investigated at 30 and 60°C. The results are presented in diagrams by plotting potential VS current. The diagrams are shown in figures 4.78-4.83. From the figures a clear view about inhibiting property of Margosa oil in lubricating oil is seen as described below:

(i) Corrosion behavior of 0.16% carbon steel in Margosa oil blended and other lubricant

The corrosion behavior of 0.16% carbon steel in 2%, 4%, 6%, and 8% Margosa oil blended lubricating oil, 100% Margosa oil, 100% lubricating oil, and Mobil has been investigated at 30 and 60°C. The results are presented in figures 4.78-4.79. It is evident from the figures that corrosion rate is equal up to 6% Margosa oil. It is also evident from the figures that the corrosion rate on 0.16% carbon steel in 8% Margosa blended lubricating oil is higher than those in 100% Margosa, 100% lubricating oil and Mobil at 30°C.

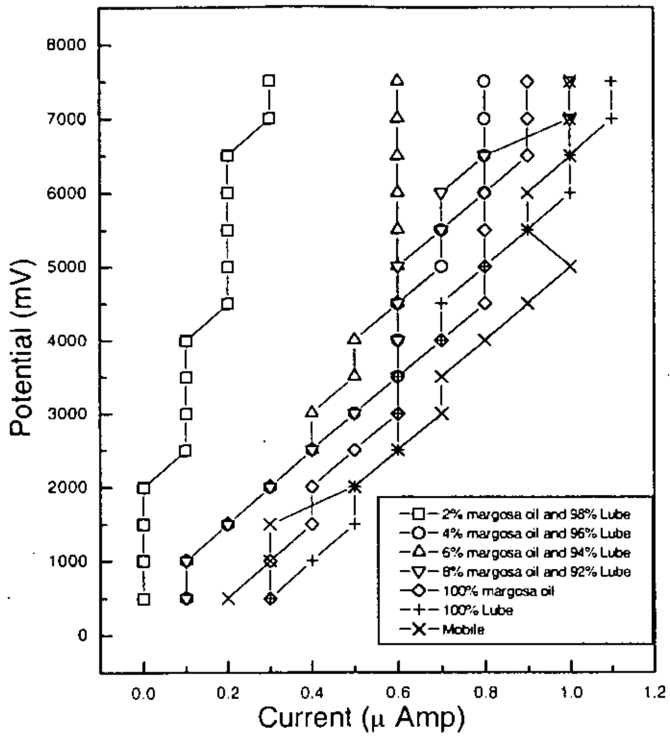


Fig. 4.80: The corrosion behavior of 0.79% carbon steel in different margosa oil blended lubricating oil at 30°C temperature.

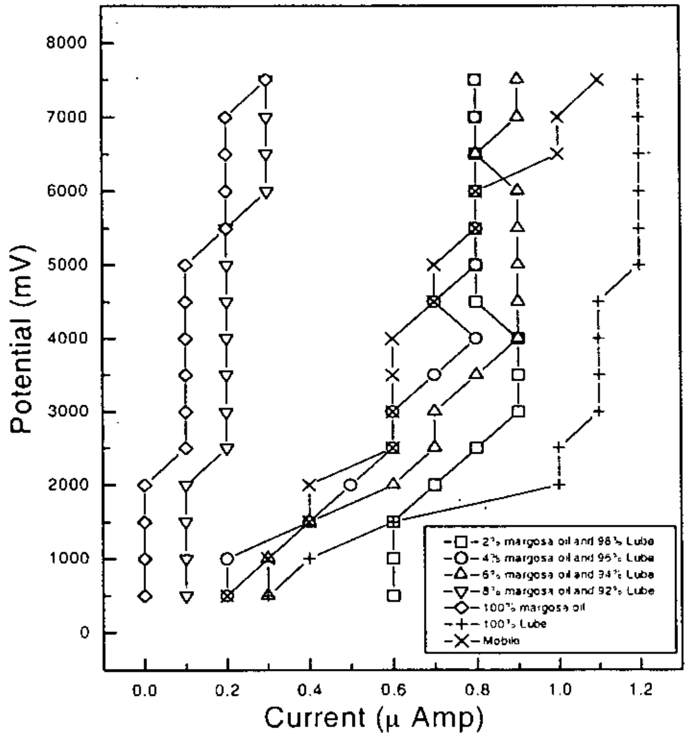


Fig. 4.81: The corrosion behavior of 0.79% carbon steel in different margosa oil blended lubricating oil at 60°C temperature.

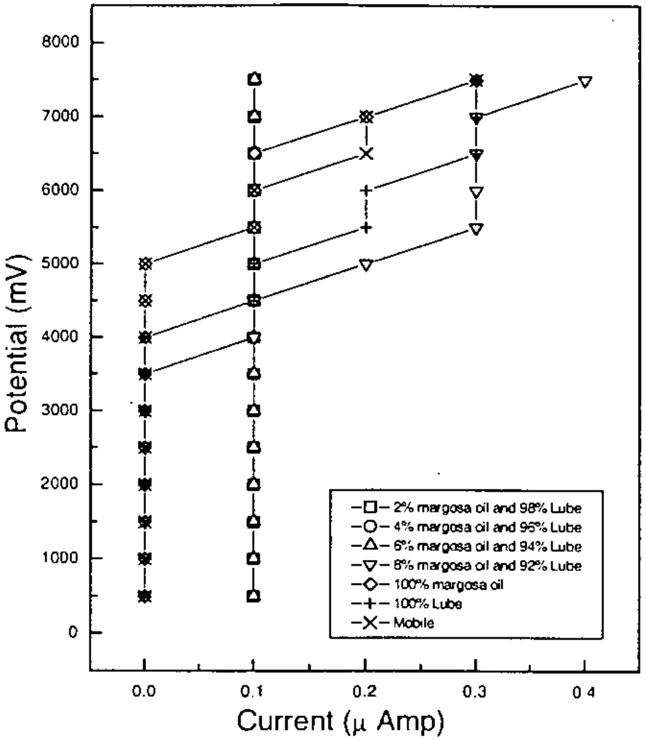


Fig. 4.82: The corrosion behavior of brass alloy in different margosa oil blended lubricating oil at 30°C temperature.

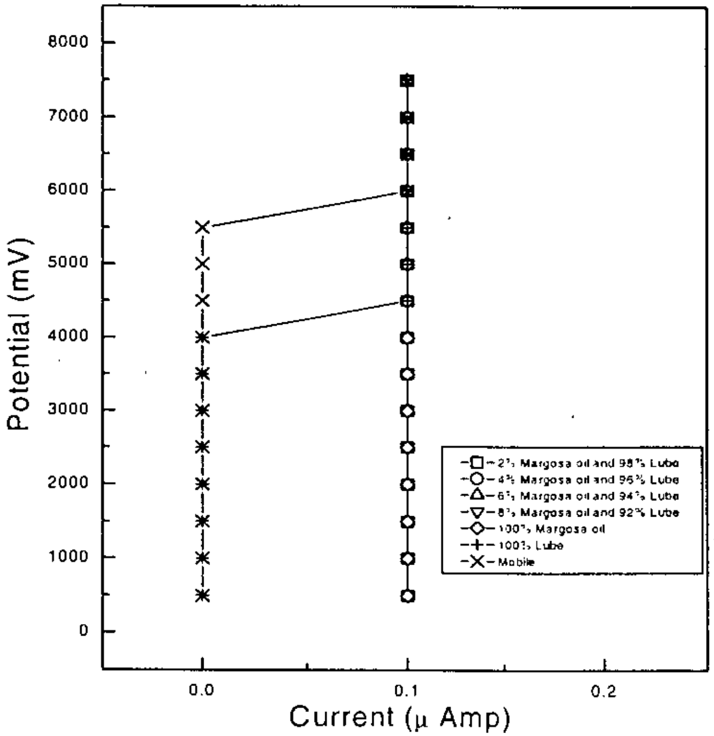


Fig. 4.83: The corrosion behavior of brass alloy in different margosa oil blended lubricating oil at 60°C temperature.

But at 60°C temperature as shown in figure 4.79, a high corrosion rate is observed in 2%, 4%, 6%, 100% and Mobil. In 8% and 100% Margosa oil a decrease corrosion rate is found than other lubricating oil at this temperature.

(ii) Corrosion behavior of 0.79% carbon steel in Margosa oil blended and other lubricants.

The corrosion behavior of 0.79% carbon steel in 2%, 4%, 6%, and 8% Margosa oil blended lubricating oil, 100% Margosa oil, 100% lubricating oil, and Mobil at 30 and 60°C is presented in figures 4.80 and 4.81. respectively. It is observed from the figures the corrosion trend of 0.79% carbon steel is more or less same as that of 0.16% carbon steel at both the temperatures. It is also observed that for 0.79 % carbon steel at 30°C, 2% Margosa blended lubricant is corrosive at and above 2500 mV. However, at 60°C, 100% Margosa oil is corrosive at 2500 mV.

(iii) Corrosion behavior of brass alloy in palm oil blended and other lubricants.

The corrosion behaviors of brass alloy in 2%, 4%, 6%, and 8% Margosa oil blended lubricating oil, 100% Margosa oil, 100% lubricating oil, and Mobil at 30 and 60°C are presented in figures 4.82 and 4.83. It observed form the figures that in 2%-6% Margosa oil blended lubricants the corrosion rate on brass is almost negligible. But in 8% Margosa oil blended lubricants and also in 100% Margosa oil and other lubricants corrosion current is found to flow at 3500 mV. The highest corrosion rate is observed at 7500 mV in 8% Margosa blended lubricant at 30°C. Corrosion rate on brass is found to be negligible in 2% Margosa oil blended lubricant and also in 100% Margosa oil at 60°C. In 100% lubricating oil and Mobil oil corrosion on brass is found to be a trace amount at high potential.

The above experimental results presented in figures 4.55-4.83 show that the corrosion on 0.16% and 0.79% of carbon steel increases with the increase of temperature at 2%, 4% and 6% Margosa oil blended lubricants. But at 8% Margosa oil blended lubricant, corrosion rate decreases with the increase of temperature. The highest corrosion inhibition of steels is found to be in 2% Margosa oil blended lubricant at 30^0C. At 60^0C temperature the highest corrosion inhibition of 0.16% and 0.79% carbon steel is found in 8% Margosa oil blended lubricant. In the case of brass alloy, negligible corrosion rate is observed at all temperatures in 2%, 4% and 6% Margosa oil blended lubricants. At 30^0C the higher corrosion is found. At 60^0C temperature, the corrosion rate of brass in 8% Margosa oil blended lubricants reduces and the corrosion rate is equal to that 30^0C.

Margosa oil contains of glyceride, mixed fatty acid and some organic sulfates s (50-53). Organic sulfate cause compounds the corrosion of steels. Although the fatty acid inhibits the corrosion of steel. But because of the presence of other two substances the corrosion inhibition character is not highlighted at all temperatures. At 60^0C, 8% Margosa oil blended lubricant shows reversed character. In this case the decomposition of glyceride and fatty acid makes a strong barrier against sulfate compounds for corrosion reaction. Thus, 8% Margosa oil blended lubricant inhibits the corrosion at 60^0C.

4.6.10. Comparison of Corrosion behavior on Metal and Alloys in Palm and Margosa oil Blended Lubricants:

Form the experimental results presented above it is found that 2% palm and 2% Margosa oil blended lubricating oils shows the highest corrosion inhibition for all the three metallic alloys under study at room temperature. 2% palm oil blended lubricants also shows the maximum corrosion inhibition at 60^0C for all the three the metallic alloys. On the other hand 8% Margosa oil blended lubricants shows the highest corrosion inhibition for all the three metarials at 60^0 C.

Comparison of results presented in the figures 4.49, 4.51 & 4.53 with those presented in figures 4.78, 4.80 and 4.82 reveals that 2% palm oil blended lubricants has the lowest corrosion inhibition for all three metallic alloys at room temperature. In the same way comparison of the results presents in figures 4.50, 4.52 and 4.54 with those presented in figures 4.79, 4.81 and 4.83 it is clear that 2% palm blended lubricant has higher corrosion inhibition properties for the three metallic alloys under study than 8% Margosa oil blended lubricant at 60^0C temperature.

The experiential results show that palm oil has better corrosion inhibition properties than Margosa oil at all temperature. However, 2% Margosa oil is a good inhibitor for all the three metallic alloys at 30^0C. and 8% Margosa show the highest corrosion inhibition at 60^0C than other Margosa oil blended lubricant.

Chapter-5

Conclusion
&
Recommendation

Conclusion and Recommendation

5.1 Conclusion:

Palm and Margosa oil blended lubricants are studied for the automotive tribo-materials. Three different alloys (two steel and one brass sample), were used in this study. Material composition of alloys was analyzed. Analysis of lubricating oils was performed to investigate the oil degradation by oxidation. The electrochemical corrosion of the metal alloys in palm and Margosa oil blended lubricants were studied by potentiostat i.e. method. From the results obtained in this study following conclusion can be drawn:

I. The change of viscosity and density of palm and margosa oil blended lubricants was found due to the formation of carbonyl compound.

II. Palm and Margosa oil have no influence on flash and fire point due to their small quantity in blended lubricants.

III. Palm and Margosa oil has blended lubricants have highest TAN at 8% Margosa oil blended lubricant oil. Decomposition of ester or glycride into carboxylic took place during oxidation.

IV. 2% palm oil blended oil is the best corrosion inhibitor than any other of palm and margosa oil blended lubricants at all temperature.

V. Margosa oil can not be used as corrosion inhibitor in lubrication system, due to the presence of organic sulfate containing organic compound.

5.2 Recommendation for future work.

In this work palm and margosa oil were used as additive to the base oil. In this study viscosity, density, oxidation test by TAN and IR analysis were performed. The electrochemical phenomena of blended lubricants also studied. But the oils activity with metal surface, solution composition after corrosion or oxidation test were not carried out. Therefore the following works are recommended for future study.

I. In this study IR and TAN analysis have been carried out after cooling of lubricants. In future work TAN and IR analysis may be performed at higher temperature.

II. After chemical interaction of metal and lubricants, the lubricants composition may be analyzed by using Differential Scanning Calorimetry (DSC).

III. The whole experiment has been carried out in the laboratory in static condition. It is recommended to perform this study in actual engine test.

IV. After and before the corrosion test of metal, the metal surface is not studied. It is recommended to carry out this by Scanning Electron Microscope (SEM).

Experimental Data

Experimental Data

Table-1: Effect of temperature on viscosity at different Palm oil blended Lubricants (Fig. 4.1).

Temperature ^{0}C	Viscosity of different palm blended lubricant (centistokes)				
	0% Palm	2% Palm	4% Palm	6% Palm	8% Palm
30	197.13	196.28	196.11	204.01	53.9
40	128.4	133.9	143.91	160.2	41.21
60	55.4	56.2	57.1	64.01	26.1
80	36.35	38.8	42.01	43.05	16.59
100	15.11	16.61	21.92	23.11	9.11

Table-2: Effect of different palm blended lubricants on viscosity at different Temperature (Fig. 4.2).

Different % of Palm oil in lube oil	Viscosity at different temperature (centistokes)				
	30°C	40°C	60°C	80°C	100°C
0	370.47	188.99	58.44	33.16	19.02
2	260.13	140.4	55.4	36.35	15.11
4	196.28	133.9	56.2	38.8	16.61
6	196.11	143.91	57.1	42.01	21.92
8	204.01	160.2	64.01	43.05	21.85

Table-3: Effect of temperature on viscosity at different Margosa oil blended Lubricants (Fig. 4.3).

Temperature ^{0}C	Viscosity of different Margosa blended lubricant (centistokes)				
	0% Margosa	2% Margosa	4% Margosa	6% Margosa	8% Margosa
30	370.47	341.43	331.64	324.59	317.77
40	188.99	188.52	186.31	181.28	179.07
60	86.44	82.03	82.28	81.89	81.53
80	33.16	34.57	38.14	38.41	37.01
100	19.02	20.67	19.72	20.67	21.85

Table-4 : Effect of different margosa oil blended lubricants on viscosity at different temperature (Fig. 4.4).

Different % of margosa oil in lube oil	Viscosity at different temperature (centistokes)				
	30°C	40°C	60°C	80°C	100°C
0	370.47	188.99	86.44	33.16	19.02
2	341.43	188.51	82.02	34.57	20.67
4	331.64	183.31	82.28	38.14	19.72
6	324.59	181.28	81.89	38.41	20.67
8	317.77	179.07	81.53	37.01	21.85

Table-5 : Effect of temperature on density at different palm oil blended Lubricants (Fig. 4.5).

Temperature ^{0}C	Density of different palm blended lubricant (gm/cc)				
	0%Palm	2%Palm	4%Palm	6%Palm	8%Palm
30	0.0333	0.5315	0.5235	0.523	0.531
40	0.0633	0.527	0.5135	0.531	0.5315
60	0.07303	0.523	0.52	0.523	0.5415
80	0.1074	0.515	0.5185	0.51	0.5425
100	0.181	0.519	0.5133	0.525	0.5415

Table-6 : Effect of different palm blended lubricants on density at different temperature (Fig. 4.6).

Different % palm oil in lube oil	Density at different temperature (gm/cc)				
	30°C	40°C	60°C	80°C	100°C
0	0.0333	0.0633	0.0708	0.1074	0.141
2	0.5315	0.527	0.523	0.515	0.519
4	0.5235	0.5135	0.52	0.5185	0.5133
6	0.523	0.513	0.523	0.51	0.525
8	0.531	0.5315	0.5415	0.5425	0.5415

Table-7 : Effect of temperature on density at different Margosa oil blended Lubricants (Fig. 4.7).

Temperature ^{0}C	Density at different Margosa blended lubricant (gm/cc)				
	0% Margosa	2% Margosa	4% Margosa	6% Margosa	8% Margosa
30	0.0333	0.877	0.8696	0.8851	0.8889
40	0.0633	0.874	0.8721	0.8731	0.877
60	0.0708	0.8734	0.8752	0.8703	0.8703
80	0.1074	0.8555	0.8579	0.8562	0.8588
100	0.141	0.8432	0.8481	0.8451	0.8537

Table-8: Effect of different margosa blended lubricants on density at different temperature (Fig. 4.8).

Different % of margosa oil in lube oil	Density at different temperature (gm/cc)				
	30°C	40°C	60°C	80°C	100°C
0	0.0333	0.0633	0.0708	0.1074	0.141
2	0.877	0.874	0.874	0.855	0.8432
4	0.8696	0.8721	0.8752	0.8579	0.8481
6	0.8851	0.8731	0.8703	0.8562	0.8451
8	0.8889	0.877	0.8703	0.8588	0.8537

Table-9: The corrosion behavior of 0.16% carbon steel in 100% lubricating oil at different temperature (Fig. 4.14).

Potential (mV)	Current flow in different temperature (μA)		
	30^0C	40^0C	60^0C
500	0.4	0.4	0.4
1000	0.4	0.4	0.4
1500	0.5	0.5	0.6
2000	0.5	0.5	0.6
2500	0.5	0.6	0.7
3000	0.6	0.6	0.7
3500	0.6	0.6	0.7
4000	0.7	0.7	0.8
4500	0.7	0.7	0.8
5000	0.7	0.7	0.8
5500	0.8	0.8	0.8
6000	0.8	0.8	0.9
6500	0.8	0.8	1
7000	0.9	0.9	1.1
7500	1	1.1	1.2

Table-10: The corrosion behavior of 0.79% carbon steel in 100% lubricating oil at different temperature (Fig. 4.15).

Potential (mV)	Current flow in different temperature (μA)		
	30^0C	40^0C	60^0C
500	0.3	0.3	0.3
1000	0.4	0.4	0.4
1500	0.5	0.5	0.6
2000	0.5	0.5	1
2500	0.6	0.6	1
3000	0.6	0.7	1.1
3500	0.6	0.8	1.1
4000	0.7	0.9	1.1
4500	0.7	1	1.1
5000	0.8	1	1.2
5500	0.9	1	1.2
6000	1	1	1.2
6500	1	1.1	1.2
7000	1.1	1.1	1.2
7500	1.1	1.1	1.2

Table-11 : The corrosion behavior of brass alloy in 100% lubricating oil at different temperature (Fig. 4.16).

Potential (mV)	Current flow in different temperature (μA)		
	30^0C	40^0C	60^0C
500	0	0	0
1000	0	0	0
1500	0	0	0
2000	0	0	0
2500	0	0	0
3000	0	0	0
3500	0	0	0
4000	0	0	0
4500	0.1	0.1	0.1
5000	0.1	0.1	0.1
5500	0.2	0.1	0.1
6000	0.2	0.1	0.1
6500	0.3	0.1	0.1
7000	0.3	0.2	0.1
7500	0.3	0.2	0.1

Table-12: The corrosion behavior of different metal at 30°C temperature in 100% lubricating oil (Fig. 4.17).

Potential (mV)	Current flow in different metals (μA)		
	0.16% Carbon steel	0.79% Carbon steel	Brass alloy
500	0.4	0.3	0
1000	0.4	0.4	0
1500	0.5	0.5	0
2000	0.5	0.5	0
2500	0.5	0.6	0
3000	0.6	0.6	0
3500	0.6	0.6	0
4000	0.7	0.7	0
4500	0.7	0.7	0.1
5000	0.7	0.8	0.1
5500	0.8	0.9	0.2
6000	0.8	1	0.2
6500	0.8	1	0.3
7000	0.9	1.1	0.3
7500	1	1.1	0.3

Table-13: The corrosion behavior of different metal at 60^0C temperature in 100% lubricating oil (Fig. 4.18).

Potential (mV)	Current flow in different metals (μA)		
	0.16% Carbon steel	0.79% Carbon steel	Brass alloy
500	0.4	0.3	0
1000	0.4	0.4	0
1500	0.6	0.6	0
2000	0.6	1	0
2500	0.7	1	0
3000	0.7	1.1	0
3500	0.7	1.1	0
4000	0.8	1.1	0
4500	0.8	1.1	0.1
5000	0.8	1.2	0.1
5500	0.8	1.2	0.1
6000	0.9	1.2	0.1
6500	1	1.2	0.1
7000	1.1	1.2	0.1
7500	1.2	1.2	0.1

Table-14: The corrosion behavior of 0.16% carbon steel in Mobil oil at different temperature (Fig. 4.19).

Potential (mV)	Current flow in different temperature (μA)		
	30^0C	40^0C	60^0C
500	0.1	0.1	0.2
1000	0.2	0.2	0.2
1500	0.3	0.2	0.3
2000	0.4	0.3	0.4
2500	0.4	0.4	0.6
3000	0.5	0.5	0.6
3500	0.5	0.6	0.6
4000	0.5	0.6	0.7
4500	0.6	0.6	0.8
5000	0.6	0.7	0.8
5500	0.6	0.7	0.8
6000	0.6	0.7	0.9
6500	0.7	0.8	0.9
7000	0.8	0.8	0.9
7500	0.8	0.9	1

Table-15: The corrosion behavior of 0.79% carbon steel in Mobil oil at different temperature (Fig. 4.20).

Potential (mV)	Current flow in different temperature (μA)		
	30^0C	40^0C	60^0C
500	0.2	0.2	0.2
1000	0.3	0.3	0.3
1500	0.3	0.3	0.4
2000	0.5	0.4	0.4
2500	0.6	0.4	0.6
3000	0.7	0.5	0.6
3500	0.7	0.5	0.6
4000	0.8	0.6	0.6
4500	0.9	0.7	0.7
5000	1	0.8	0.7
5500	0.9	0.8	0.8
6000	0.9	0.8	0.8
6500	1	0.9	1
7000	1	0.9	1
7500	1	1	1.1

Table -16: The corrosion behavior of brass alloy in Mobil oil at different temperature (Fig. 4.21).

Potential (mV)	Current flow in different temperature (μA)		
	30^0C	40^0C	60^0C
500	0	0	0
1000	0	0	0
1500	0	0	0
2000	0	0	0
2500	0	0	0
3000	0	0	0
3500	0	0	0
4000	0	0	0
4500	0	0	0
5000	0	0	0
5500	0.1	0.1	0
6000	0.1	0.1	0.1
6500	0.2	0.1	0.1
7000	0.2	0.2	0.1
7500	0.3	0.2	0.1

Table-17: The corrosion behavior of different metal in Mobil oil at 30°C temperature (Fig. 4.22).

Potential (mV)	Current flow in different metals (μA)		
	0.16% Carbon steel	0.79% Carbon steel	Brass alloy
500	0.1	0.2	0
1000	0.2	0.3	0
1500	0.3	0.3	0
2000	0.4	0.5	0
2500	0.4	0.6	0
3000	0.5	0.7	0
3500	0.5	0.7	0
4000	0.5	0.8	0
4500	0.6	0.9	0
5000	0.6	1	0
5500	0.6	0.9	0.1
6000	0.6	0.9	0.1
6500	0.7	1	0.2
7000	0.8	1	0.2
7500	0.8	1	0.3

Table -18: The corrosion behavior of different metal in Mobil oil at 60°C temperature (Fig. 4.23).

Potential (mV)	Current flow in different metals (μA)		
	0.16% Carbon steel	0.79% Carbon steel	Brass alloy
500	0.2	0.2	0
1000	0.2	0.3	0
1500	0.3	0.4	0
2000	0.4	0.4	0
2500	0.6	0.6	0
3000	0.6	0.6	0
3500	0.6	0.6	0
4000	0.7	0.6	0
4500	0.8	0.7	0
5000	0.8	0.7	0
5500	0.8	0.8	0
6000	0.9	0.8	0.1
6500	0.9	1	0.1
7000	0.9	1	0.1
7500	1	1.1	0.1

Table-19: The corrosion behavior of 0.16% carbon steel in 100% palm oil at different temperature (Fig. 4.24).

Potential (mV)	Current flow in different temperature (μA)		
	30^0C	40^0C	60^0C
500	0	0	0
1000	0	0	0
1500	0	0	0
2000	0	0	0
2500	0	0	0
3000	0.1	0.1	0.1
3500	0.1	0.1	0.1
4000	0.1	0.1	0.1
4500	0.1	0.1	0.1
5000	0.1	0.1	0.1
5500	0.1	0.1	0.1
6000	0.1	0.1	0.1
6500	0.1	0.1	0.1
7000	0.1	0.1	0.2
7500	0.1	0.2	0.2

Table-20: The corrosion behavior of 0.79% carbon steel in 100% palm oil at different temperature (Fig. 4.25).

Potential (mV)	Current flow in different temperature (μA)		
	30^0C	40^0C	60^0C
500	0	0	0
1000	0	0	0
1500	0	0	0
2000	0	0	0
2500	0	0	0
3000	0	0	0
3500	0.1	0.1	0.1
4000	0.1	0.1	0.1
4500	0.1	0.1	0.1
5000	0.1	0.1	0.1
5500	0.1	0.1	0.1
6000	0.1	0.1	0.1
6500	0.1	0.1	0.1
7000	0.2	0.2	0.2
7500	0.2	0.2	0.2

Table-21 : The corrosion behavior of brass alloy in 100% palm oil at different temperature. (Fig. 4.26)

Potential (mV)	Current flow in different temperature (μA)		
	30^0C	40^0C	60^0C
500	0	0	0
1000	0	0	0
1500	0	0	0
2000	0	0	0
2500	0	0	0
3000	0	0	0
3500	0.1	0.1	0.1
4000	0.1	0.1	0.1
4500	0.1	0.1	0.1
5000	0.1	0.1	0.1
5500	0.1	0.1	0.1
6000	0.1	0.1	0.1
6500	0.1	0.1	0.1
7000	0.1	0.2	0.2
7500	0.2	0.2	0.2

Table-22 : The corrosion behavior of different metal in 100% palm oil at 30^0C temperature. (Fig. 4.27)

Potential (mV)	Current flow in different metals (μA)		
	0.16% Carbon steel	0.79% Carbon steel	Brass alloy
500	0	0	0
1000	0	0	0
1500	0	0	0
2000	0	0	0
2500	0	0	0
3000	0.1	0	0
3500	0.1	0.1	0.1
4000	0.1	0.1	0.1
4500	0.1	0.1	0.1
5000	0.1	0.1	0.1
5500	0.1	0.1	0.1
6000	0.1	0.1	0.1
6500	0.1	0.1	0.1
7000	0.1	0.2	0.1
7500	0.1	0.2	0.2

Table-23: The corrosion behavior of different metal in 100% palm oil at 60^0C temperature. (Fig. 4.28)

Potential (mV)	Current flow in Different metals (μA)		
	0.16% Carbon steel	0.79% Carbon steel	Brass alloy
500	0	0	0
1000	0	0	0
1500	0	0	0
2000	0	0	0
2500	0	0	0
3000	0.1	0	0
3500	0.1	0.1	0.1
4000	0.1	0.1	0.1
4500	0.1	0.1	0.1
5000	0.1	0.1	0.1
5500	0.1	0.1	0.1
6000	0.1	0.1	0.1
6500	0.1	0.1	0.1
7000	0.1	0.2	0.2
7500	0.2	0.2	0.2

Table-24: The corrosion behavior of 0.16% carbon steel in 2% palm and 98% lubricating oil at different temperature.(Fig. 4.29)

Potential (mV)	Current flow in different temperature (μA)		
	30^0C	40^0C	60^0C
500	0	0	0
1000	0	0	0
1500	0	0	0
2000	0	0	0
2500	0	0	0
3000	0	0	0
3500	0	0	0
4000	0	0	0
4500	0	0	0
5000	0	0	0
5500	0	0	0
6000	0	0.1	0.1
6500	0.1	0.1	0.1
7000	0.1	0.1	0.1
7500	0.1	0.1	0.1

Table-25: The corrosion behavior of 0.16% carbon steel in 4% palm and 96% lubricating oil at different temperature. Fig. 4.30

Potential (mV)	Current flow in different temperature (μA)		
	30⁰C	40⁰C	60⁰C
500	0	0	0
1000	0	0	0
1500	0	0	0
2000	0	0	0
2500	0	0	0
3000	0	0	0
3500	0	0	0
4000	0	0	0
4500	0	0	0
5000	0	0	0
5500	0.1	0.1	0.1
6000	0.1	0.1	0.1
6500	0.1	0.1	0.1
7000	0.2	0.1	0.1
7500	0.2	0.1	0.2

Table-26: The corrosion behavior of 0.16% carbon steel in 6% palm and 94% lubricating oil at different temperature. (Fig. 4.31)

Potential (mV)	Current flow in different temperature (μA)		
	30⁰C	40⁰C	60⁰C
500	0	0	0
1000	0	0	0
1500	0	0	0
2000	0	0	0
2500	0	0	0
3000	0	0.1	0.1
3500	0.1	0.1	0.1
4000	0.1	0.1	0.1
4500	0.1	0.1	0.1
5000	0.1	0.1	0.1
5500	0.1	0.1	0.1
6000	0.2	0.1	0.1
6500	0.2	0.2	0.1
7000	0.2	0.2	0.2
7500	0.2	0.2	0.2

Table-27: The corrosion behavior of 0.16% carbon steel in 8% palm and 92% lubricating oil at different temperature. (Fig. 4.32)

Potential (mV)	Current flow in different temperature (μA)		
	30^0C	40^0C	60^0C
500	0	0	0
1000	0	0	0
1500	0	0	0
2000	0	0	0
2500	0	0	0
3000	0	0	0
3500	0.1	0.1	0.1
4000	0.1	0.1	0.1
4500	0.1	0.1	0.1
5000	0.1	0.1	0.1
5500	0.1	0.1	0.1
6000	0.1	0.1	0.1
6500	0.1	0.1	0.1
7000	0.1	0.1	0.1
7500	0.2	0.1	0.1

Table-28: The corrosion behavior of 0.79% carbon steel in 2% palm and 98% lubricating oil at different temperature. (Fig. 4.33)

Potential (mV)	Current flow in different temperature (μA)		
	30^0C	40^0C	60^0C
500	0	0	0
1000	0	0	0
1500	0	0	0
2000	0	0	0
2500	0	0	0
3000	0	0	0
3500	0.1	0.1	0.1
4000	0.1	0.1	0.1
4500	0.1	0.1	0.1
5000	0.1	0.1	0.1
5500	0.1	0.1	0.1
6000	0.1	0.1	0.1
6500	0.1	0.1	0.1
7000	0.2	0.2	0.2
7500	0.2	0.2	0.2

Table-29: The corrosion behavior of 0.79% carbon steel in 4% palm and 96% lubricating oil at different temperature. (Fig. 4.34)

Potential (mV)	Current flow in different temperature (μA)		
	30^0C	40^0C	60^0C
500	0	0	0
1000	0	0	0
1500	0	0	0
2000	0	0	0
2500	0	0	0
3000	0	0	0
3500	0.1	0.1	0.1
4000	0.1	0.1	0.1
4500	0.1	0.1	0.1
5000	0.1	0.1	0.1
5500	0.1	0.1	0.1
6000	0.1	0.1	0.1
6500	0.1	0.2	0.2
7000	0.2	0.2	0.2
7500	0.2	0.2	0.2

Table-30: The corrosion behavior of 0.79% carbon steel in 6% palm and 94% lubricating oil at different temperature. (Fig. 4.35)

Potential (mV)	Current flow in different temperature (μA)		
	30^0C	40^0C	60^0C
500	0	0	0
1000	0	0	0
1500	0	0	0
2000	0	0	0
2500	0	0	0
3000	0	0	0
3500	0.1	0.1	0.1
4000	0.1	0.1	0.1
4500	0.1	0.1	0.1
5000	0.1	0.1	0.1
5500	0.1	0.1	0.1
6000	0.1	0.1	0.1
6500	0.1	0.1	0.1
7000	0.1	0.1	0.2
7500	0.2	0.2	0.2

Table-31: The corrosion behavior of 0.79% carbon steel in 8% palm and 92% lubricating oil at different temperature. (Fig. 4.36)

Potential (mV)	Current flow in different temperature (µA)		
	30^0C	40^0C	60^0C
500	0	0	0
1000	0	0	0
1500	0	0	0
2000	0	0	0
2500	0	0	0
3000	0	0	0
3500	0.1	0.1	0.1
4000	0.1	0.1	0.1
4500	0.1	0.1	0.1
5000	0.1	0.1	0.1
5500	0.1	0.1	0.1
6000	0.1	0.1	0.1
6500	0.1	0.1	0.1
7000	0.2	0.2	0.2
7500	0.2	0.2	0.2

Table-32: The corrosion behavior of brass alloy in 2% palm and 98% lubricating oil at different temperature. (Fig. 4.37).

Potential (mV)	Current flow in different temperature (µA)		
	30^0C	40^0C	60^0C
500	0	0	0
1000	0	0	0
1500	0	0	0
2000	0	0	0
2500	0	0	0
3000	0	0	0
3500	0.1	0.1	0.1
4000	0.1	0.1	0.1
4500	0.1	0.1	0.1
5000	0.1	0.1	0.1
5500	0.1	0.1	0.1
6000	0.1	0.1	0.1
6500	0.1	0.1	0.1
7000	0.1	0.1	0.1
7500	0.2	0.2	0.2

Table-33: The corrosion behavior of brass alloy in 4% palm and 96% lubricating oil at different temperature. (Fig. 4.38)

Potential (mV)	Current Flow in different temperature (μA)		
	30^0C	40^0C	60^0C
500	0	0	0
1000	0	0	0
1500	0	0	0
2000	0	0	0
2500	0	0	0
3000	0	0	0
3500	0.1	0.1	0.1
4000	0.1	0.1	0.1
4500	0.1	0.1	0.1
5000	0.1	0.1	0.1
5500	0.1	0.1	0.1
6000	0.1	0.1	0.1
6500	0.1	0.1	0.1
7000	0.1	0.2	0.2
7500	0.2	0.2	0.2

Table-34: The corrosion behavior of brass alloy in 6% palm and 94% lubricating oil at different temperature. (Fig. 4.39)

Potential (mV)	Current Flow in different temperature (μA)		
	30^0C	40^0C	60^0C
500	0	0	0
1000	0	0	0
1500	0	0	0
2000	0	0	0
2500	0	0	0
3000	0	0	0
3500	0.1	0.1	0.1
4000	0.1	0.1	0.1
4500	0.1	0.1	0.1
5000	0.1	0.1	0.1
5500	0.1	0.1	0.1
6000	0.1	0.1	0.1
6500	0.1	0.1	0.1
7000	0.2	0.1	0.1
7500	0.2	0.2	0.2

Table-35: The corrosion behavior of brass alloy in 8% palm and 92% lubricating oil at different temperature. (Fig. 4.40)

Potential (mV)	Current Flow in different temperature (μA)		
	30^0C	40^0C	60^0C
500	0	0	0
1000	0	0	0
1500	0	0	0
2000	0	0	0
2500	0	0	0
3000	0	0	0
3500	0.1	0.1	0.1
4000	0.1	0.1	0.1
4500	0.1	0.1	0.1
5000	0.1	0.1	0.1
5500	0.1	0.1	0.1
6000	0.1	0.1	0.1
6500	0.1	0.1	0.1
7000	0.2	0.2	0.2
7500	0.2	0.2	0.2

Table-36: The corrosion behavior of different metals in 2% palm and 98% lubricating oil at 30^0C temperature. (Fig. 4.41)

Potential (mV)	Current flow in Different metals (μA)		
	0.16% Carbon steel	0.79% Carbon steel	Brass alloy
500	0	0	0
1000	0	0	0
1500	0	0	0
2000	0	0	0
2500	0	0	0
3000	0	0	0
3500	0	0.1	0.1
4000	0	0.1	0.1
4500	0	0.1	0.1
5000	0	0.1	0.1
5500	0	0.1	0.1
6000	0	0.1	0.1
6500	0.1	0.1	0.1
7000	0.1	0.2	0.1
7500	0.1	0.2	0.2

Table-37: The corrosion behavior of different metals in 4% palm and 96% lubricating oil at 30^{0}C temperature. (Fig. 4.42)

Potential (mV)	Current flow in Different metals (μA)		
	0.16% Carbon steel	0.79% Carbon steel	Brass alloy
500	0	0	0
1000	0	0	0
1500	0	0	0
2000	0	0	0
2500	0	0	0
3000	0	0	0
3500	0	0.1	0.1
4000	0	0.1	0.1
4500	0	0.1	0.1
5000	0	0.1	0.1
5500	0.1	0.1	0.1
6000	0.1	0.1	0.1
6500	0.1	0.1	0.1
7000	0.2	0.2	0.2
7500	0.2	0.2	0.2

Table-38: The corrosion behavior of different metals in 6% palm and 94% lubricating oil at 30^{0}C temperature. (Fig. 4.43)

Potential (mV)	Current flow in Different metals (μA)		
	0.16% Carbon steel	0.79% Carbon steel	Brass alloy
500	0	0	0
1000	0	0	0
1500	0	0	0
2000	0	0	0
2500	0	0	0
3000	0	0	0
3500	0.1	0.1	0.1
4000	0.1	0.1	0.1
4500	0.1	0.1	0.1
5000	0.1	0.1	0.1
5500	0.1	0.1	0.1
6000	0.2	0.1	0.1
6500	0.2	0.1	0.1
7000	0.2	0.1	0.1
7500	0.2	0.2	0.2

Table-39: The corrosion behavior of different metals in 8% palm and 92% lubricating oil at 30^{0}C temperature. (Fig. 4.44)

Potential (mV)	Current flow in Different metals (μA)		
	0.16% Carbon steel	0.79% Carbon steel	Brass alloy
500	0	0	0
1000	0	0	0
1500	0	0	0
2000	0	0	0
2500	0	0	0
3000	0	0	0
3500	0.1	0.1	0.1
4000	0.1	0.1	0.1
4500	0.1	0.1	0.1
5000	0.1	0.1	0.1
5500	0.1	0.1	0.1
6000	0.1	0.1	0.1
6500	0.1	0.1	0.1
7000	0.1	0.2	0.2
7500	0.2	0.2	0.2

Table-40 : The corrosion behavior of different metals in 2% palm and 98% lubricating oil at 60^{0}C temperature. (Fig. 4.45)

Potential (mV)	Current flow in Different metals (μA)		
	0.16% Carbon steel	0.79% Carbon steel	Brass alloy
500	0	0	0
1000	0	0	0
1500	0	0	0
2000	0	0	0
2500	0	0	0
3000	0	0	0
3500	0	0.1	0.1
4000	0	0.1	0.1
4500	0	0.1	0.1
5000	0	0.1	0.1
5500	0	0.1	0.1
6000	0.1	0.1	0.1
6500	0.1	0.1	0.1
7000	0.1	0.2	0.1
7500	0.1	0.2	0.2

Table-41: The corrosion behavior of different metals in 4% palm and 96% lubricating oil at 60^0C temperature. (Fig. 4.46)

Potential (mV)	Current flow in Different metals (μA)		
	0.16% Carbon steel	0.79% Carbon steel	Brass alloy
500	0	0	0
1000	0	0	0
1500	0	0	0
2000	0	0	0
2500	0	0	0
3000	0	0	0
3500	0	0.1	0.1
4000	0	0.1	0.1
4500	0	0.1	0.1
5000	0	0.1	0.1
5500	0.1	0.1	0.1
6000	0.1	0.1	0.1
6500	0.1	0.2	0.1
7000	0.1	0.2	0.2
7500	0.2	0.2	0.2

Table-42 : The corrosion behavior of different metals in 6% palm and 94% lubricating oil at 60^0C temperature. (Fig. 4.47)

Potential (mV)	Current flow in Different metals (μA)		
	0.16% Carbon steel	0.79% Carbon steel	Brass alloy
500	0	0	0
1000	0	0	0
1500	0	0	0
2000	0	0	0
2500	0	0	0
3000	0.1	0	0
3500	0.1	0.1	0.1
4000	0.1	0.1	0.1
4500	0.1	0.1	0.1
5000	0.1	0.1	0.1
5500	0.1	0.1	0.1
6000	0.1	0.1	0.1
6500	0.1	0.1	0.1
7000	0.1	0.2	0.1
7500	0.2	0.2	0.2

Table-43 : The corrosion behavior of different metals in 8% palm and 92% lubricating oil at 60^{0}C temperature. (Fig. 4.48)

Potential (mV)	Current flow in Different metals (μA)		
	0.16% Carbon steel	0.79% Carbon steel	Brass alloy
500	0	0	0
1000	0	0	0
1500	0	0	0
2000	0	0	0
2500	0	0	0
3000	0	0.1	0.1
3500	0.1	0.1	0.1
4000	0.1	0.1	0.1
4500	0.1	0.1	0.1
5000	0.1	0.1	0.1
5500	0.1	0.1	0.1
6000	0.1	0.1	0.1
6500	0.1	0.1	0.1
7000	0.1	0.2	0.2
7500	0.1	0.2	0.2

Table-44 : The corrosion behavior of 0.16% carbon steel in different palm blended lubricating oil at 30^{0}C temperature. (Fig. 4.49)

Potential (mV)	Current flow in different % of palm oil (μA)					Lube oil (μA)	Mobil (μA)
	2%	4%	6%	8%	100%		
500	0	0	0	0	0	0.4	0.1
1000	0	0	0	0	0	0.4	0.2
1500	0	0	0	0	0	0.5	0.3
2000	0	0	0	0	0	0.5	0.4
2500	0	0	0	0	0	0.5	0.4
3000	0	0	0	0	0.1	0.6	0.5
3500	0	0	0.1	0.1	0.1	0.6	0.5
4000	0	0	0.1	0.1	0.1	0.7	0.5
4500	0	0	0.1	0.1	0.1	0.7	0.6
5000	0	0	0.1	0.1	0.1	0.7	0.6
5500	0	0.1	0.1	0.1	0.1	0.8	0.6
6000	0	0.1	0.2	0.1	0.1	0.8	0.6
6500	0.1	0.1	0.2	0.1	0.1	0.8	0.7
7000	0.1	0.2	0.2	0.1	0.1	0.9	0.8
7500	0.1	0.2	0.2	0.2	0.1	1	0.8

Table-45 : The corrosion behavior of 0.16% carbon steel in different palm blended lubricating oil at 60^0C temperature. (Fig. 4.50)

Potential (mV)	Current flow in different % of palm oil (μA)					Lube oil (μA)	Mobil (μA)
	2%	4%	6%	8%	100%		
500	0	0	0	0	0	0.4	0.2
1000	0	0	0	0	0	0.4	0.2
1500	0	0	0	0	0	0.6	0.3
2000	0	0	0	0	0	0.6	0.4
2500	0	0	0	0	0	0.7	0.6
3000	0	0	0.1	0	0.1	0.7	0.6
3500	0	0	0.1	0.1	0.1	0.7	0.6
4000	0	0	0.1	0.1	0.1	0.8	0.7
4500	0	0	0.1	0.1	0.1	0.8	0.8
5000	0	0	0.1	0.1	0.1	0.8	0.8
5500	0	0.1	0.1	0.1	0.1	0.8	0.8
6000	0.1	0.1	0.1	0.1	0.1	0.9	0.9
6500	0.1	0.1	0.1	0.1	0.1	1	0.9
7000	0.1	0.1	0.2	0.1	0.2	1.1	0.9
7500	0.1	0.2	0.2	0.1	0.2	1.2	1

Table-46 : The corrosion behavior of 0.79% carbon steel in different palm blended lubricating oil at 30^0C temperature. (Fig. 4.51)

Potential (mV)	Current flow in different % of palm oil (μA)					Lube oil (μA)	Mobil (μA)
	2%	4%	6%	8%	100%		
500	0	0	0	0	0	0.3	0.2
1000	0	0	0	0	0	0.4	0.3
1500	0	0	0	0	0	0.5	0.3
2000	0	0	0	0	0	0.5	0.5
2500	0	0	0	0	0	0.6	0.6
3000	0	0	0	0	0	0.6	0.7
3500	0.1	0.1	0.1	0.1	0.1	0.6	0.7
4000	0.1	0.1	0.1	0.1	0.1	0.7	0.8
4500	0.1	0.1	0.1	0.1	0.1	0.7	0.9
5000	0.1	0.1	0.1	0.1	0.1	0.8	1
5500	0.1	0.1	0.1	0.1	0.1	0.9	0.9
6000	0.1	0.1	0.1	0.1	0.1	1	0.9
6500	0.1	0.1	0.1	0.1	0.1	1	1
7000	0.2	0.2	0.1	0.2	0.2	1.1	1
7500	0.2	0.2	0.2	0.2	0.2	1.1	1

Table-47 : The corrosion behavior of 0.79% carbon steel in different palm blended lubricating oil at 60^0C temperature. (Fig. 4.52)

Potential (mV)	Current flow in different % of palm oil (μA)					Lube oil (μA)	Mobil (μA)
	2%	4%	6%	8%	100%		
500	0	0	0	0	0	0.3	0.2
1000	0	0	0	0	0	0.4	0.3
1500	0	0	0	0	0	0.6	0.4
2000	0	0	0	0	0	1	0.4
2500	0	0	0	0	0	1	0.6
3000	0	0	0	0	0	1.1	0.6
3500	0	0	0	0.1	0.1	1.1	0.6
4000	0.1	0.1	0.1	0.1	0.1	1.1	0.6
4500	0.1	0.1	0.1	0.1	0.1	1.1	0.7
5000	0.1	0.1	0.1	0.1	0.1	1.2	0.7
5500	0.1	0.1	0.1	0.1	0.1	1.2	0.8
6000	0.1	0.1	0.1	0.1	0.1	1.2	0.8
6500	0.1	0.2	0.1	0.1	0.1	1.2	1
7000	0.2	0.2	0.2	0.2	0.2	1.2	1
7500	0.2	0.2	0.2	0.2	0.2	1.2	1.1

Table-48 : The corrosion behavior of brass alloy in different palm oil blended Lubricating oil at 30^0C temperature. (Fig. 4.53)

Potential (mV)	Current flow in different % of palm oil (μA)					Lube oil (μA)	Mobil (μA)
	2%	4%	6%	8%	100%		
500	0	0	0	0	0	0	0
1000	0	0	0	0	0	0	0
1500	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0
2500	0	0	0	0	0	0	0
3000	0	0	0	0	0	0	0
3500	0.1	0	0.1	0.1	0.1	0	0
4000	0.1	0.1	0.1	0.1	0.1	0	0
4500	0.1	0.1	0.1	0.1	0.1	0.1	0
5000	0.1	0.1	0.1	0.1	0.1	0.1	0
5500	0.1	0.1	0.1	0.1	0.1	0.2	0.1
6000	0.1	0.1	0.1	0.1	0.1	0.2	0.1
6500	0.1	0.1	0.1	0.1	0.1	0.3	0.2
7000	0.1	0.1	0.2	0.2	0.1	0.3	0.2
7500	0.2	0.2	0.2	0.2	0.2	0.3	0.3

Table-49: The corrosion behavior of brass alloy in different palm oil blended lubricating oil at 60^0C temperature. (Fig. 4.54)

Potential (mV)	Current flow in different % of palm oil (μA)					Lube oil (μA)	Mobil (μA)
	2%	4%	6%	8%	100%		
500	0	0	0	0	0	0	0
1000	0	0	0	0	0	0	0
1500	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0
2500	0	0	0	0	0	0	0
3000	0	0	0	0	0	0	0
3500	0.1	0.1	0.1	0.1	0.1	0	0
4000	0.1	0.1	0.1	0.1	0.1	0	0
4500	0.1	0.1	0.1	0.1	0.1	0.1	0
5000	0.1	0.1	0.1	0.1	0.1	0.1	0
5500	0.1	0.1	0.1	0.1	0.1	0.1	0
6000	0.1	0.1	0.1	0.1	0.1	0.1	0.1
6500	0.1	0.1	0.1	0.1	0.1	0.1	0.1
7000	0.1	0.2	0.1	0.2	0.2	0.1	0.1
7500	0.2	0.2	0.2	0.2	0.2	0.1	0.1

Table-50 : The corrosion behavior of 0.16% carbon steel in 100% margosa oil at different temperatures. (Fig. 4.55)

Potential (mV)	Current Flow in different temperature (μA)		
	30^0C	40^0C	60^0C
500	0.3	0.1	0
1000	0.3	0.1	0
1500	0.3	0.1	0
2000	0.4	0.1	0
2500	0.4	0.2	0.1
3000	0.5	0.2	0.1
3500	0.6	0.2	0.1
4000	0.6	0.3	0.1
4500	0.7	0.3	0.1
5000	0.8	0.3	0.1
5500	0.8	0.3	0.2
6000	0.8	0.3	0.2
6500	0.8	0.3	0.2
7000	0.8	0.4	0.2
7500	0.9	0.4	0.3

Table-51 : The corrosion behavior of 0.79% carbon steel in 100% margosa oil at different temperatures. (Fig. 4.56)

Potential (mV)	Current Flow in different temperature (μA)		
	30^0C	40^0C	60^0C
500	0.3	0.1	0
1000	0.3	0.1	0
1500	0.4	0.1	0
2000	0.4	0.1	0
2500	0.5	0.2	0.1
3000	0.6	0.2	0.1
3500	0.6	0.2	0.1
4000	0.7	0.3	0.1
4500	0.8	0.3	0.1
5000	0.8	0.4	0.1
5500	0.8	0.5	0.2
6000	0.8	0.6	0.2
6500	0.9	0.6	0.2
7000	0.9	0.6	0.2
7500	0.9	0.6	0.3

Table-52: The corrosion behavior of brass alloy in 100% margosa oil at different temperatures. (Fig. 4.57)

Potential (mV)	Current Flow in different temperature (μA)		
	30^0C	40^0C	60^0C
500	0	0	0.1
1000	0	0	0.1
1500	0	0	0.1
2000	0	0	0.1
2500	0	0	0.1
3000	0	0	0.1
3500	0	0	0.1
4000	0	0	0.1
4500	0	0.1	0.1
5000	0	0.1	0.1
5500	0.1	0.1	0.1
6000	0.1	0.1	0.1
6500	0.1	0.1	0.1
7000	0.2	0.1	0.1
7500	0.3	0.2	0.1

Table-53 : The corrosion behavior of different metals in 100% margosa oil at 30°C temperatures. (Fig. 4.58)

Potential (mV)	Current flow in Different metals (μA)		
	0.16% Carbon steel	0.79% Carbon steel	Brass alloy
500	0.3	0.3	0.1
1000	0.3	0.3	0.1
1500	0.3	0.4	0.1
2000	0.4	0.4	0.1
2500	0.4	0.5	0.1
3000	0.5	0.6	0.1
3500	0.6	0.6	0.1
4000	0.6	0.7	0.1
4500	0.7	0.8	0.1
5000	0.8	0.8	0.1
5500	0.8	0.8	0.1
6000	0.8	0.8	0.1
6500	0.8	0.9	0.1
7000	0.8	0.9	0.1
7500	0.9	0.9	0.1

Table-54 : The corrosion behavior of different metals in 100% margosa oil at 60°C temperatures. (Fig. 4.59)

Potential (mV)	Current flow in Different metals (μA)		
	0.16% Carbon steel	0.79% Carbon steel	Brass alloy
500	0.1	0	0.1
1000	0.1	0	0.1
1500	0.1	0	0.1
2000	0.1	0	0.1
2500	0.1	0.1	0.1
3000	0.2	0.1	0.1
3500	0.2	0.1	0.1
4000	0.2	0.1	0.1
4500	0.3	0.1	0.1
5000	0.3	0.1	0.1
5500	0.3	0.2	0.1
6000	0.3	0.2	0.1
6500	0.4	0.2	0.1
7000	0.4	0.2	0.1
7500	0.4	0.3	0.1

Table-55 : The corrosion behavior of 0.16% carbon steel in 2% margosa oil and 98% lubricating oil at different temperatures. (Fig.4.60)

Potential (mV)	Current Flow in different temperature (μA)		
	30^0C	40^0C	60^0C
500	0.1	0.4	0.5
1000	0.1	0.4	0.6
1500	0.1	0.4	0.6
2000	0.1	0.5	0.7
2500	0.1	0.5	0.7
3000	0.1	0.5	0.8
3500	0.1	0.5	0.8
4000	0.1	0.6	0.9
4500	0.2	0.6	0.8
5000	0.2	0.7	0.8
5500	0.2	0.7	0.8
6000	0.2	0.8	0.8
6500	0.3	0.8	0.9
7000	0.3	0.9	0.9
7500	0.3	0.9	0.9

Table-56 : The corrosion behavior of 0.16% carbon steel in 4% margosa oil and 96% lubricating oil at different temperatures. (Fig.4.61)

Potential (mV)	Current Flow in different temperature (μA)		
	30^0C	40^0C	60^0C
500	0.1	0.2	0.3
1000	0.1	0.2	0.3
1500	0.1	0.2	0.5
2000	0.1	0.2	0.6
2500	0.1	0.3	0.6
3000	0.1	0.3	0.6
3500	0.1	0.4	0.7
4000	0.1	0.4	0.8
4500	0.1	0.5	0.8
5000	0.1	0.5	0.9
5500	0.2	0.6	0.9
6000	0.2	0.6	0.9
6500	0.3	0.6	0.8
7000	0.3	0.7	0.9
7500	0.3	0.7	0.9

Table-57 : The corrosion behavior of 0.16% carbon steel in 6% margosa oil and 94% lubricating oil at different temperatures. (Fig.4.62)

Potential (mV)	Current Flow in different temperature (μA)		
	30^0C	40^0C	60^0C
500	0.1	0.1	0.2
1000	0.1	0.1	0.3
1500	0.1	0.1	0.5
2000	0.1	0.2	0.6
2500	0.1	0.2	0.6
3000	0.1	0.3	0.7
3500	0.2	0.3	0.8
4000	0.2	0.4	0.7
4500	0.2	0.4	0.8
5000	0.3	0.4	0.8
5500	0.3	0.4	0.8
6000	0.3	0.4	0.9
6500	0.3	0.4	0.9
7000	0.3	0.5	0.9
7500	0.3	0.5	0.9

Table-58 : The corrosion behavior of 0.16% carbon steel in 8% margosa oil and 92% lubricating oil at different temperatures. (Fig.4.63)

Potential (mV)	Current Flow in different temperature (μA)		
	30^0C	40^0C	60^0C
500	0.1	0.1	0.1
1000	0.1	0.1	0.1
1500	0.2	0.1	0.1
2000	0.3	0.2	0.2
2500	0.4	0.3	0.3
3000	0.5	0.3	0.4
3500	0.6	0.3	0.4
4000	0.7	0.4	0.4
4500	0.8	0.4	0.4
5000	0.9	0.5	0.4
5500	1	0.5	0.5
6000	1.1	0.5	0.5
6500	1.1	0.6	0.6
7000	1.1	0.7	0.6
7500	1.2	0.8	0.6

Table-59 : The corrosion behavior of 0.79% carbon steel in 2% margosa oil and 98% lubricating oil at different temperatures. (Fig.4.64)

Potential (mV)	Current Flow in different temperature (μA)		
	30^0C	40^0C	60^0C
500	0	0.1	0.6
1000	0	0.1	0.6
1500	0	0.1	0.6
2000	0	0.2	0.7
2500	0.1	0.2	0.8
3000	0.1	0.3	0.9
3500	0.1	0.3	0.9
4000	0.1	0.4	0.9
4500	0.2	0.4	0.8
5000	0.2	0.5	0.8
5500	0.2	0.5	0.8
6000	0.2	0.6	0.8
6500	0.2	0.7	0.8
7000	0.3	0.7	0.8
7500	0.3	0.8	0.8

Table-60: The corrosion behavior of 0.79% carbon steel in 4% margosa oil and 96% lubricating oil at different temperatures. (Fig.4.65)

Potential (mV)	Current Flow in different temperature (μA)		
	30^0C	40^0C	60^0C
500	0.1	0.1	0.2
1000	0.1	0.1	0.2
1500	0.2	0.2	0.4
2000	0.3	0.3	0.5
2500	0.4	0.4	0.6
3000	0.5	0.5	0.6
3500	0.6	0.6	0.7
4000	0.6	0.7	0.8
4500	0.6	0.7	0.7
5000	0.7	0.8	0.8
5500	0.7	0.8	0.8
6000	0.8	0.8	0.8
6500	0.8	0.8	0.8
7000	0.8	0.8	0.8
7500	0.8	0.8	0.8

Table-61: The corrosion behavior of 0.79% carbon steel in 6% margosa oil and 94% lubricating oil at different temperatures. (Fig.4.66)

Potential (mV)	Current Flow in different temperature (μA)		
	30^0C	40^0C	60^0C
500	0.1	0.1	0.3
1000	0.1	0.1	0.3
1500	0.2	0.2	0.4
2000	0.3	0.3	0.6
2500	0.4	0.4	0.7
3000	0.4	0.5	0.7
3500	0.5	0.5	0.8
4000	0.5	0.6	0.9
4500	0.6	0.6	0.9
5000	0.6	0.7	0.9
5500	0.6	0.7	0.9
6000	0.6	0.7	0.9
6500	0.6	0.8	0.8
7000	0.6	0.8	0.9
7500	0.6	0.8	0.9

Table-62 : The corrosion behavior of 0.79% carbon steel in 8% margosa oil and 92% lubricating oil at different temperatures. (Fig.4.67)

Potential (mV)	Current Flow in different temperature (μA)		
	30^0C	40^0C	60^0C
500	0.1	0.1	0.1
1000	0.1	0.1	0.1
1500	0.2	0.1	0.1
2000	0.3	0.2	0.1
2500	0.4	0.2	0.2
3000	0.5	0.3	0.2
3500	0.6	0.3	0.2
4000	0.6	0.3	0.2
4500	0.6	0.4	0.2
5000	0.6	0.4	0.2
5500	0.7	0.4	0.2
6000	0.7	0.4	0.3
6500	0.8	0.4	0.3
7000	1	0.4	0.3
7500	1	0.4	0.3

Table-63 : The corrosion behavior of brass alloy in 2%, 4%,and 6% margosa oil added lubricating oil at different temperatures. (Fig.4.68)

Potential (mV)	Current Flow in different temperature (μA)		
	30^0C	40^0C	60^0C
500	0.1	0.1	0.1
1000	0.1	0.1	0.1
1500	0.1	0.1	0.1
2000	0.1	0.1	0.1
2500	0.1	0.1	0.1
3000	0.1	0.1	0.1
3500	0.1	0.1	0.1
4000	0.1	0.1	0.1
4500	0.1	0.1	0.1
5000	0.1	0.1	0.1
5500	0.1	0.1	0.1
6000	0.1	0.1	0.1
6500	0.1	0.1	0.1
7000	0.1	0.1	0.1
7500	0.1	0.1	0.1

Table-64: The corrosion behavior of brass alloy 8% margosa oil and 92% lubricating oil at different temperatures. (Fig.4.69)

Potential (mV)	Current Flow in different temperature (μA)		
	30^0C	40^0C	60^0C
500	0	0	0.1
1000	0	0	0.1
1500	0	0	0.1
2000	0	0.1	0.1
2500	0	0.1	0.1
3000	0	0.1	0.1
3500	0	0.1	0.1
4000	0.1	0.1	0.1
4500	0.1	0.1	0.1
5000	0.2	0.1	0.1
5500	0.3	0.1	0.1
6000	0.3	0.1	0.1
6500	0.3	0.1	0.1
7000	0.3	0.1	0.1
7500	0.4	0.1	0.1

Table-65: The corrosion behavior of different metals in 2% margosa oil and 98% lubricating oil at 30^{0}C temperature. (Fig. 4.70)

Potential (mV)	Current flow in Different metals (μA)		
	0.16% Carbon steel	0.79% Carbon steel	Brass alloy
500	0.1	0	0.1
1000	0.1	0	0.1
1500	0.1	0	0.1
2000	0.1	0	0.1
2500	0.1	0.1	0.1
3000	0.1	0.1	0.1
3500	0.1	0.1	0.1
4000	0.1	0.1	0.1
4500	0.1	0.2	0.1
5000	0.2	0.2	0.1
5500	0.2	0.2	0.1
6000	0.2	0.2	0.1
6500	0.3	0.2	0.1
7000	0.3	0.3	0.1
7500	0.3	0.3	0.1

Table-66: The corrosion behavior of different metals in 4% margosa oil and 96% lubricating oil at 30^{0}C temperature. (Fig. 4.71)

Potential (mV)	Current flow in Different metals (μA)		
	0.16% Carbon steel	0.79% Carbon steel	Brass alloy
500	0.1	0.1	0.1
1000	0.1	0.1	0.1
1500	0.1	0.2	0.1
2000	0.1	0.3	0.1
2500	0.1	0.4	0.1
3000	0.1	0.5	0.1
3500	0.1	0.6	0.1
4000	0.1	0.6	0.1
4500	0.1	0.6	0.1
5000	0.1	0.7	0.1
5500	0.2	0.7	0.1
6000	0.2	0.8	0.1
6500	0.3	0.8	0.1
7000	0.3	0.8	0.1
7500	0.3	0.8	0.1

Table-67: The corrosion behavior of different metals in 6% margosa oil and 94% lubricating oil at 30^{0}C temperature. (Fig. 4.72)

Potential (mV)	Current flow in Different metals (µA)		
	0.16% Carbon steel	0.79% Carbon steel	Brass alloy
500	0.1	0.1	0.1
1000	0.1	0.1	0.1
1500	0.1	0.2	0.1
2000	0.1	0.3	0.1
2500	0.1	0.4	0.1
3000	0.1	0.4	0.1
3500	0.2	0.5	0.1
4000	0.2	0.5	0.1
4500	0.2	0.6	0.1
5000	0.3	0.6	0.1
5500	0.3	0.6	0.1
6000	0.3	0.6	0.1
6500	0.3	0.6	0.1
7000	0.3	0.6	0.1
7500	0.3	0.6	0.1

Table-68: The corrosion behavior of different metals in 8% margosa oil and 92% lubricating oil at 30^{0}C temperature. (Fig. 4.73)

Potential (mV)	Current flow in Different metals (µA)		
	0.16% Carbon steel	0.79% Carbon steel	Brass alloy
500	0.1	0.1	0
1000	0.1	0.1	0
1500	0.2	0.2	0
2000	0.3	0.3	0
2500	0.4	0.4	0
3000	0.5	0.5	0
3500	0.6	0.6	0
4000	0.7	0.6	0.1
4500	0.8	0.6	0.1
5000	0.9	0.6	0.2
5500	1	0.7	0.3
6000	1.1	0.7	0.3
6500	1.1	0.8	0.3
7000	1.1	1	0.3
7500	1.2	1	0.4

Table-69 : The corrosion behavior of different metals in 2% margosa oil and 98% lubricating oil at 60^{0}C temperature. (Fig. 4.74)

Potential (mV)	Current flow in Different metals (μA)		
	0.16% Carbon steel	0.79% Carbon steel	Brass alloy
500	0.5	0.6	0.1
1000	0.6	0.6	0.1
1500	0.6	0.6	0.1
2000	0.7	0.7	0.1
2500	0.7	0.8	0.1
3000	0.8	0.9	0.1
3500	0.8	0.9	0.1
4000	0.9	0.9	0.1
4500	0.8	0.8	0.1
5000	0.8	0.8	0.1
5500	0.8	0.8	0.1
6000	0.8	0.8	0.1
6500	0.9	0.8	0.1
7000	0.9	0.8	0.1
7500	0.9	0.8	0.1

Table-70 : The corrosion behavior of different metals in 4% margosa oil and 96% lubricating oil at 60^{0}C temperature. (Fig. 4.75)

Potential (mV)	Current flow in Different metals (μA)		
	0.16% Carbon steel	0.79% Carbon steel	Brass alloy
500	0.3	0.2	0.1
1000	0.3	0.2	0.1
1500	0.5	0.4	0.1
2000	0.6	0.5	0.1
2500	0.6	0.6	0.1
3000	0.6	0.7	0.1
3500	0.7	0.8	0.1
4000	0.8	0.7	0.1
4500	0.8	0.8	0.1
5000	0.9	0.8	0.1
5500	0.9	0.8	0.1
6000	0.9	0.8	0.1
6500	0.8	0.8	0.1
7000	0.9	0.8	0.1
7500	0.9	0.8	0.1

Table-71 : The corrosion behavior of different metals in 6% margosa oil and 94% lubricating oil at 60^0C temperature. (Fig. 4.76)

Potential (mV)	Current flow in Different metals (μA)		
	0.16% Carbon steel	0.79% Carbon steel	Brass alloy
500	0.2	0.3	0.1
1000	0.3	0.3	0.1
1500	0.5	0.4	0.1
2000	0.6	0.6	0.1
2500	0.6	0.7	0.1
3000	0.7	0.7	0.1
3500	0.8	0.8	0.1
4000	0.7	0.9	0.1
4500	0.8	0.9	0.1
5000	0.8	0.9	0.1
5500	0.8	0.9	0.1
6000	0.9	0.9	0.1
6500	0.9	0.8	0.1
7000	0.9	0.9	0.1
7500	0.9	0.9	0.1

Table-72 : The corrosion behavior of different metals in 8% margosa oil and 92% lubricating oil at 60^0C temperature. (Fig. 4.77)

Potential (mV)	Current flow in Different metals (μA)		
	0.16% Carbon steel	0.79% Carbon steel	Brass alloy
500	0.1	0.1	0.1
1000	0.1	0.1	0.1
1500	0.1	0.1	0.1
2000	0.2	0.1	0.1
2500	0.3	0.2	0.1
3000	0.4	0.2	0.1
3500	0.4	0.2	0.1
4000	0.4	0.2	0.1
4500	0.4	0.2	0.1
5000	0.4	0.2	0.1
5500	0.5	0.2	0.1
6000	0.5	0.3	0.1
6500	0.6	0.3	0.1
7000	0.6	0.3	0.1
7500	0.6	0.3	0.1

Table-73: The corrosion behavior of 0.16% carbon steel in different margosa oil blended lubricating oil at 30^{0}C temperature. (Fig. 4.78)

Potential (mV)	Current flow in different % of margosa oil (μA)					Lube oil (μA)	Mobil (μA)
	2%	4%	6%	8%	100%		
500	0.1	0.1	0.1	0.1	0.3	0.4	0.1
1000	0.1	0.1	0.1	0.1	0.3	0.4	0.2
1500	0.1	0.1	0.1	0.2	0.3	0.5	0.3
2000	0.1	0.1	0.1	0.3	0.4	0.5	0.4
2500	0.1	0.1	0.1	0.4	0.4	0.5	0.4
3000	0.1	0.1	0.1	0.5	0.5	0.6	0.5
3500	0.1	0.1	0.2	0.6	0.6	0.6	0.5
4000	0.1	0.1	0.2	0.7	0.6	0.7	0.5
4500	0.1	0.1	0.2	0.8	0.7	0.7	0.6
5000	0.2	0.1	0.3	0.9	0.8	0.7	0.6
5500	0.2	0.2	0.3	1	0.8	0.8	0.6
6000	0.2	0.2	0.3	1.1	0.8	0.8	0.6
6500	0.3	0.3	0.3	1.1	0.8	0.8	0.7
7000	0.3	0.3	0.3	1.1	0.8	0.9	0.8
7500	0.3	0.3	0.3	1.2	0.9	1	0.8

Table-74: The corrosion behavior of 0.16% carbon steel in different margosa oil blended lubricating oil at 60^{0}C temperature. (Fig. 4.79)

Potential (mV)	Current flow in different % of margosa oil (μA)					Lube oil (μA)	Mobil (μA)
	2%	4%	6%	8%	100%		
500	0.2	0.3	0.2	0.1	0.1	0.4	0.2
1000	0.6	0.3	0.3	0.1	0.1	0.4	0.2
1500	0.6	0.5	0.5	0.1	0.1	0.6	0.3
2000	0.7	0.6	0.6	0.2	0.1	0.6	0.4
2500	0.7	0.6	0.6	0.3	0.1	0.7	0.6
3000	0.8	0.6	0.7	0.4	0.2	0.7	0.6
3500	0.8	0.7	0.8	0.4	0.2	0.7	0.6
4000	0.9	0.8	0.7	0.4	0.2	0.8	0.7
4500	0.8	0.8	0.8	0.4	0.3	0.8	0.8
5000	0.8	0.9	0.8	0.4	0.3	0.8	0.8
5500	0.8	0.9	0.8	0.5	0.3	0.8	0.8
6000	0.8	0.9	0.9	0.5	0.3	0.9	0.9
6500	0.9	0.8	0.9	0.6	0.4	1	0.9
7000	0.9	0.9	0.9	0.6	0.4	1.1	0.9
7500	0.9	0.9	0.9	0.6	0.4	1.2	1

Table-75: The corrosion behavior of 0.79% carbon steel in different margosa oil blended lubricating oil at 30^{0}C temperature. (Fig. 4.80)

Potential (mV)	Current flow in different % of margosa oil (μA)					Lube oil (μA)	Mobil (μA)
	2%	4%	6%	8%	100%		
500	0	0.1	0.1	0.1	0.3	0.3	0.2
1000	0	0.1	0.1	0.1	0.3	0.4	0.3
1500	0	0.2	0.2	0.2	0.4	0.5	0.3
2000	0	0.3	0.3	0.3	0.4	0.5	0.5
2500	0.1	0.4	0.4	0.4	0.5	0.6	0.6
3000	0.1	0.5	0.4	0.5	0.6	0.6	0.7
3500	0.1	0.6	0.5	0.6	0.6	0.6	0.7
4000	0.1	0.6	0.5	0.6	0.7	0.7	0.8
4500	0.2	0.6	0.6	0.6	0.8	0.7	0.9
5000	0.2	0.7	0.6	0.6	0.8	0.8	1
5500	0.2	0.7	0.6	0.7	0.8	0.9	0.9
6000	0.2	0.8	0.6	0.7	0.8	1	0.9
6500	0.2	0.8	0.6	0.8	0.9	1	1
7000	0.3	0.8	0.6	1	0.9	1.1	1
7500	0.3	0.8	0.6	1	0.9	1.1	1

Table-76 : The corrosion behavior of 0.79% carbon steel in different margosa oil blended lubricating oil at 60^{0}C temperature. (Fig. 4.81)

Potential (mV)	Current flow in different % of margosa oil (μA)					Lube oil (μA)	Mobil (μA)
	2%	4%	6%	8%	100%		
500	0.6	0.2	0.3	0.1	0	0.3	0.2
1000	0.6	0.2	0.3	0.1	0	0.4	0.3
1500	0.6	0.4	0.4	0.1	0	0.6	0.4
2000	0.7	0.5	0.6	0.1	0	1	0.4
2500	0.8	0.6	0.7	0.2	0.1	1	0.6
3000	0.9	0.6	0.7	0.2	0.1	1.1	0.6
3500	0.9	0.7	0.8	0.2	0.1	1.1	0.6
4000	0.9	0.8	0.9	0.2	0.1	1.1	0.6
4500	0.8	0.7	0.9	0.2	0.1	1.1	0.7
5000	0.8	0.8	0.9	0.2	0.1	1.2	0.7
5500	0.8	0.8	0.9	0.2	0.2	1.2	0.8
6000	0.8	0.8	0.9	0.3	0.2	1.2	0.8
6500	0.8	0.8	0.8	0.3	0.2	1.2	1
7000	0.8	0.8	0.9	0.3	0.2	1.2	1
7500	0.8	0.8	0.9	0.3	0.3	1.2	1.1

Table-77 : The corrosion behavior of brass alloy in different margosa oil blended lubricating oil at 30^{0}C temperature. (Fig. 4.82)

Potential (mV)	Current flow in different % of margosa oil (µA)					Lube oil (µA)	Mobil (µA)
	2%	4%	6%	8%	100%		
500	0.1	0.1	0.1	0	0	0	0
1000	0.1	0.1	0.1	0	0	0	0
1500	0.1	0.1	0.1	0	0	0	0
2000	0.1	0.1	0.1	0	0	0	0
2500	0.1	0.1	0.1	0	0	0	0
3000	0.1	0.1	0.1	0	0	0	0
3500	0.1	0.1	0.1	0	0	0	0
4000	0.1	0.1	0.1	0.1	0	0	0
4500	0.1	0.1	0.1	0.1	0	0.1	0
5000	0.1	0.1	0.1	0.2	0	0.1	0
5500	0.1	0.1	0.1	0.3	0.1	0.2	0.1
6000	0.1	0.1	0.1	0.3	0.1	0.2	0.1
6500	0.1	0.1	0.1	0.3	0.1	0.3	0.2
7000	0.1	0.1	0.1	0.3	0.2	0.3	0.2
7500	0.1	0.1	0.1	0.4	0.3	0.3	0.3

Table-78 : The corrosion behavior of brass alloy in different margosa oil blended lubricating oil at 60^{0}C temperature. (Fig. 4.83)

Potential (mV)	Current flow in different % of margosa oil (µA)					Lube oil (µA)	Mobil (µA)
	2%	4%	6%	8%	100%		
500	0.1	0.1	0.1	0.1	0.1	0	0
1000	0.1	0.1	0.1	0.1	0.1	0	0
1500	0.1	0.1	0.1	0.1	0.1	0	0
2000	0.1	0.1	0.1	0.1	0.1	0	0
2500	0.1	0.1	0.1	0.1	0.1	0	0
3000	0.1	0.1	0.1	0.1	0.1	0	0
3500	0.1	0.1	0.1	0.1	0.1	0	0
4000	0.1	0.1	0.1	0.1	0.1	0	0
4500	0.1	0.1	0.1	0.1	0.1	0.1	0
5000	0.1	0.1	0.1	0.1	0.1	0.1	0
5500	0.1	0.1	0.1	0.1	0.1	0.1	0
6000	0.1	0.1	0.1	0.1	0.1	0.1	0.1
6500	0.1	0.1	0.1	0.1	0.1	0.1	0.1
7000	0.1	0.1	0.1	0.1	0.1	0.1	0.1
7500	0.1	0.1	0.1	0.1	0.1	0.1	0.1

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