

COPPER CORROSION RATE PREDICTION IN BIODIESEL BLENDS USING MACHINE LEARNING MODELS

Submitted in partial fulfillment of the requirements for the award of
Bachelor of Engineering degree in Mechanical engineering.

By

BOGAM SANTOSH (37150035)

DUNABOINA LOHIT MUKESH (37150057)



**DEPARTMENT OF MECHANICAL ENGINEERING
SCHOOL OF MECHANICAL ENGINEERING**

SATHYABAMA

INSTITUTE OF SCIENCE AND TECHNOLOGY

(DEEMED TO BE UNIVERSITY) JEPPIAAR NAGAR, RAJIV GANDHI SALAI,

CHENNAI - 600 119

Accredited with Grade "A" by NAAC

MARCH - 2021

DECLARATION

We Bogam Santosh (37150035) and Dunaboina Lohit Mukesh (37150057) hereby declare that the Project Report entitled **“METAL CORROSION RATE PREDICTION OF COPPER IN BIODIESEL BLENDS USING MACHINE LEARNING MODELS”** done by us under the guidance of **Dr. G.SENTHILKUMAR M.E. Ph.D.** at **SATHYABAMA Institute Of Science and Technology**, Chennai is submitted in partial fulfillment of the requirements for the award of Bachelor of Engineering degree in Mechanical engineering

1.

2.

DATE:

PLACE:

SIGNATURE OF THE CANDIDATE



SATHYABAMA

INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)

Accredited with “A” grade by NAAC

Jeppiaar Nagar, Rajiv Gandhi Salai, Chennai – 600 119

www.sathyabama.ac.in



DEPARTMENT OF MECHANICAL ENGINEERING

BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of BOGAM SANTOSH (37150035), DUNABOINA LOHIT MUKESH (37150057) who carried out the project entitled “**COPPER CORROSION RATE PREDICTION IN BIODIESEL BLENDS USING MACHINE LEARNING MODELS**” under our supervision from November 2020 to March 2021.

Internal Guide

Dr. G.SENTHILKUMAR M.E., Ph.D.

External Guide

Dr. DAWN SS M.Tech., Ph.D.

Head of the Department

Dr.G.ARUN KUMAR M.E.,Ph.D.

Submitted for Viva voce Examination held on _____

Internal Examiner

External Examiner

ACKNOWLEDGEMENT

I am pleased to acknowledge my sincere thanks to Board of Management of SATHYABAMA for their kind encouragement in doing this project and for completing it successfully. I am grateful to them.

I convey my thanks to **Dr.S.PRAKASH, M.E.Ph.D**, Dean, School of Mechanical engineering and **Dr.G.ARUNKUMAR,M.E.Ph.D**, Head of the Department, Dept. of Mechanical engineering for providing me necessary support and details at the right time during the progressive reviews.

I would like to express my sincere and deep sense of gratitude to my Project Guide **Dr.G.SENTHILKUMAR, M.E.Ph.D.**, for his valuable guidance, suggestions and constant encouragement paved way for the successful completion of my project work.

I wish to express my thanks to all Teaching and Non-teaching staff members of the Department of Mechanical engineering who were helpful in many ways for the completion of the project.

ABSTRACT

This study is intended to examine the corrosion rate of diesel engines when, they undergo combustion with biodiesel. As biodiesel is the most alternative form of fuel accepted widely, when they undergo combustion, the major factor affecting the engine performance is corrosion. To understand the corrosion of metals in biodiesel, an experiment is carried out to find out the effect of corrosion on metals in biodiesel. Additionally, experimental data which is available across literature articles is collected and analysed using data visualisation software. Based on the analysis, the prediction of corrosion rate of metals in biodiesel is done using machine learning model. Since copper is more adherent to corrosion; we have chosen to study the corrosion trends in copper metal. By using TABLEAU software, the literature data is sorted and visualized to understand trends in the data of biodiesel types and corrosion rates in copper. To estimate the corrosion rate on metal based on data obtained, machine learning tool is utilized, for example R-STUDIO. An algorithm is feed into the machine along with the literature data to train the machine with the data. Based on the analysis, system provides the corrosion rates of copper. For experimental proof, an experiment is performed by using an instrument called water bath, and images are taken before and after the corrosion of metal with the help of optical microscope. And, for further studies on reducing copper roughness analysis AFM results are collected.

CONTENTS

	CHAPTERTITLE	Page no
	ABSTRACT	v
LIST OF FIGURES	ix	
	LIST OF TABLES	x
1	INTRODUCTION	
1.1	HISTORY AND BACKGROUND OF BIODIESEL	1
1.2	TRANSESTERIFICATION TO BIODIESEL	2
	1.2.1 Trans-esterification Process	2
	1.3 PROPERTIES OF BIODIESEL	5
	1.3.1 Density of biodiesel	5
	1.3.2 Viscosity of biodiesel	5
	1.3.3 Thermal conductivity of biodiesel	6
	1.3.4 Flash and Fire point of biodiesel	6
	1.3.5 Cloud point and Pour point	6
1.4	HISTORY AND BACKGROUND OF COPPER METALS	7
	1.4.1 Copper Alloys	8
	1.4.2 Copper Applications	9

	1.4.3 Copper Corrosion Resistance	10
	1.4.4 Pitting Corrosion	10
	1.4.5 Crevice Corrosion	11
1.5	BACKGROUND OF MACHINE LEARNING	11
1.6	REGRESSION ANALYSIS IN	
	MACHINE LEARNING	12
	1.6.1 Types of Regression	13
	1.6.1.1 Linear Regression	13
	1.6.1.2 Logistic Regression	14
	1.6.1.3 Polynomial Regression	16
	1.6.1.4 Support Vector Regression	16
	1.6.1.5 Decision Tree Regression	18
	1.6.1.6 Random Forest Regression	19
	1.6.1.7 Ridge Regression	19
	1.6.1.8 Lasso Regression	20
	1.7 PRESENT STUDY	20
2	LITERATURE SURVEY	22
2.1	INTRODUCTION	22
3	AIM AND SCOPE OF THE PROJECT	27
3.1	AIM OF THE PROJECT	27
3.2	SCOPE OF TH PROJECT	27

4	MATERIALS AND METHOD	28
4.1	METHODOLGY OF RESEARH	28
4.2	MATERIALS REQUIRED	28
4.3	METHODS INVOLVED	
	4.3.1 Cutting	28
4.3.1.1	<i>Electric Discharge</i>	
	<i>Machining (EDM)</i>	28
	4.3.2 Polishing and Cleaning	32
	4.3.3 Optical Microscope	33
	4.3.4 Water Bath	35
	4.3.5 Atomic Force Microscope	37
	4.3.6 Data analysis using	
	Machine learning model	39
5	RESULTS AND DISCUSSION	41
5.1	DATA VISUALIZATION	41
5.2	CORROSION RATE PREDICTION	
	USING MACHINE LEARNING TOOL	41
5.3	OPTICAL MICROSCOPIC RESULTS	43
5.4	SURFACE ROUGHNESS	
	RESULTS USING AFM	45
6	SUMMARY AND CONCLUSION	47
	REFERENCES	48

APENDIX52

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE NO.
1.1	Schematic Diagram of Trans-esterification Process of Biodiesel	5
1.2	Linear Regression model graph	14
1.3	Logistic Regression model graph	15
1.4	Polynomial Regression model graph	16
1.5	Support Vector Regression model graph	17
1.6	Decision Tree Regression model graph	19
1.7	Random Forest Regression model graph	20
4.1	Schematic Diagram of Electric Discharge Machining (EDM)	29
4.2	Schematic Diagram of Wire Cut Electric Discharge Machining (EDM)	31
4.3	Optical Microscope Apparatus	34
4.4	Water Bath Apparatus	36
4.5	Atomic Force Microscope (AFM)	38
5.1	Data visualization of corrosion data of copper using Tableau software	41
5.2	Image of RStudio (machine learning tool)	42

5.3	optical microscopic image of copper strip after etching with hydrofluoric acid about 5 minutes	43
5.4	Optical microscopic image of copper metal strip immersed in biodiesel blend up to 3 hours of duration	44
5.5	Optical microscopic image of copper metal strip immersed in biodiesel blend up to 6 hours of duration	45
5.6	AFM 2D and 3D Images of Copper Metal Strip	45

LIST OF TABLES

TABLE NO.	TITLE	PAGE NO.
1.1	Specific gravity of Glycerol, biodiesel, methanol reactants in biodiesel transesterification processing	3
5.1	Corrosion rate (in mpy) of Copper metal in various Biodiesels	42

CHAPTER 1

INTRODUCTION

1.1 HISTORY AND BACKGROUND OF BIODIESEL FUEL

Utilizing vegetable oil for fuel has been around as long as the diesel motor. Rudolph Diesel, the designer of the motor that bears his name, tried different things with powers going from powdered coal to nut oil. In the mid twentieth century, nonetheless, diesel motors were adjusted to consume petrol distillate, which was modest and abundant. In the late twentieth century, nonetheless, the expense of oil, distillate rose, and by the last part of the 1970s, there was restored interest in biodiesel. Business creation of biodiesel in the United States started during the 1990s. Biodiesel is an alternate source of fuel which was developed in year 1937's by G. Chavanne from University of Brussels which is located in Belgium from which he had achieved a patent for a paper "Procedure for the transformation of vegetable oils for their uses as fuel", Rudolph Diesel was an inventor of diesel engine who introduced a compression engine to the world in late 1890's. biodiesel fuel is specifically characterized as Mono alkyl esters which are extracted from waste cooking oils or animal fats. The best competitor for compression-ignition engines which are combusted using diesel is biodiesel. Biodiesel gets combusted like gasoline as it also evolves regular emission pollutants. Biodiesel also manifests a magnificent amount for compression-ignition engines. Most of energy request is satisfied by ordinary fuel sources like coal, petrol, and flammable gas. Oil based fills are restricted stores gathered in specific locales of the world. These sources are very nearly arriving at their pinnacle creation. The shortage of realized petrol stores will make environmentally friendly power sources more appealing. The cycle for making fuel from biomass feedstock utilized during the 1800s is fundamentally a similar one utilized today. The historical backdrop of biodiesel is more political and monetary than mechanical. The mid twentieth century saw the presentation of fuel-controlled autos. Oil organizations were obliged to refine such a lot of raw petroleum to supply gas that they were left with an excess of distillate, which is a great fuel for diesel motors and significantly less costly than vegetable oils. On the other hand, asset consumption

has consistently been a worry concerning petrol, and ranchers have consistently looked for new business sectors for their items. Therefore, work has proceeded on the utilization of vegetable oils as fuel.

1.2 TRANSESTERIFICATION TO BIODIESEL

The transesterification of vegetable oils, animal fats, or waste cooking oils is the cycle behind ordinary biodiesel. In the transesterification interaction, a glyceride responds with a liquor (regularly methanol or ethanol) within the sight of an impetus framing unsaturated fat alkyl esters and liquor. The transesterification interaction is a reversible response and done by blending the reactants – unsaturated fats, liquor, and impetus. A strong base or a strong acid can be used as a catalyst. At the modern scale, for the most part sodium or potassium methanolate is utilized. The final results of the transesterification interaction are crude biodiesel and crude glycerol. Transesterification of vegetable oils to biodiesel with methanol can be done utilizing both homogeneous (corrosive or base) and heterogeneous (corrosive, base and enzymatic) impetuses. In a further cycle, these crude items go through a cleaning step. On account of utilizing methanol as liquor FAME (unsaturated fat methyl ester) biodiesel is created. The sanitized glycerol can be utilized in the food and restorative businesses, just as in the oleochemical business. The glycerol can likewise be utilized as a substrate for anaerobic assimilation. The pre-owned cooking oil is gathered from eateries. The esterification response utilized sulfuric corrosive (HPLC grade, 99.8%, Pharmaco-AAPER) as the impetus and methanol (HPLC grade, 99.9%, Pharmaco-AAPER) as the reactant.

1.2.1 Trans-esterification Process

The first method of manufacturing biodiesel is done by solvent extraction. During the time spent making biodiesel through transesterification, we noticed that biodiesel and glycerol are the items, with some water arrangement and undesirable potential cleanser development. Along these lines, the items are fluid, however they are likewise immiscible (don't break up in one another) and have contrasts in explicit gravity. The particular gravity of the items.

Table 1.1: Specific gravity of Glycerol, biodiesel, methanol reactants in biodiesel transesterification processing.

Materials	Specific gravity(g/cm ³)
Biodiesel	0.88
Methanol	0.79
Glycerol pure	1.29
Glycerol crude	1.05

Biodiesel is manufactured by having two main default materials Animal fat and plant fat which are oils forming triglycerides, though they are esters formed by reacting with three free fatty acids and a by-product of alcohol, glycerol. in this process, methanol or ethanol alcohols are added to form Deprotonation as a strong base according to this manufacturing process there are no other inputs to be used other than triglyceride and alcohol. Under steady-state conditions, the manufacturing process is only continued slowly but, with the help of using catalysts the process is speeding up. The most common catalyst used in transesterification is sodium hydroxide, potassium hydroxide, and sodium methoxide. Deciphering the cycle, we should specify that the liquor, the catalyst, and the oil are blended in a reactor and mixed for one hour at 60 ° C approx. More modest limit plants regularly utilize non-consistent reactors (group reactors); yet most enormous plant reactors are utilizing persistent and complete blending. The response by and large incorporates two stages: during the first, it is added 80% liquor and the catalyst in the oil. At that point, the reactor yield stream is directed to the evacuation of glycerin, prior to entering the leftover 20% of liquor. Following the reaction, the glycerol is isolated from the methyl esters. Due to the weak solubility of the glycerol esters, their division can be achieved simply and swiftly utilizing a precipitating tank or simple centrifugation. The outlay of methanol that becomes not reacted, acts as a solvent by keeping the separation of glycerol and

methyl. However, excess methanol is normally not separated from the reaction stream till an entire detachment of glycerol and methyl esters has been accomplished because of the primary reaction of transesterification of results. Often, after the fulfillment of the transesterification, H₂O is added to the reaction compound to promote the glycerol separation. It is conceivable to make oil react with methanol in the deficiency of a catalyst to depreciate the requirement for cleaning with water. In this case, still, high temperatures are needed and higher excess quantities of methanol. Additionally, there has been trouble in replication kinetics of the reaction, which has been associated with many catalysts on the outside of the reactor. Further, it has been observed that by high temperature and pressure 90bar, 240°C the transesterification of fatty acids can get a place without previous extraction or exchange of free fatty acids. Although, utmost biodiesel plants for economic and surety reasons still favor to explore at low temperatures and atmospheric pressure holding more extensive reaction circumstances. The blend of the methyl ester is counterbalanced and then distributed from contaminants utilizing vacuum distillation or distillation, before rinsing with water. During the neutralization of biodiesel, an acid is combined, which neutralizes the deposits of the necessary catalyst and separates any soap deposit that can be composed during the reaction. The soap acts with the acid-forming hydrophilic salts and fatty acids. The salts are eliminated during washing, while the free unsaturated fats stay in the biodiesel. The washing water is applied to eliminate any excess catalyst, detergent, salt, methanol, and free glycerol from biodiesel. Balance before washing lessens the measure of water required and limits the inclination to deliver emulsions. After washing, the water left in the biodiesel is refined off under a vacuum.

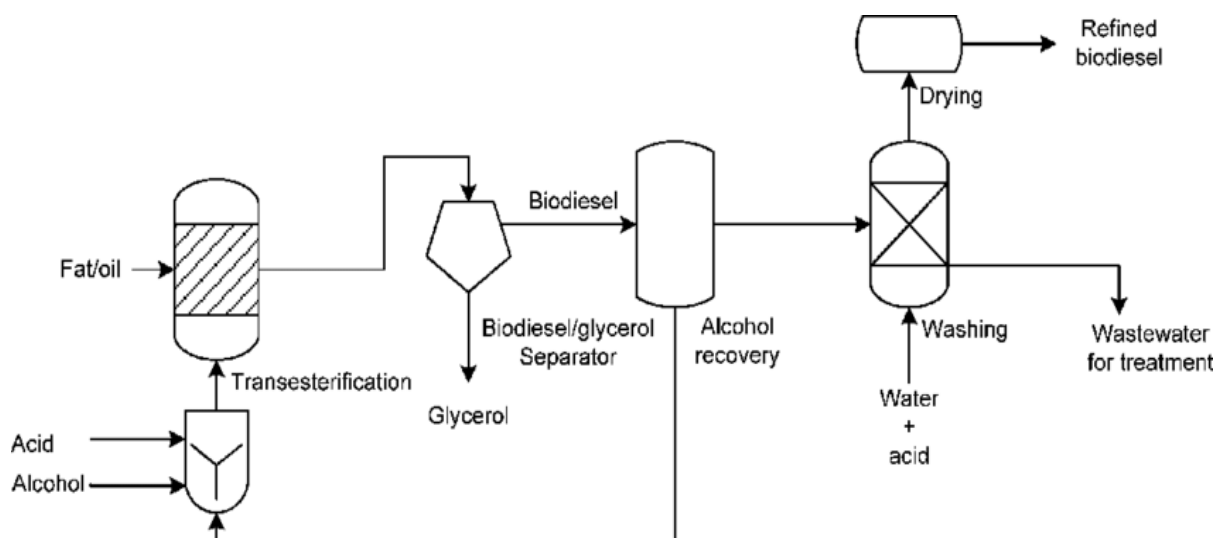


Fig 1.1: Schematic Diagram of Transesterification Process of Biodiesel

1.3 PROPERTIES OF BIODIESEL

The excessive cost of various biodiesels and the requirement for a large number of their crude fixings as food materials are the primary limitations to be defeated when looking for the best-expected elective energizes to petrol-diesel. Aside from that, a few properties like high density, viscosity, and acid incentive alongside low cloud and pour points block their utilization in pressure start (CI) motors as these properties can make genuine harm the pieces of the motor and decrease motor life. In this investigation, biodiesel was created from the oil of unused green growth by a two-attempt acid esterification accompanied by a transesterification' system

1.3.1 Density of biodiesel

Density is a significant biodiesel boundary, with control on fuel quality. Anticipating density is of great consistency for a right definition of a satisfactory mix of crude materials that upgrade the expense of biodiesel fuel formulation while permitting the delivered fuel to satisfy the necessary quality guidelines. The density of a biodiesel is $\sim 0.88 \text{ g/cm}^3$

1.3.2 Viscosity of biodiesel

Fluid viscosity plays a crucial role in fluid properties, according to fluid parameters behavior of fluid and motion in solid boundaries define the viscosity of a fluid.

The resistance force began by the boundary of the fluid body tends to progressively deform by applying shear and tensile stress on the fluid. This effect is caused by the intermolecular frictional force exerted layer by layer as we know, biodiesel is a non-Newtonian fluid.

1.3.3 Thermal conductivity of biodiesel

Thermal conductivity is defined as a heat transfer coefficient of the material which is used to identify the heat transfer rate but, thermal conductivity also helps to define heat transfer rate phenomena during the process of combustion of biodiesel fuel. The methyl ester is the component of biodiesel the thermal conductivity is measured to a wide range of temperature 27 to 327 °C and with a basic pressure gradient of 0.1-60 MPA

1.3.4 Flash and Fire point of biodiesel

The Flashpoint of biodiesel is defined as the stage at which it tends to auto ignition at a certain temperature that temperature leads to instantaneous ignition. The fire point of biodiesel is to justify that at the lowest temperature the vapor molecules keep on burning after the completion of combustion. The tendency of fire point is drastically more than the flashpoint because in flashpoint process a greater number of molecules are not produced when compared to fire point so it is not sustained for combustion but, in a practical way both fire point and flash point are not generated in between combustion process due to the combustion temperature is very higher than that so either this both points does not affect the combustion process. Fire and flash point are only used to know the fuel energy level.

1.3.5 Cloud point and Pour point

There are few temperatures in which a fluid changes its state from solid to liquid and liquid to gas vice versa but when it comes to biodiesel at a certain temperature it changes its phase from liquid to solid with a transparent solution that point is said to be dew point or cloud point it is also called as waxing of biodiesel fuel. It can be reduced by increasing the viscosity of the fuel if not this type of solidification tends to clog the fuel channels. Clogging can occur at below zero-degree temperature. The

pour point of a fluid is the temperature beneath which the fluid loses its stream qualities. It is characterized as the base temperature in which the oil can pour down from a container.

1.4 HISTORY AND BACKGROUND OF COPPER METALS

Copper has a face-centered cubic crystal structure. It is yellowish red in natural representation and when polished produces a shiny metallic luster. Copper appears normally as historical metallic copper and was identified as the official most seasoned human progress on record. The traditional backdrop of copper use dates to 9000 BC in the Middle East a copper jewelry was discovered in northern Iraq that dates to 8700 BC. Proof suggests that gold and emigrating iron, however not purified iron were the alone metals appropriated by people before copper. The ancient backdrop of copper metallurgy is thought to follow this arrangement: First, chilly manipulation of local copper, at that point toughening, refining, and, at last, lost-wax pitching. In southeastern Anatolia, each one of the four of these procedures confers up great much all the while toward the start of the 7500 BC. Copper is a synthetic component with the image Cu (from Latin: cuprum) and nuclear number 29. It is a delicate, moldable, and malleable metal with extremely high warm and electrical conductivity. A newly uncovered surface of unadulterated copper has a pinkish-orange tone. Copper is utilized as a conduit of warmth and power, as a structure material, and as a constituent of different metal composites, like authentic silver utilized in adornments, cupronickel used to make marine equipment and coins, and constantan utilized in strain checks and thermocouples for temperature estimation. Copper is one of only a handful few metals that can happen in nature in a straightforwardly usable metallic structure local metal. This prompted early human use in a few locales, from 8000 BC. Millennia later, it was the main metal to be purified from sulfide minerals, 5000 BC; the initial metal to be projected into a shape in a form, 4000 BC; and the primary metal to be deliberately alloyed with another metal, tin, to make bronze, 3500 BC. Copper, silver, and gold are in bunch 11 of the periodic table; certain three elements have individual s-orbital electron on tip of a filled d-electron shell and are characterized by high malleability and electrical and hot conductivity. The filled d-

shells in these elements provide limited to interatomic correlations, which are conquered by the s-electrons within metallic bonds. Not at all like elements within entire d-shells, metallic bonds in copper are ineffectual with notices to a covalent character and are enough strength less. This perception interprets the low hardness and high susceptibility of single valuable masses of copper. At the discernible scale, the experience of augmented disfigurements with the precious stone grid, for example, grain limits, ruins the stream of the material under applied pressure, along these lines expanding its hardness. Consequently, copper is typically provided in a fine-grained polycrystalline structure, which has more noteworthy strength than monocrystalline structures. Copper does not react with water, but it does slowly react with atmospheric oxygen to form a layer of brown-black copper oxide which, unlike the rust that forms on iron in moist air, protects the underlying metal from further corrosion passivation. A green layer of verdigris copper carbonate can often be seen on old copper structures, such as the roofing of many older buildings and the Statue of Liberty. Copper tarnishes when exposed to some sulfur compounds, with which it reacts to form various copper sulfides. Most copper is mined or classified as copper sulfides from enormous open-pit mines in porphyry copper reserves that contain 0.4 to 1.0% copper. Locales incorporate Chuquicamata, in Chile, Bingham Canyon Mine, in Utah, United States, and El Chino Mine, in New Mexico, United States. As per the British Geological Survey, in 2005, Chile was the top maker of copper within any event 33% of the world offer followed by the United States, Indonesia, and Peru.

1.4.1 Copper Alloys

Various copper combinations have been formed, numerous with significant employments. Metal is a compound of copper and zinc. Bronze ordinarily alludes to copper-tin amalgams, yet can allude to any compound of copper, for example, aluminum bronze. Copper is perhaps the main constituent of silver and karat gold fastens utilized in the gems business, altering the tone, hardness, and softening mark of the subsequent compounds. Some without lead binds comprise of tin alloyed with a little extent of copper and different metals. The compound of copper and nickel, called cupronickel, is utilized in low-division coins, regularly for external cladding. The US

five-penny coin (as of now called a nickel) comprises 75% copper and 25% nickel in a homogeneous organization. Before the presentation of cupronickel, which was broadly received by nations in the last 50% of the twentieth century, combinations of copper and silver were additionally utilized, with the United States utilizing an amalgam of 90% silver and 10% copper until 1965 when flowing silver was eliminated from all coins except for the Half dollar - these were spoiled to a composite of 40% silver and 60% copper somewhere in the range of 1965 and 1970. The compound of 90% copper and 10% nickel, exceptional for its protection from erosion, is utilized for different items presented to seawater however; it is powerless against the sulfides here and there found in contaminated harbors and estuaries. Composites of copper with aluminum (about 7%) have a brilliant tone and are utilized in beautifications. Shaku do is a Japanese enlivening amalgam of copper-containing a low level of gold, regularly 4–10% that can be patinated to a dim blue or dark tone. Brasses accommodate Zinc as the main alloying component. Additional alloying components may moreover be possible to consult worthwhile properties. These components organize Iron, aluminum, Nickel, and Silicon. Brasses are most ordinarily represented by their free-machining grades by which machining policies are set for any remaining metals. Brasses can likewise have high consumption opposition and high elasticity. The term bronze initially depicted alloys with Tin as the just or chief alloying component. Cutting edge bronze will in general be copper amalgams in which the major alloying component isn't Nickel or Zinc. Bronzes can be additionally separated into four families for both created and cast alloys.

1.4.2 Copper Applications

Copper and copper composite can be utilized in a phenomenal scope of utilizations. A portion of these applications incorporate

- Power transmission lines
- Architectural applications
- Cooking utensils
- Spark plugs
- Electrical wiring, bus bars and cables

- High conductivity wires
- Electrodes
- Heat exchangers
- Refrigeration tubing
- Plumbing
- Water-cooled copper crucibles

1.4.3 Copper Corrosion Resistance

All copper composites oppose consumption by new water and steam. In generally rustic, marine and mechanical climates copper combinations additionally impervious to erosion. Copper is impervious to saline arrangements, soils, non-oxidizing minerals, natural acids and harsh arrangements. Wet smelling salts, incandescent lamp, sulfides, arrangements containing alkali particles and oxidizing acids, as nitric corrosive, will assault Copper. Copper combinations additionally have helpless protection from inorganic acids. The corrosion opposition of copper composites comes from the development of follower films on the material surface. These movies are generally impenetrable to erosion thusly shielding the base metal from additional assault. Copper Nickel alloys, aluminum Brass, and aluminum exhibit better obstruction than saltwater consumption. Surface Oxidation of Copper Most copper combinations will build up a blue-green coating when presented to the components outside. Run of the mill of this is the shade of the copper Statue of Liberty in New York. Some copper alloys will be wrapped after delayed openness to the components and take on a natural stained to dark tone.

1.4.4 Pitting Corrosion

Pitting is a confined type of consumption that can happen because of openness to explicit conditions, most outstandingly those containing chlorides. In most primary applications, the degree of pitting is probably going to be shallow and the decrease in the segment of a segment is unimportant. Be that as it may, consumption items can stain building highlights. A less open-minded perspective on pitting ought to be received for administrations like pipes, funneling, and regulation constructions.

1.4.5 Crevice Corrosion

Crevice corrosion is a restricted type of erosion happening in kept spaces, to which the entrance of the working liquid from the climate has restricted. The development of a differential air circulation cell prompts consumption inside the hole. Instances of the fissure are holes and contact territories between parts, under gaskets or seals, inside breaks and creases, spaces loaded up with stores, and following waste deposits is affected by the fissure type (metal to metal, metal to nonmetal), cleft math (size, surface completion), and metallurgical and natural elements. The powerlessness to fissure consumption can be assessed with ASTM standard strategies. A basic whole erosion temperature is usually used to rank a material's protection from whole consumption.

1.5 BACKGROUND OF MACHINE LEARNING

Machine learning is a part of artificial intelligence (AI) that enables users to develop applications that can learn information or data given by the user and develop the solution without the help of programming. Currently Machine learning is one of the emerging trends in the field of data science. Data sciences deal with the study of data and analysis of the data with the help of algorithms given to the machine by the user. Machine Learning includes PCs finding how they can perform errands without being unequivocally modified to do as such. It includes PCs gaining from information gave with the goal that they complete certain errands. For straightforward errands relegated to PCs, it is conceivable to program calculations advising the machine how to execute all means needed to tackle the current issue; on the PC's part, no learning is required. For further developed undertakings, it tends to be trying for a human to physically make the required calculations. In reality, it can end up being more viable to assist the machine with building up its own calculation, as opposed to having human software engineers determine each required step.

The term Machine Learning was given in 1959 by Arthur Samuel, an American IBMer and pioneer in the field of PC gaming and artificial intelligence. An agent book of the AI research during the 1960s was the Nilsson's book on Learning Machines, managing AI for design arrangement. Interest identified with design acknowledgment

proceeded into the 1970s, as depicted by Duda and Hart in 1973. In 1981 a report was given on utilizing encouraging systems so a neural organization figures out how to perceive 40 characters (26 letters, 10 digits, and 4 exceptional images) from a work station.

Tom M. Mitchell gave a generally cited, more plossor meaning of the calculations concentrated in the AI field: "A PC program is said to gain as a matter of fact E as for some class of errands T and execution measure P if its exhibition at assignments in T, as estimated by P, improves with experience E." This meaning of the undertakings where in AI is concerned offers an on a very basic level operational definition instead of characterizing the field in intellectual terms. This follows Alan Turing's proposition in his paper "Figuring Machinery and Intelligence", in which the inquiry "Can machines believe?" is supplanted with the inquiry "Can machines do what we (as speculation elements) can do?"

Cutting ridge Machine Learning has two goals, one is to order information dependent on models which have been created, and the other reason for existing is to make expectations for future results dependent on these models. A speculative calculation explicit to arranging information may utilize PC vision of moles combined with administered learning to prepare it to characterize the harmful moles. Whereas, Machine Learning calculation for stock exchanging may advise the dealer regarding future likely expectations.

1.6 REGRESSION ANALYSIS IN MACHINE LEARNING

Regression analysis is a measurable strategy to display the connection between a needy (target) and autonomous (indicator) factors with at least one free factor. All the more explicitly, Regression investigation causes us to see how the estimation of the variable is changing, comparing to a free factor when other autonomous factors are held fixed. It predicts persistent/genuine qualities like temperature, age, salary, price, and so on. As referenced above, Regression investigation helps in the forecast of a ceaseless variable. There are different situations in reality where we need some future forecasts like climate condition, sales expectation, marketing trends, and so forth, for such case we need some innovation which can make expectations all the

more precisely. So, for such case we need Regression examination which is a measurable strategy and utilized in machine learning and data science. The following are some different explanations behind utilizing Regression analysis:

Regression assesses the connection between the objective and the independent variable.

It is utilized to discover the patterns in data.

It assists with foreseeing real/continuous values.

By playing out the Regression, we can unquestionably decide the main factor, the most un-significant factor, and how each factor is affecting the other factors.

1.6.1 Types of Regression

There are different sorts of Regressions which are utilized in data science and Machine Learning. Each type has its own significance on various situations, however at the core; all the Regression methods analyze the impact of the independent variable on dependent variables. Here we are examining some important types of regression which are given below:

Linear Regression

Logistic Regression

Polynomial Regression

Support Vector Regression

Decision Tree Regression

Random Forest Regression

Ridge Regression

Lasso Regression

1.6.1.1 Linear Regression

Linear regression is a factual regression technique which is utilized for prediction analysis. It is one of the basic and simple calculations which deals with regression and shows the connection between the continuous variables. It is utilized for solving of the regression tasks in machine learning. Linear Regression shows the direct connection between the independent variable (X-axis) and the dependent variable (Y-axis), consequently called Linear Regression. On the off chance that there is just one input variable (x), such linear regression is called simple linear regression.

Furthermore, in the event that there is more than one input variable, such regression is called multiple linear regressions.

The connection between variables in the linear regression model can be clarified utilizing the below graph. Here we are predicting the compensation of a worker based on the bases of the year of experience.

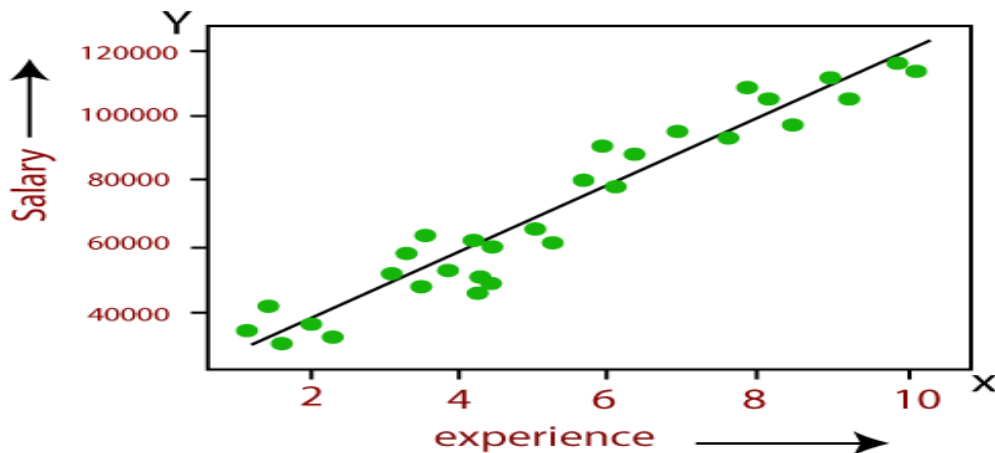


Fig 1.2: Linear Regression model graph

Below is the mathematical equation for Linear regression:

- $Y = aX + b$

Here, Y = dependent variables (target variables),
 X = Independent variables (predictor variables),
 a and b are the linear coefficients

Some popular applications of linear regression are:

- o Analyzing trends and sales estimates
- o Salary forecasting
- o Real estate prediction

1.6.1.2 Logistic Regression

Logistic Regression is another regulated learning algorithm which is utilized to tackle the classification problems. In classification problems, we have dependent variables in a binary or discrete configuration like 0 or 1. Logistic Regression algorithm works with the absolute variable like 0 or 1, Yes or No, True or False, Spam or not spam,

and etc. It is a predictive analysis algorithm which chips away at the idea of probability. Logistic Regression is a sort of Regression, yet it is not the same as the linear regression algorithm in the term how they are utilized.

Logistic Regression utilizes sigmoid function or logistic function which is a complex cost function. This sigmoid function is utilized to demonstrate the information in logistic regression. The function can be addressed as:

$$f(x) = \frac{1}{1+e^{-x}}$$

- o $f(x)$ = Output between the 0 and 1 value.
- o x = input to the function
- o e = base of natural logarithm.

When we provide the input values (data) to the function, it gives the S-curve as follows:

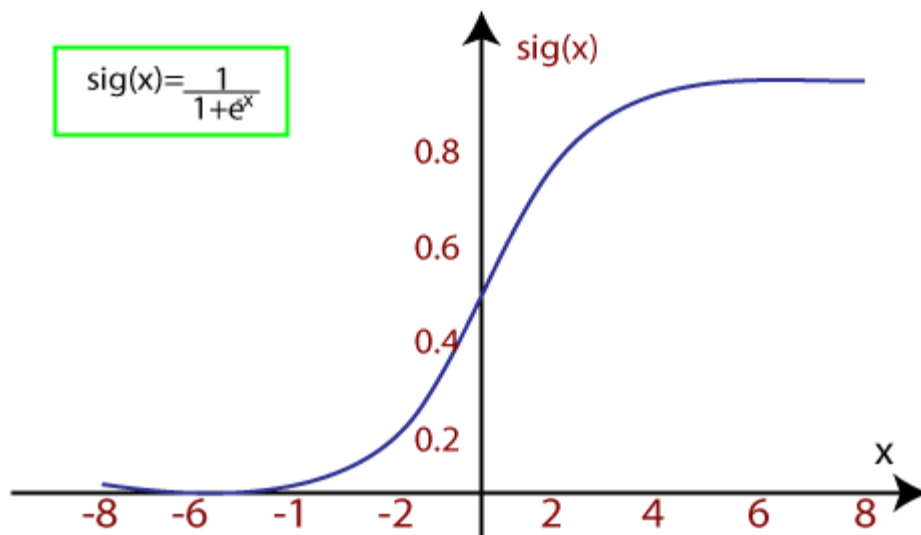


Fig 1.3: Logistic Regression model graph

It utilizes the idea of threshold levels, values over the threshold level are rounded up to 1, and values beneath the threshold level are rounded up to 0.

There are three types of logistic regression:

- o **Binary (0/1, pass/fail)**

- o **Multi (cats, dogs, lions)**
- o **Ordinal (low, medium, high)**

1.6.1.3 Polynomial Regression

Polynomial Regression is a sort of Regression which models the non-linear dataset utilizing a linear model. It is like multiple linear regression, yet it fits a non-linear curve between the estimation of x and corresponding conditional values of y . Assume there is a dataset which comprises of data points which are available in a non-linear style, so for such case, linear regression won't best fit to those data points. To cover such data points, we need Polynomial regression.

In Polynomial regression, the original features are transformed into polynomial features of given degree and then modeled using a linear model. Which implies the data points are best fitted utilizing a polynomial line.

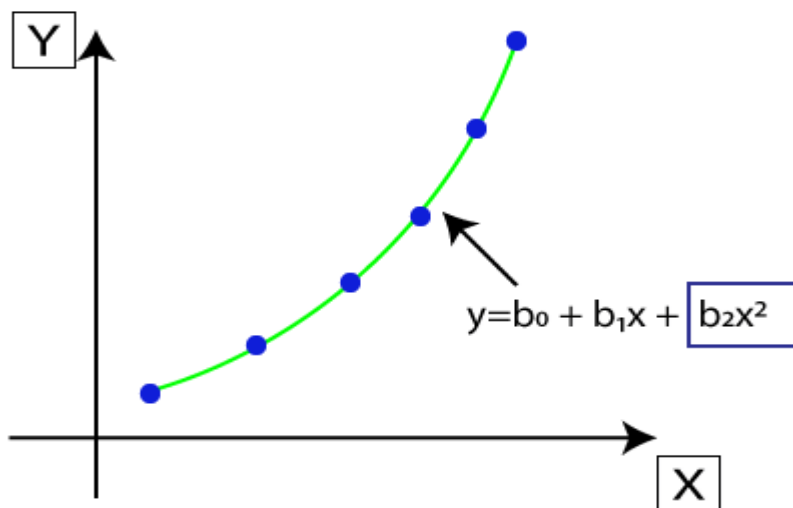


Fig 1.4: Polynomial Regression model graph

- o The equation for polynomial regression additionally got from linear regression equation that implies Linear Regression equation $Y = b_0 + b_1x$, is changed into Polynomial regression condition $Y = b_0 + b_1x + b_2x^2 + b_3x^3 + \dots + b_nx^n$.

Here Y is the anticipated/target yield, b_0 , b_1 , b_n are the Regression coefficients. x is our independent/input variable.

1.6.1.4 Support Vector Regression

Support Vector Machine is a directed learning algorithm which can be utilized for regression just as clarification issues. So, in the event that we use it for regression issues, it is named as Support Vector Regression. Support Vector Regression is a regression algorithm which works for continuous variables. The following are a few keywords which are utilized in Support Vector Regression:

Kernel: It is a function used to plan lower-dimensional information into higher dimensional information.

Hyperplane: In regular SVM, it is a division line between two classes, yet in SVR, it is a line which assists with anticipating the continuous variables and covers the majority of the data points.

Boundary line: Boundary lines are the two lines separated from hyperplane, which makes a ridge for data points.

Support vectors: Support vectors are the data points which are closest to the hyperplane and opposite class.

In SVR, we generally attempt to decide a hyperplane with a maximum margin, so that number of data points is canvassed in that margin. The primary objective of SVR is to consider the most extreme data points inside the limit lines and the hyperplane (best-fit line) should contain a maximum number of data points. The graph is given below:

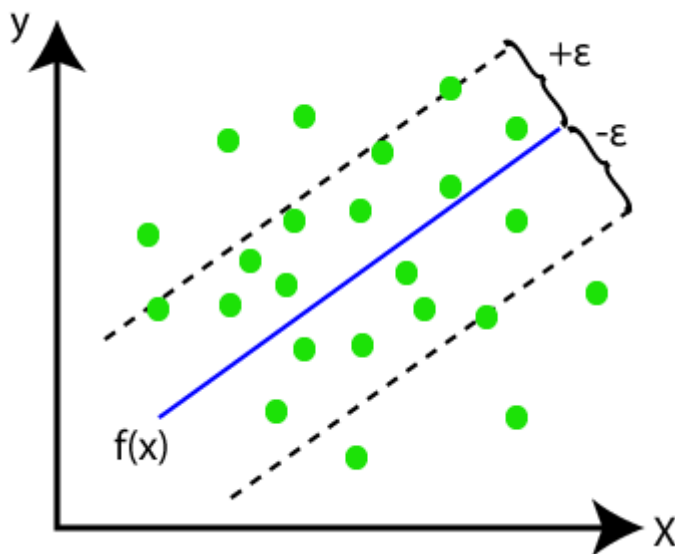


Fig 1.5: Support Vector Regression model graph

Here, the blue line is called hyperplane, and the other two lines are known as boundary lines.

1.6.1.5 Decision Tree Regression

Decision Tree is an administered learning algorithm which can be utilized for tackling both classification and regression issues. It can take care of problems for categorical and numerical data. Decision Tree Regression constructs a tree-like design in which each interior node addresses the "test" for a plassorty, each branch address the after effect of the test, and each leaf node addresses an official conclusion or result. A decision tree is developed beginning from the root node/parent node (dataset), what parts into left and right child nodes (subsets of dataset). These child nodes are additionally isolated into their children node, and themselves become the parent node of those nodes.

Consider the graph below:

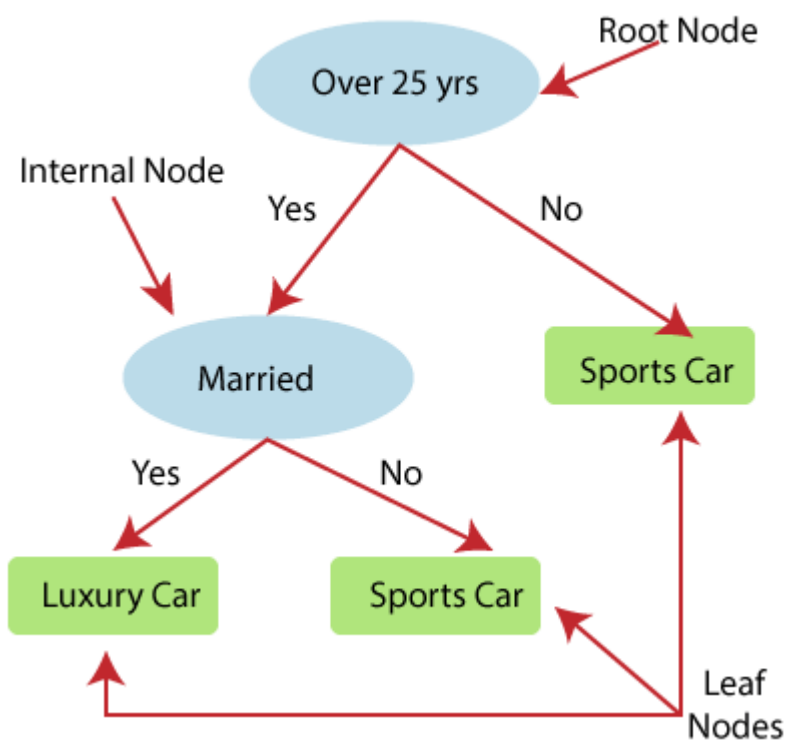


Fig 1.6: Decision Tree Regression model graph

Above picture showing the case of Decision Tree Regression, here, the model is attempting to predict the decision of an individual between Sports vehicles or Luxury vehicle.

1.6.1.6 Random Forest Regression

Random forest is perhaps the most impressive regulated learning algorithm which is fit for performing regression just as classification tasks.

The Random Forest Regression is a gathering learning method which consolidates multiple decision trees and predicts the last yield dependent on the average of each tree yield. The joined decision trees are called as base models, and it very well may be addressed all the more officially as:

$$g(x) = f_0(x) + f_1(x) + f_2(x) + \dots$$

Random forest utilizes Bagging or Bootstrap Aggregation procedure of ensemble learning in which aggregated decision tree runs in parallel and don't cooperate with one another.

With the assistance of Random Forest regression, we can prevent over fitting in the model by creating arbitrary subsets of the dataset.

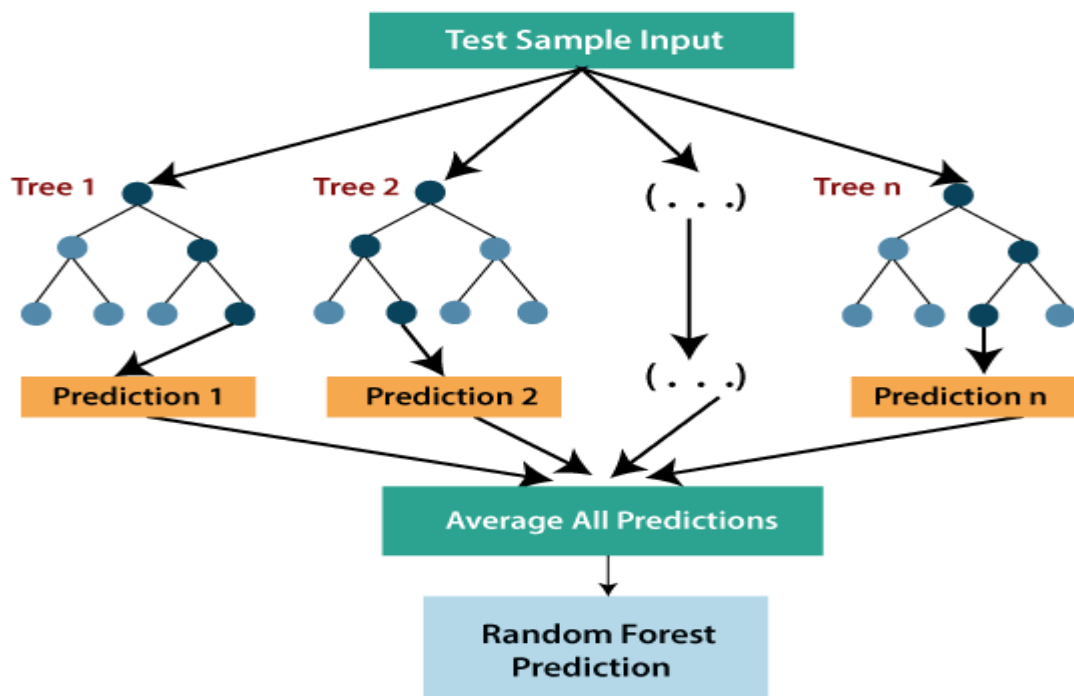


Fig 1.7: Random Forest Regression model graph

1.6.1.7 Ridge Regression:

Ridge Regression is quite possibly the most powerful forms of linear regression in which a limited quantity of bias is presented with the goal that we can improve term predictions. The amount of bias added to the model is known as Ridge Regression penalty. We can register this penalty term by multiplying with the lambda to the squared load of every individual highlights.

The condition for ridge regression will be:

$$L(x, y) = \text{Min}(\sum_{i=1}^n (y_i - w_i x_i)^2 + \lambda \sum_{i=1}^n (w_i)^2)$$

An overall linear or polynomial regression will fizzle if there is high co linearity between the independent variables, so to tackle such issues, ridge regression can be utilized. Ridge regression is a regularization procedure, which is utilized to diminish the intricacy of the model. It is additionally called as L2 regularization. It assists with solving of the issues on the off chance that we have a bigger number of parameters than samples.

1.6.1.8 Lasso Regression

Lasso Regression is another regularization method to lessen the intricacy of the model. It is like the Ridge Regression with the exception of that penalty term contains just the absolute weights rather than a square of weights. Since it takes absolute values, thus, it can shrivel the slope to 0, while ridge regression can just shrink it close to 0. It is additionally called as L1 regularization. The condition for Lasso Regression will be:

$$L(x, y) = \text{Min}(\sum_{i=1}^n (y_i - w_i x_i)^2 + \lambda \sum_{i=1}^n |w_i|)$$

1.7 PRESENT STUDY

In order to predict the corrosion rate of copper at varying temperatures and in biodiesel, literature experimental data of corrosion rate of copper is collected. Copper is generally more prone to corrosion effect. The corrosion is varying with the variation in biodiesel blends. Copper is majorly used for fuel feed pump, fuel pump, and piston bearings where the components are exposed to biodiesel for long hours and at high

temperatures. Biodiesel has bio film and bio fouling effects on copper material when the material is exposed for longer duration. These corrosive effects can cause failure of component which is not ideal for the working of engine. These failures might affect the economy of the corporation which manufactures these engines. The amount at which the corrosion is occurring in copper in various biodiesel blends is to be known so that effective measures are taken against it. The existing experimental data of corrosion rate of copper in various biodiesel blends at a certain temperature and duration of immersion of copper in biodiesel is made use from literature for analysis and prediction purpose. Machine Learning has emerged as a powerful tool for the prediction of corrosion rate of metals exposed to different biodiesel. In this work, a machine learning model has been selected and trained with corrosion data collected from experimental values and scientific publications considering different input variables such as metal blend biodiesel/diesel, the temperature and exposure time. An experiment is also conducted on copper metal by exposing it to biodiesel/diesel blends at varying temperatures and varying exposure time. The samples are taken under optical microscope and images are taken to understand the grain structure of copper before and after corrosion. Additionally, AFM studies are also carried out on corroded copper metal to understand the surface morphology and roughness value of copper after corrosion experiment.

CHAPTER 2

LITERATURE SURVEY

2.1 INTRODUCTION

According to many researches' biodiesel, as an elective fuel is getting more important to replace diesel fuel totally or mostly. To infer by reference of many research articles the corrosion rate of different metal and metal alloys like copper, aluminum, and steel have been collected in a data form. But, corrosion rate for copper is considered to be very high according to this survey and also copper is more ductile to manufacture so to determine then average corrosion rate copper metal is selected as a data sheet. The collected data is analyzed by using the tableau open software system with this analysis of data we have come to interpret the average corrosion rate, average temperature, and average duration. These collected data are analyzed in machine language, to get a hypotheses value of particular biodiesel by using linear regression, lasso, and rigid model codes to measure the corrosion rate value in an analytic way. By this, the analysis of corrosion value of different biodiesel oils has been further completed and experimental values will be taken by conducting a corrosion experiment on copper and these values will be cross-checked to the analyzed value to make an approximate corrosion rate value.

Corrosion mechanism of copper in palm biodiesel

M.A. Fazal et al Biodiesel is an assuring alternative fuel. However, it begins improved corrosion of automotive materials, particularly of copper-based elements. In the modern study, the corrosion mechanism of copper was examined by scanning electron microscope (SEM), energy dispersive spectroscopy (EDS), X-ray diffraction (XRD), and X-ray photoelectron spectroscopy (XPS). Compositional development of biodiesel due to the susceptibility of copper was also examined. Corrosion coating on copper is determined to be constituted of Cu_2O , CuO , $\text{Cu}(\text{OH})_2$, and CuCO_3 . Dissolved O_2 , H_2O , CO_2 , and RCOO organic in biodiesel appear to be the leading agents in improving the corrosiveness of biodiesel. Corrosion of copper in biodiesel

increments with the increment of submersion time. In any case, after a specific drenching period, the arrangement of oxygenated accumulates on biodiesel uncovered copper surface diminishes the corrosion rate.

A comparison of corrosion behavior of copper and its alloy in pongamia pinnata oil at different conditions

Meenakshi H. N. Parameswaran Vegetable oils are securing replacements for Petro diesel as they can be fabricated from various oilseed vegetables that can be farmed anywhere and have great potential contents, showing clean oxidization behavior with zero CO₂ emission and negligible SO₂ composition. The influence of biofuel on the corrosion of numerous industrial alloys is a summons for using biofuel as an automotive fuel. Fuel comes in association with a broad mixture of metallic elements under distinctive temperatures, velocities, and masses thereby generating corrosion during accommodation and flow of fuel. Hence, the present research resembles the corrosion rate of copper and brass in *Pongamia pinnata* oil (O100), 3% NaCl, and oil mixture with NaCl (O99) collected by static immersion test and using the rotating crate. The corrosivity and conductivity of the test mechanisms are assuredly correlated. This study advised that the corrosion rate of copper is higher than brass in *Pongamia pinnata* oil (PO).

Corrosion behaviour of metals in biodiesel from rapeseed oil and methanol

E. Hu et al the impact of biodiesel fuel manufactured from rapeseed oil and methanol on the corrosion characteristics of copper, mild carbon steel, aluminum, and stainless steel were analyzed and correlated with those of industrial diesel fuel. The conclusions show that the metals discussed above decayed with shifting degrees as they remained immersed in the biodiesel fuel at 43 degrees for 1440 hours. Their corrosion rates were 0.02334, 0.01819, 0.00324, and 0.00087 mm/year, sequentially. Though, the corrosion rate of the metals submerged in commercial diesel fuel was moderately lower below the identical corrosion conditions. The consequences of biodiesel on the corrosion of copper and mild carbon steel were more vital than on aluminum and stainless steel. The corrosion manner of metal surfaces in the

biodiesel was chiefly connected to the petrochemical corrosion according to the laboratory results with the help of SEM/EDS, AAS, and XPS.

Mechanical and corrosion properties of brass exposed to waste sunflower oil biodiesel-diesel fuel blends

Olusegun David Samuel Biodiesel has latterly received developing concentration because of several advantages such as greater cetane number and flash point associated with diesel fuel. Yet, corrosion of locomotive parts exhibited to biodiesel or biodiesel-diesel fuel mixtures is still a significant difficulty in biodiesel management. In the current literature, there is still a dearth of methodical studies including corrosion method in light alloy and changes in mechanical and fuel characteristics of engine parts (such as brass) following exposure to biodiesel. Hence, in this study, waste sunflower oil biodiesel (WSOB, B100) was provided and blended with diesel fuel (B0) at the quantity ratios of 10%, 20%, and 40%, which are called B10, B20, and B40, as common. The significant fuel characteristics of the biodiesel-diesel fuel blends were also examined using ASTM test methods. Corrosion properties of brass presented to the biodiesel-diesel fuel blends were defined utilizing a static immersion process at room temperature. Mechanical attributes of brass were studied before and after the corrosion inspection. Ultimately, variations in surface morphologies of the brass coupons remained examined. ***Corrosion rate prediction for metals in biodiesel using artificial neural networks***

C.I. Rocabruno-Valdes et al. The purpose of this research was to improve a direct artificial neural network with the capacity to forecast the corrosion rate of metals in different biodiesel. Preliminary values were acquired by the electrochemical noise technique, EN, as well as, information published in the literature. A backpropagation model was introduced with three layers; metal and biodiesel synthesis, blend biodiesel/diesel, total acid number (TAN), temperature, and exposure time were granted as information variables in the model. Analyzing a Levenberg Marquardt training algorithm, a hyperbolic tangent, and linear transfer functions in the hidden and output layer individually. The best-fitting training data were collected with an architecture of three courses, type 24:4:1 considering. Laboratory and simulated data were analyzed satisfactorily within a linear regression method with a similarity

coefficient of 0.98851 and a mean square error, MSE, of 2.15×10^{-4} in the validation stage. Furthermore, the pattern matches the specifications of the slope and the intercept statistical analysis with a 99% confidence. The chemical synthesis of metals and the total acid number TAN are the information variables with the highest frequency on the corrosion rate, with 35% and 33% sequentially.

A review of the effect of biodiesel on the corrosion behaviour of metals/alloys in diesel engines

A. T. HOANG ET AL. Biodiesel is the most encouraging bio-based option in contrast to the enormous amount of fossil diesel fuel utilized in the transportation areas. Notwithstanding, its destructive conduct when in contact with the diesel motor and fuel framework segments is of genuine concern. The current work exhaustively surveys the effects of biodiesel on the consumption conduct of metal-based parts in diesel motors, for example, copper and copper-based alloys, aluminum and aluminum-based alloys, cast iron, carbon steel, and tempered steel. The consumption systems of the referenced metals in biodiesel are likewise introduced and examined in detail. Techniques applied to contemplate the consumption wonder and their levels are additionally introduced. The reasons prompting the higher destructiveness of biodiesel versus diesel fuel, including its higher hygroscopicity, higher electrical conductivity, higher extremity, higher dissolvability, the presence of water and oxygen in biodiesel advancing microbial development, lastly, its auto-oxidation bringing about the age of destructive specialists, i.e., monocarboxylic acids, are additionally pointed by point. At long last, the utilization of corrosion inhibitors in biodiesel to upgrade metals/combinations' protection from consumption is evaluated. The future examination needs to additionally grow biodiesel usage overall is likewise imagined.

Many researchers have made immense contributions in the field of corrosion studies of engine materials in biodiesel blends. There are several experimental results available in the literature for different types of biodiesel blends and corrosion related studies based on it. Research was mainly confined to obtain the corrosion rate of material in specified biodiesel environment. Of all the researches done not much

effort were put on analysing the obtained experimental results to obtain optimum range of corrosion rate of copper in different biodiesel blends.

The empirical modelling techniques are extensively used in corrosion behaviour analysis. But due to the restricted regression ability of conventional algorithms, modelling aims are often confined to specific factors and specific conditions. This study proposed a modelling approach based on machine learning to predict the corrosion behaviour of copper in various biodiesel blends. The correlations between material, temperature and immersion time factor and corrosion rate were evaluated, and their influences on the corrosion behaviour of copper were analyzed intuitively. By using the selected dominating factors as input variables, an optimized ridge model and lasso regression model was established with a high prediction accuracy of corrosion rate to copper samples in several typical biodiesel blends. The results proved that machine learning was efficient in corrosion behaviour analysis, which usually involves a regression analysis of multiple factors.

CHAPTER 3

AIM AND SCOPE OF THE PROJECT

3.1 AIM OF THE PROJECT

- To collect experimental corrosion rate data of copper, aluminium, steel in various biodiesel blends from the existing literature.
- To write a suitable regression analysis algorithm in machine learning tool and train the machine with the collected experimental data from the literature.
- To perform the prediction analysis of copper corrosion data and provide the results of optimum range of copper corrosion rate in various biodiesel blends.
- To perform experiment on copper metal strips by dipping in various biodiesel blends at specific temperature and time.
- To obtain optical microscopic images of copper metal strips before and after corrosion and perform AFM study on corroded copper strip to understand the surface morphology and suitable conclusion is drawn based on results.

3.2 SCOPE OF THE PROJECT

Biodiesel has become more competent as an alternative fuel for vehicles because of its environmental advantages and the point that it is produced from renewable sources. However, corrosion of metals in biodiesel is one of the concerns related to biodiesel compatibility issues. There are many experimental studies carried out to know about the corrosion rate of copper in various biodiesel blends at varying conditions but none of the studies could provide the optimum corrosion rate of copper. In this study, efforts are taken to analyse and predict the optimum corrosion rate of copper in various biodiesel blends with the help of machine learning models so that obtained results further helps in the study of preventing corrosion of copper in biodiesel. The experimental results provide the information of surface morphology of copper after getting corroded, which helps in further study of anti-corrosion coatings on copper.

CHAPTER4

MATERIALS AND METHODS

4.1 METHODOLOGY OF RESEARCH

After analysing and reviewing the numerous works of literature with the information and facts learned, the transparent process of the methodology recommended for the research work is illuminated as follows.

4.2 MATERIALS REQUIRED

The material required for this experimental study is a copper sheet from it the copper strips are made with a dimension of 2cm/2cm. after this process this metal strips are roughed by using emery paper of P400 grade to get a mirror polish of copper strips ethanol is used to remove the unwanted dust practical and then by using polishing paste the work piece is polished on the grinding wheel and then an etching agent is used to improve the grain structure in microscopic study.

4.3 METHODS INVOLVED

4.3.1 Cutting

To make a precise cut a non-traditional machine is used for reducing minimum contact a wire cut EDM machining process is used to make a required dimension of 2/2 cm

4.3.1.1 Electric Discharge Machining (EDM)

Introduction

Electron discharge machining is a non-conventional machining process in which the machining is conducted by noncontact process melting and vaporization is the mechanism followed by this device. Power supply is given to tool and work piece.

RLC Circuit

RLC circuit works on a same principle as that of flywheel in mechanical system therefore 75-85% of cycle time energy is only stored in R-L-C circuit, whereas for remaining 15-25% of cycle time, entire energy is released at tip of tool and workpiece and therefore flow of electrons and ions generates lot of sparking it is utilized for melting and vaporization of workpiece material.

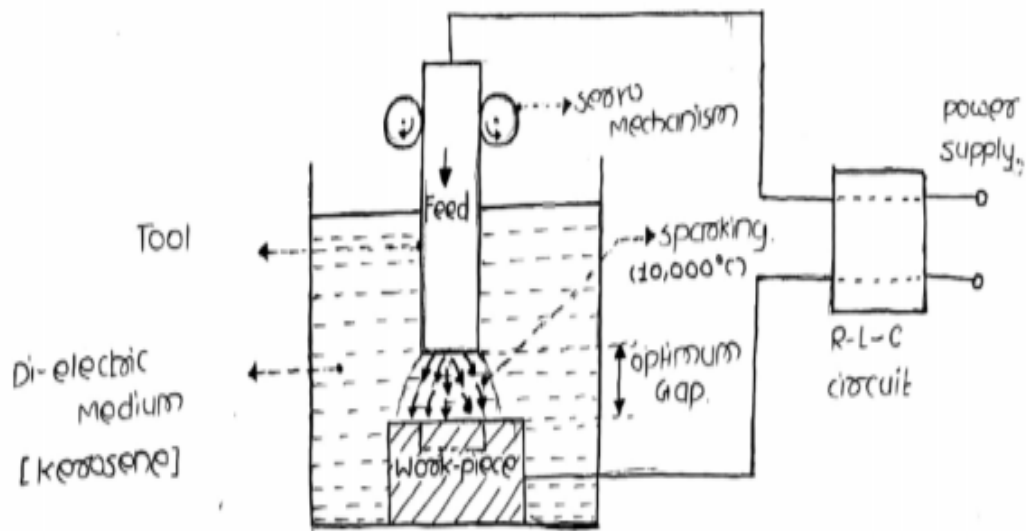


Fig 4.1: Schematic Diagram of Electric Discharge Machining (EDM)

To improve the efficiency of a machining entire machining is immersed in a dielectric medium, entire machining is immersed in a dielectric medium (kerosene) because of generation of vapor, cavitation is created which further falls the pressure below atmosphere, therefore melting point decreases a cavitation is formed due to low pressure. When a discharge takes place between two points of anode and cathode, the intense heat generated near the zone melts and evaporates the materials in the sparking zone. If anode and cathode are of same materials, it has been found that greater erosion takes place at anode (positive terminal). Workpiece material should be having high melting point temperature, high thermal conductivity, good conductor of electricity, high specific heat.

Summary of EDM characteristics

- Mechanics of MRR melting and evaporation aided by cavitation's
- Tool material CU- brass, CU-W alloy, AG-w-alloy, graphite. Wear ratio 0.1-10
- Gap between work piece and tool is 10 to 125 μ m.

Advantages

- There is no physical contact between tool and workpiece, so no forces are acting in machining, so no residual stresses are generated in machining.
- Out of all the unconventional machining of methods. EDM is the one which gives highest MRR, and EBM will give the lowest MRR.
- Because melting and evaporation is the mechanism of chip formation, the mechanical properties of work piece material will not affect the material removal rate MRR. Surface finish produced will be better.

Disadvantages

- This type of machining is used only for electrically conductive materials. Electrode wear is more. Re- hardening takes place due to heat generated during machining. Perfectly square corners cannot be made.

Applications

- Blind cavities and narrow slots in dies, minimum diameter hole produced is 0.13mm.
- It is used to produce a hole in diesel injection nozzle and air brakes, and extensively used to produce a hole in dies used during metal forming and sheet metal operation.

Wire- Cut EDM

dw – diameter of wire

S – spark gap

VF – feed velocity

Kerf – it is the width of material which is getting cut during wire cut EDM $2S+dw$

The wire-cut kind of machine originated in the 1960s for producing tools from tempered steel. The auxiliary electrode in wire EDM is just a wire. To bypass the decay of the wire producing it to break, the wire is wound among two spools so that the dynamic part of the wire is continually changing. The most advanced numerical controlled (NC) machines continued conversions of punched-tape upright milling machines. The first commercially prepared NC machine developed as a wire-cut EDM machine was constructed in the USSR in 1967. Wire EDM machining is an electrothermal creation measure in which a thin single-strand metal wire related to de-ionized water allows the wire to slice through metal by the utilization of thermic from electrical sparkles.

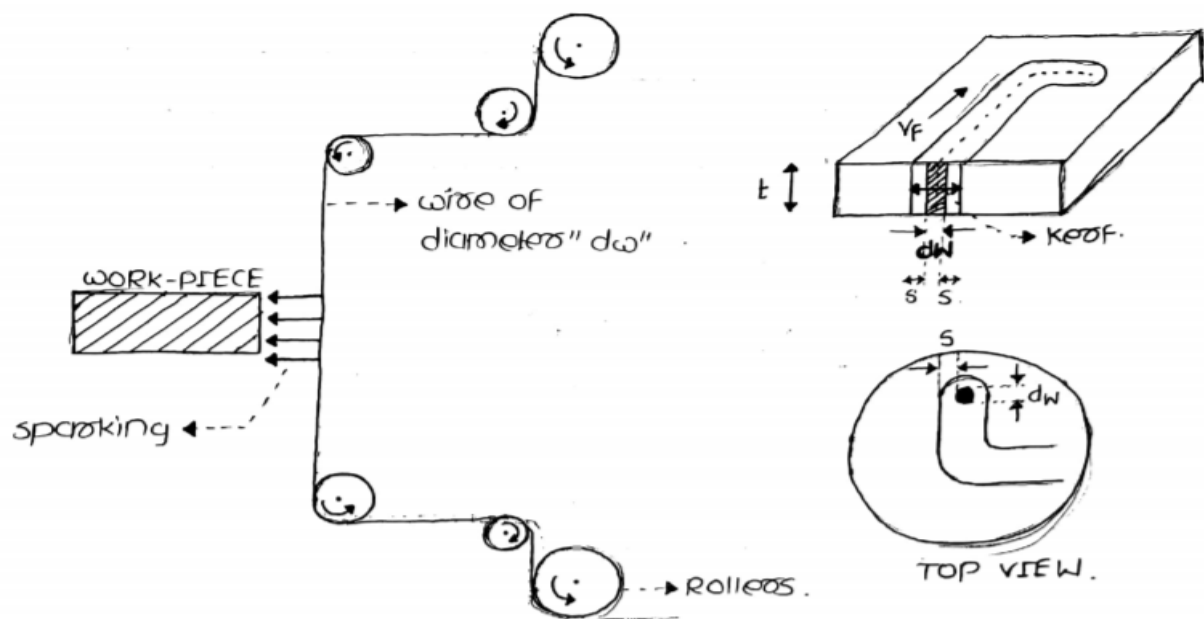


Fig 4.2: Schematic Diagram of Wire Cut Electric Discharge Machining (EDM)

Due to the inherent characteristics of the method, wire cut EDM can be efficiently machine complex parts and accurate components out of dense conductive materials. Wire cut EDM machining is also known as spark EDM process. In wire cut EDM, recirculating wire of diameter d_w is acting as tool. It is passing near to the surface of workpiece material and therefore sparking takes place between circumference

surface of wire and workpiece material which is utilized for melting and vaporization of work piece material. a slender single-strand metal wire, normally metal, is taken care of through the workpiece. The wire, which is continually taken care of from a spool, is held among upper and lower guides. The aides move in the X-Y plane, and some of the time the upper guide can likewise move autonomously offering to ascend to changing shapes (circle on the base square at the top). This enables the Wire EDM to be customized to cut exceptionally mind-boggling and fragile shapes. The wire-cut uses water as its dielectric with the water's resistivity and other electrical properties painstakingly constrained by channels and de-ionizer units.

4.3.2 Polishing and Cleaning

Polishing is the method of macro-flattening and micro-smoothing of non-uniform surfaces using mechanical, chemical, electrolytic, or thermal processes, or a synergistic aggregate of these. Diamond polishing appears to have been identified since the diamond was discovered and extricated from the ground as early as 16 A.D. Historically diamond polishing was associated to jewelry requirements and continued a trade secret for decades. The earliest record of diamond jewels were polished years back to 1352 in the French royal records. The fabrication of diamond is traditionally based on the application of the hardness of the diamond powder or different diamond stone counterparts following the origin “diamond cuts diamond”. Its progression as a procedure has been based individually on experimental research. It is suggested that plane grinding is taken out among the most accurate potential resolution to avoid any unnecessary mechanical deformation. Hardness, size, and several individuals have to be carried into account, but also with larger samples of pure copper, plane grinding with 500# SiC Foil/Paper is enough. Huge cast parts of copper alloys can be crushed with 220# or 320#. It is also noted that the force for grinding is leveled to avoid extensive deformation. Diamond polishing must be brought out till all deformation and implant embedded abrasives from grinding have been removed. The chemical-mechanical fine polishing with silicon dioxide is particularly important as a nearly scratch-free surface can be produced. For pure copper, the final polish with a liquid

containing iron nitrate has been determined to give quite immeasurable results, and for copper alloys

Copper stripes which are precisely cut are proceeded to make the surface roughness by using sandpaper or emery paper of grade p400 or p600 is get a neat and clean surface after making rough of the metal ethanol is used for cleaning the dust. Aluminum powder which is used on the grinding wheel as a paste for polishing this powder is made into paste and applied on the wheel as well to the workpiece mold. This grinding wheel consists of diamond abrasives on it this wheel is connected to electric DC motor by means of belt drive which drive at 500rps. When an electric supply is given to the motor the wheel starts to spin and, at higher rpms the mold is placed gentle on it along with the paste and without applying any external force this polishing is done according to ASTM G1 if a metal piece is polished for longer duration the surface finish will be much better, however to obtain mirror finish we need to do polishing of at least 120 minutes.

4.3.3 Optical Microscope

Light microscope is an alternate of optical microscope generally term microscope is determined by ancient Greek which is used to examine the object which is too small by naked eye. According to present generation there many microscope introduced by researchers they can be grouped in many different category simple microscope, electron microscopes, scanning probe microscopes, fluorescence microscopes, super resolution microscope, X-ray microscopes, but for this experimental study we have concluded optical microscope. The most used microscope and the first invention is the optical microscope according to modern microscopes. This is an optical instrument comprising one or more lenses presenting an augmented image of the sample deposited in the focal plane. Optical microscopes have a refractive glass infrequently plastic or quartz, to concentrate light on the eye or onto the different light detector. Mirror-based optical microscopes operate in an identical manner. Standard magnification of a normal light microscope, allowing visible spectrum light, is up to 1250x with a technical resolution boundary of around 0.250 micrometers or 250 nanometers. This defines practical magnification to ~1500x. Techno scientifically

techniques like scanning confocal microscopy, Vertigo SMI may better this magnification barring the resolution is diffraction limited. The use of smaller wavelengths of light, such as ultraviolet, is one way to develop the spatial resolution of the optical microscope, as are tools such as the near field scanning optical microscope. The traditional optical microscope has also been newly developed into the digital microscope. In supplement to, or instead of, directly observing the sample through the eyepieces, a type of sensor comparable to those used in a digital camera is applied to capture an illustration, which is then displayed on a computer monitor. These sensors will be using CMOS or charge coupled device (CCD) technology, depending on the utilization. Digital microscopy with extremely low light levels to avoid damage to exposed biological samples is possible using delicate photon-counting digital cameras. It has been confirmed that a light source producing pairs of entangled photons may reduce the risk of damage to the most light-sensitive samples.

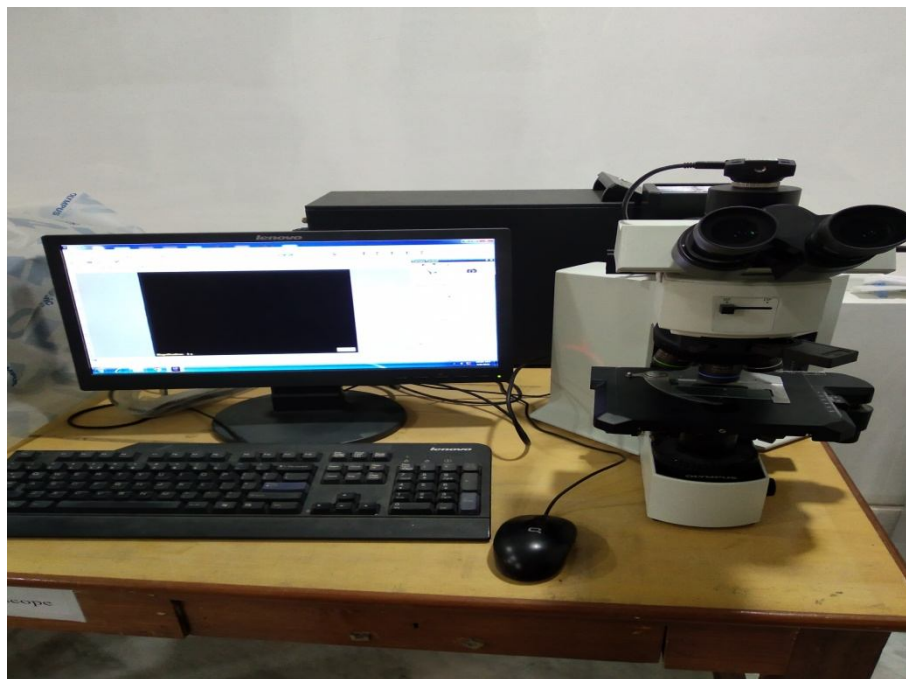


Fig 4.3: Optical Microscope Apparatus

In this case study the metal pieces which were polished before are now etched by using an etching agent (hydrofluoric acid) this agent is used to make the microstructure visible more clearly when observed under optical microscope this etching agent is apply to the metal about five minutes. After completing this process

the copper piece are washed out without touching the surface area by only holding the mold by the completion of washing process the metal piece are held out for drying to the atmosphere (for drying it more fast a blower is used), as soon as the metal piece is dried they are taken under optical micro scope which are used to take surface structure of the metal piece this surface morphology is used for only comparing with the corroded metal piece after the immersion test which is conducted by water bath instrument, the metal piece which is tested under optical microscope are now send for corrosion test using water bath

4.3.4 Water Bath

With the completion of the analytical work it is started by taking an experimental procedure which is done by using equipment called water bath. A water bath is laboratory equipment made from a container filled with heated water. It is used to incubate samples in water at a constant temperature over a long period of time. This experiment is conducted by filling biodiesel blends in the conical flask and placing it over the equipment and raising the temperature to 60 degrees and by maintaining a constant time and temperature the metal is immersed into the biodiesel blend and kept for observing under the optical microscope after dipping it into the biodiesel.



Fig 4.4: Water Bath Apparatus

Immersion test 1

- For making this immersion a biodiesel blend is prepared by insisting 12% waste cooking oil and remaining 88% of diesel this ratio of blend is prepared for 150ml.
- This blend is transferred into the beaker which will be placed in the corrosion bomb this beaker is now placed in the corrosion test bomb (water bath) by immersing the copper piece into the beaker.
- Now the equipment is switched on, and the temperature can be adjusted by using thermistor controller we have to set the temperature to 60 degree initially the temperature will be 25-30 degree inside the bomb which, will be raised slowly.
- After reaching the obtained temperature 60degree the duration will be noted from now this immersion test will be continued till 3 hours with constant temperature.

- By completing 3hours of duration the equipment is switched off and work piece is left over night in the beaker and will be then taken out after 12hours and optical microscopic images are taken for 3 hours of corrosion test of copper metal strip.

Immersion test 2

- For making the second immersion a biodiesel blend is prepared by insisting 50% waste cooking oil and remaining 50% of diesel this ratio of blend is prepared for 150ml.
- This blend is transferred into the beaker which will be placed in the corrosion bomb this beaker is now placed in the corrosion test bomb (water bath) by immersing the copper piece into the beaker.
- Now the equipment is switched on, and the temperature can be adjusted by using thermistor controller we have to set the temperature to 60 degree initially the temperature will be 25-30 degree inside the bomb which, will be raised slowly.
- After reaching the obtained temperature 60 degree the duration will be noted from now this immersion test will be continued till 6 hours with constant temperature.
- By completing 6hours of duration the equipment is switched off and work piece is left over night in the beaker and will be then taken out after 12hours and optical microscopic images are taken for 6 hours of corrosion test of copper metal strip.

4.3.5 Atomic Force Microscope

The AFM was developed by IBM scientists in 1985. The forerunner to the AFM, the scanning tunnelling microscope (STM), was introduced by Gerd Binnig and Heinrich Rohrer in the early 1980s at IBM Research - Zurich, a community that earned them the 1986 Nobel Prize for Physics. Invented the atomic force microscope and the first preliminary implementation was made by Binnig, Quate, and Gerber in 1986. The first

commercially obtainable atomic force microscope was launched in 1989. The AFM is one of the leading tools for imaging, measuring, and manipulating matter at the nanoscale.



Fig 4.5: Atomic Force Microscope (AFM)

AFM is also called as nano technology microscope this microscope is a high-resolution probe tip microscope this probe is used for imaging, measuring, and manipulating matter at the nano scale it can image all type of surfaces like polymer, ceramics, glass, composites, and biological matters atomic force microscope works by physically pushing a cantilever tip against the sample. The tip movement of the cantilever is analysed and converted into 3 dimensional image of the sample surface, atomic force microscope consist a microscale cantilever of length of around $100 \text{ E-}10 \text{ m}$ with a sharp tip which is called probe which, is having radius of $10 \text{ E-}10 \text{ m}$. initially a laser source is projected on the cantilever which has a mirror fixed initially on it and this laser source is reflected towards the array of photo detector. The light source collected by this array of photo detector is later computed by computer device with this a 3D image of the sample piece are constructed. When this probe tip is brought near to the proximity sample piece forces will be applied like Vander Waal's forces, electrostatic forces, magnetic forces and other forces which arises due to the physical interaction between the surface atoms, cause the cantilever tip to deflect. This is how

the cantilever tip will be deflected as the cantilever tip is deflected the angle of the mirror also changes and depending on the change in angle the reflected light ray will change the direction with this the different light rays are collected by different photo detectors present in array of photo detectors we can also find the amount of deflection produced in the reflected laser beam by analysing which photo detector is collecting that particular reflected laser source so this analysis can be done by computer aided software. In this copper metal strip is placed below the cantilever probe tip and roughness results obtained which will be followed up results.

Advantages

- Resolution of better than 1 nm strong under ultra-high vacuum conditions.
- 3D images of the sample surface are constructed.
- It can be used on nonconductive surface also.
- It can be used to drag atoms one by one and deposit them at particular point on the sample.

Disadvantages

- Scanning speed is low
- If the tip comes in contact with the sample surface, it can distort the surface.

Applications

- Semiconductor science and technology
- Thin film and coatings
- Tribology surface and friction interactions
- Surface chemistry
- Polymer chemistry and physics
- Cell biology
- Molecular biology
- Energy storage (battery) and energy generation (photovoltaic) materials
- Piezoelectric and ferroelectric materials.

4.3.6 Data analysis using machine learning model

To carry out the prediction of optimum range of corrosion of copper in biodiesel blends, an advanced and effective method is adopted for further processing of data. The experimental data with the required parameters has been collected vastly and filed together. The Literature review has helped the study to fetch more data on corrosion rates of various metals in various biodiesel blends. For better understanding of the collected data, advanced data visualisation tool is utilized for understanding the trends and interpreting the data. To handle and analyze the data effectively and efficiently, the latest advanced and emerging trends in data analysis are utilized for example, Machine Learning. Machine Learning is the utilization of numerical and additionally measurable models to get an overall comprehension of the information for analysis of data. In Machine learning, machine is fed with data by the user and the machine is trained to analyze data using the algorithms given by the user. The information is cleaned and coordinated in a way that the machine can comprehend. Algorithms are written to the machine based on various mathematical and statistical models. Hypothetical prediction is done at 95% confidence level for each biodiesel blend .Regression analysis method is utilized for predicting the data on the basis of mathematical and statistical modelling. Ridge regression and Lasso regression models are used and obtained result are compared and the best fit is taken into consideration for results. At present efforts are taken to analyze the corrosion data of copper which is obtained from literature data. The machine is trained with data and suitable algorithms are implemented to test and train the machine with the data. The optimum corrosion rates of copper in different biodiesels are obtained and the results are listed below in results.

CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 DATA VISUALIZATION USING TABLEAU SOFTWARE

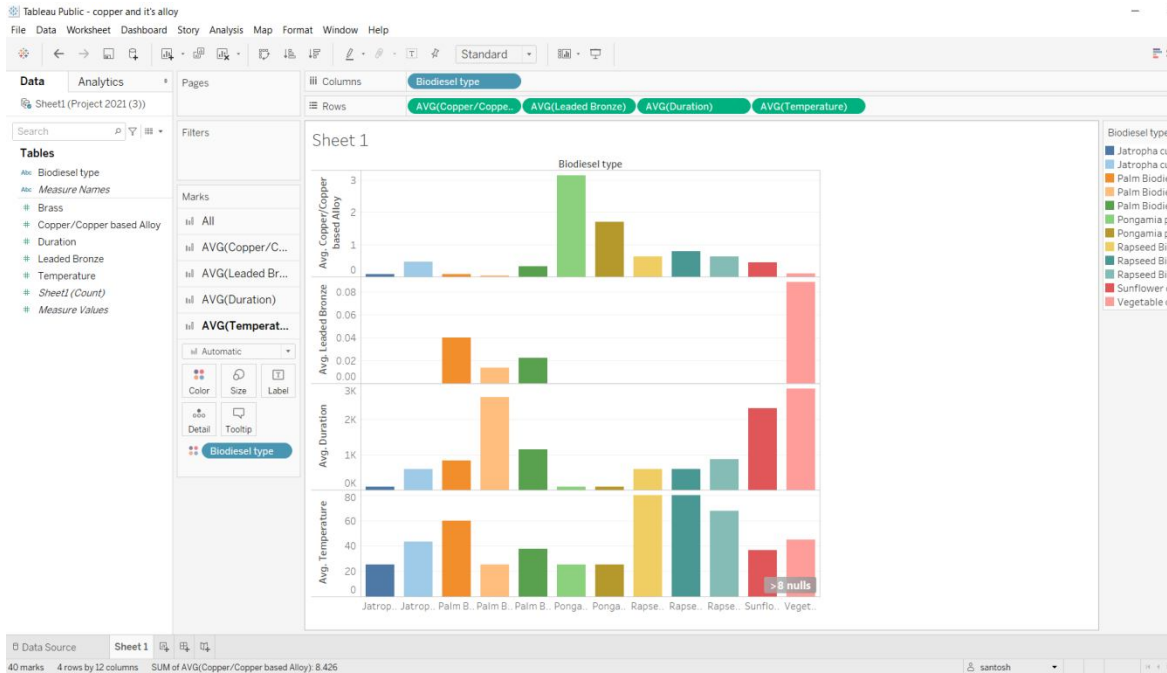


Fig 5.1: Data visualization of corrosion data of copper using Tableau software

The data visualization of copper corrosion rate in various biodiesel blends at varying temperatures and exposure duration helps to understand the trends in data and sorting according to it. It provides with various formats of visualizing the data so that the extremities of the data are easily identified. From the above data the graph suggest that palm biodiesel (B100) has less corrosion rate when compared to other biodiesels.

5.2 CORROSION RATE PREDICTION USING MACHINE LEARNING TOOL

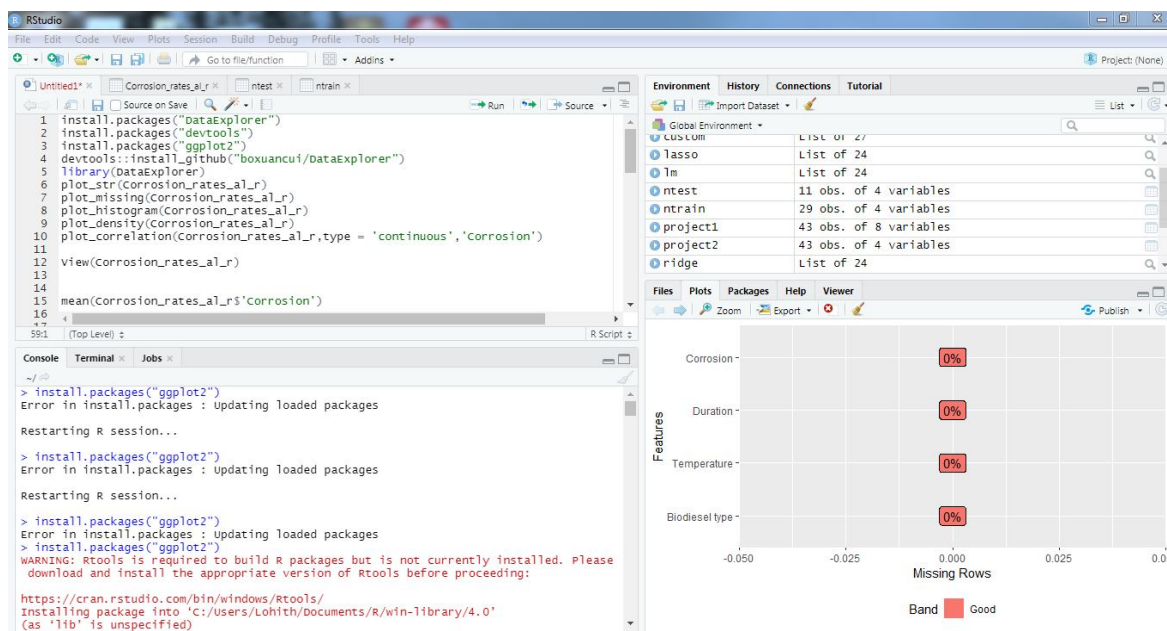


Fig 5.2: Image of RStudio (machine learning tool)

RStudio is a machine learning tool in which the algorithm is fed to predict the results. The machine is fed with corrosion data and it is trained with data for further forecasting of the optimum ranges of corrosion rate of copper in various biodiesel blends. The table mentioned below represents the optimum ranges of corrosion rate of copper in various biodiesel blends. The values are obtained from the data set of copper corrosion rate fed into RStudio machine learning tool. Out of the biodiesels mentioned in the table below, Palm Biodiesel has the lowest range of corrosion rate (in millimetre per year).

Table 5.1: Corrosion rate (in mpy) of Copper metal in various Biodiesels

Biodiesel Type	Corrosion Rate Range (in mpy)
Palm Biodiesel	0.165-0.468
Pongamia Pinnata Biodiesel	0.194-5.015
Rapeseed oil Biodiesel	0.191-1.122
Sunflower oil Biodiesel	0.043-0.865

5.3 OPTICAL MICROSCOPIC RESULTS

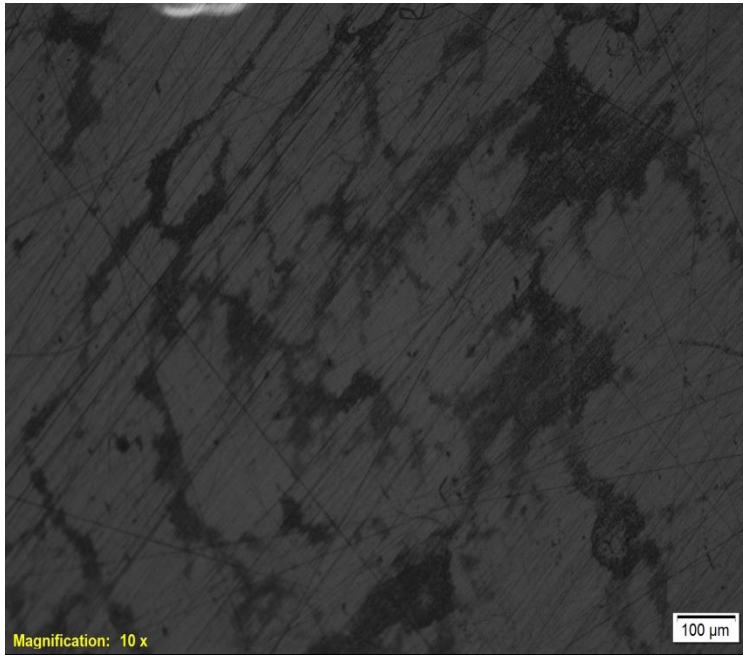


Fig 5.3 optical microscopic image of copper strip after etching with hydrofluoric acid about 5 minutes

Optical microscope was used to study the surface structure of the copper metal strip this metallic strip of fig5. is etched with hydrofluoric acid for amount 5-10 and then washed without contacting the surface of the metal and the dried and placed under optical microscope and this image is taken 100 microns.

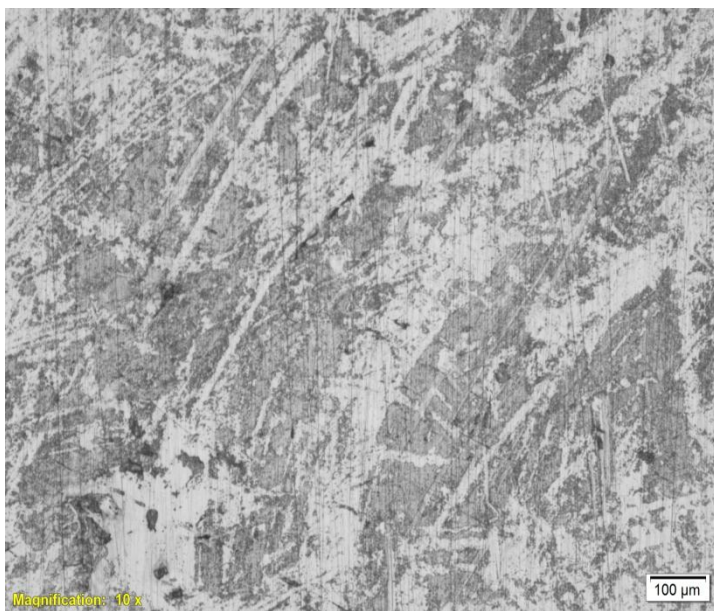


Fig 5.4: Optical microscopic image of copper metal strip immersed in biodiesel blend up to 3 hours of duration

Optical microscope was used to study the surface structure of the copper metal strip. This metallic strip of Fig. 5.4 shows immersion in the biodiesel blend of 12% waste cooking oil and 88% diesel. This ratio is taken for 150ml. This corrosion test was conducted for 3 hours in constant temperature (60 degree). This image shows the corrosion surface formed on copper metal is an initial stage of corrosion or starting point for corrosion which is magnified to 100 microns.

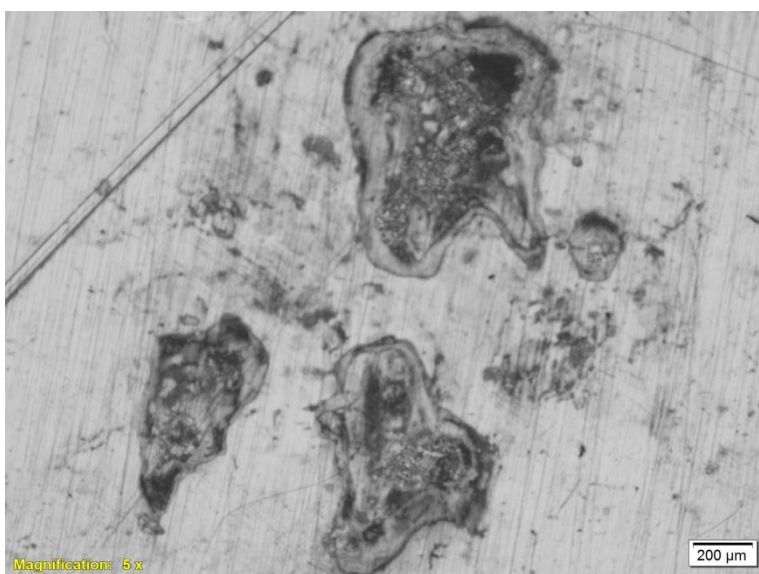


Fig 5.5: Optical microscopic image of copper metal strip immersed in biodiesel blend up to 6 hours of duration

Optical microscope was used to study the surface structure of the copper metal strip this metallic strip of fig 5. Shows copper strip immersed inside the biodiesel of blend ratio 50% waste cooking oil and 50% diesel this ratio is taken for 150ml. this corrosion test was conducted for 6 hours in constant temperature (60 degree). This image shows the pitting corrosion started on copper metal which is magnified to 100microns.

5.4 SURFACE ROUGHNESS RESULTS USING AFM

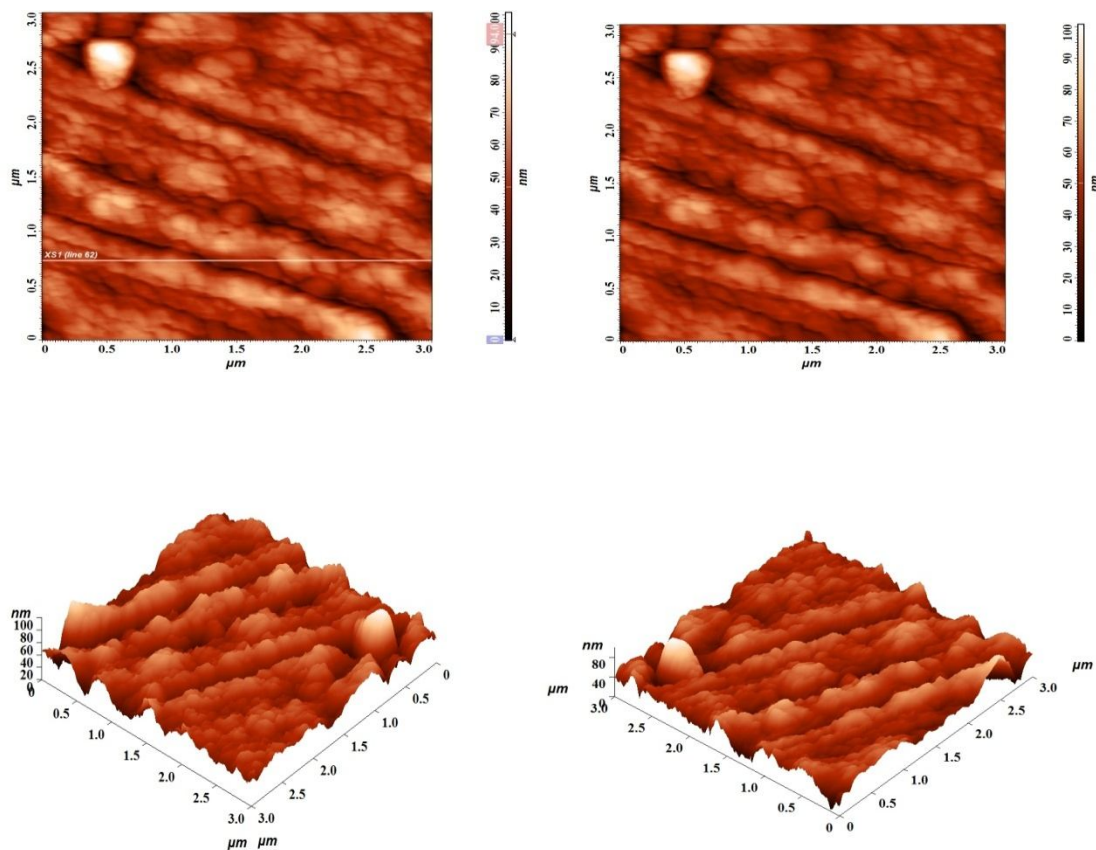


Fig 5.6: AFM 2D and 3D Images of Copper Metal Strip

Roughness analysis

Amount of sampling	65536
Max	100.554 nm

Min	0 nm
Peak-to-peak, Sy	100.554 nm
Ten point height, Sz	51.3485 nm
Average	48.8982 nm
Average Roughness, Sa	8.69352 nm
Root Mean Square, Sq	11.1875 nm

Additionally AFM testing is carried out on corroded copper metal which is exposed to biodiesel for six hours at 60 degrees centigrade. The roughness value of copper after corrosion is compared with roughness of copper surface before corrosion. These AFM helps in further study of suitable coatings to prevent corrosion of copper in biodiesel.

CHAPTER 6

SUMMARY AND CONCLUSION OF THE RESEARCH

Based on the research performed on copper metal strip and data analysis conducted on corrosion rate value of copper metal which are obtained from various literature survey, the corrosion values of copper which are predicted by using regression models (machine learning) are used to correlate with the experimental values. The results suggest that corrosion of copper metal alloys is high. The experimental result which are obtained from optical microscope shows corrosion occurs on copper were quickly when compare to other metals this conclude that if the immersion duration increases the corrosion rate increases subsequently. Also, Oxygen content on biodiesel exposed metal surface increases with increase of temperature. Oxygen may present in the form of compounds namely iron carbide or iron oxides. Subsequent formation of oxide compounds and their dissolution seems to degrade the metal surfaces. Corrosion attacks for metal surfaces are comparatively more in biodiesel than that in diesel fuel. For further study on reducing corrosion rate on copper metals AFM analysis is taken for roughness calculation the remedy to reduce corrosion is to use a coating of zinc or any other anti-corrosive layers which acts as anti-corrosion shield for metal. The other alternate way of reducing corrosion is by adding fuel additives in biodiesel which are used to reduce corrosion rate and increase the performance of a diesel engine. This coating process will be continued as an extended study in reducing copper corrosion rate when they are used in diesel engine with biodiesel.

REFERENCES

1. A.S.M.A. Haseeb, H.H. Masjuki, L.J. Ann, M.A. Fazal, Corrosion characteristics of copper and leaded bronze in palm biodiesel, *Fuel Processing Technology*, 91, (2010), 329–334.
2. A.S.M.A. Haseeb, M.A. Fazal, H.H. Masjuki, Comparative corrosive characteristics of petroleum diesel and palm biodiesel for automotive materials, *Fuel Processing Technology*, 91, (2010), 1308–1315.
3. A.S.M.A. Haseeb, M.A. Fazal, H.H. Masjuki, Effect of different corrosion inhibitors on the corrosion of cast iron in palm biodiesel, *Fuel Processing Technology*, 92, (2011), 2154–2159.
4. Abubakar, H. G., A. S. Abdulkareem, A. Jimoh, O. D. Agbajelola, J. O. Okafor, and E. A. Afolabi, "Optimization of biodiesel production from waste cooking oil", *Energy Sources, Part A: Recovery, Utilization, and Environmental*, 2016, 1-8.
5. Ahmmad, M. S., H. Hassan, M. Bin, and M. A. Kalam, "Comparative corrosion characteristics of automotive materials in Jatropha biodiesel", *International Journal of Green Energy*, 2018, 15:393–99.
6. Aksoy Fatih, Alkaline catalyzed biodiesel production from safflower (*Carthamus tinctorius* L.) oil: Optimization of parameters and determination of fuel properties, *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, 2016, 835-841.
8. Alemayehu Gashaw, AbileTeshita. Production of Biodiesel From Waste Cooking Oil and Factors Affecting Its Formation: A Review. *International Journal of Renewable and Sustainable Energy*. Vol. 3, No. 5, 2014, pp. 92-98.
9. Alfredo Luís Pereira Elias, Murilo Shiniti Koizumi, Eder Lopes Ortiz, João Felipe Queiroz Rodrigues, Ausdinir Danilo Bortolozo, Wislei Riuper Osório , Giovana da Silva Padilha, Corrosion behavior of an Al-Si casting and a sintered Al/Si composite

immersed into biodiesel and blends, *Fuel Processing Technology*, 202, (2020), 106360.

10. Amaya, A., O. Piamba, and J. Olaya, Improvement of corrosion resistance for gray cast iron in palm biodiesel application using thermoreactive diffusion niobium carbide (NbC) coating, 2018, *Coatings* 8:216.

11. C. Wen, Y. Zhang, C. Wang, D. Xue, Y. Bai, S. Antonov, L. Dai, T. Lookman, Y. Su Machine learning assisted design of high entropy alloys with desired property *Acta. Mater.*170, (2019), pp. 109-117.

12. Fazal, M.A, Haseeb, A.S.M.A., Masjuki, H.H., 2013. Corrosion mechanism of copper in palm biodiesel, *Corros. Sci.* 67, 50-59.

13. G. Labeckas, S. Slavinskas, The effect of rapeseed oil methyl ester on direct injection diesel engine performance and exhaust emissions, *Energy Conversion and Management*, 47, (2006), 1954–1967.

14. Gao C, Zhai Y, Ding Y, Wu Q. Application of sweet sorghum for biodiesel production by heterotrophic microalga *Chlorella protothecoides*. *Appl Energy* 87(3), 2010, 756–61.

15. H.Wan, G.F. Chen, C.P. Li, X.B. Qi, G.P. Zhang, Data-driven evaluation of fatigue performance of additive manufactured parts using miniature specimens, *J. Mater. Sci. Technol.* 35 (6), (2019), 1137–1146.

16. Huang G, Chen F, Wei D, Zhang X, Chen G. Biodiesel production by microalgal biotechnology. *Appl Energy* 87(1), 2010, 38–46.

17. J. Yu, C.Wang, Y. Chen, C.Wang, X. Liu, accelerated design of L12-strengthened cobase superalloys based on machine learning of experimental data, *Mater. Des.* 195, (2020), 108996.

18. Karatay SE, Dönmez G. Microbial oil production from thermophile cyanobacteria for biodiesel production. *Appl Energy* 88(11), 2011, 3632–5.

19. Lam MK, Lee KT. Potential of using organic fertilizer to cultivate *Chlorella vulgaris* for biodiesel production. *Applied Energy* 94, 2012, 303–8.
20. M.A. Maleque, H.H. Masjuki, A.S.M.A. Haseeb, Effect of mechanical factors on tribological properties of palm oil methyl ester blended lubricant, *Wear* 239, (2000), 117–125.
21. Michael J. Haas, Improving the economics of biodiesel production through the use of low value lipids as feedstocks: vegetable oil soapstock, *Fuel Processing Technology*, 86, (2005), 1087 – 1096.
22. Rasoul-Amini S, Montazeri-Najafabady N, Mobasher MA, Hoseini-Alhashemi S, Ghasemi Y. *Chlorella* sp.: a new strain with highly saturated fatty acids for biodiesel production in bubble-column photobioreactor. *Appl Energy* 88(10), 2011, 3354–6.
23. S. Kaul, R.C. Saxena, A. Kumar, M.S. Negi, A.K. Bhatnagar, H.B. Goyal, A.K. Gupta, Corrosive behavior of biodiesel from seed oils of Indian origin on diesel engine parts, *Fuel Processing Technology*, 88, (2007), 303–307.
24. Savita Kaul, R.C. Saxena, Ajay Kumar, M.S. Negi, A.K. Bhatnagar, H.B. Goyal, A.K. Gupta, Corrosion behavior of biodiesel from seed oils of Indian origin on diesel engine parts, *Fuel Processing Technology*, 88, (2007), 303–307.
25. Shahrouz Norouzi, Farshad Eslami, Mirosław L. Wyszynski, Athanasios Tsolakis, Corrosion effects of RME in blends with ULSD on aluminium and copper, *Fuel Processing Technology*, 104, (2012), 204–210.
26. V. M. Mello, G. P. A. G. Pousa, M. S. C. Pereira, I. M. Dias, and P. A. Z. Suarez, “Metal oxides as heterogeneous catalysts for esterification of fatty acids obtained from soybean oil,” *Fuel Processing Technology*, vol. 92, 2011, pp. 53–57.
27. W. Mu, M. Rahaman, F.L. Rios, J. Odqvist, P. Hedström, Predicting strain-induced martensite in austenitic steels by combining physical modelling and machine learning, *Mater. Des.* 197, (2021), 109199.

28. Xiangmei Meng, Guanyi Chen, Yonghong Wang, Biodiesel production from waste cooking oil via alkali catalyst and its engine test, fuel processing technology, 89, (2008), 851 – 857.
29. Y. Diao, L. Yan and K. Gao, Improvement of the machine learning-based corrosion rate prediction model through the optimization of input features, Materials and Design 198, (2021), 109326.
30. Yan J, Lin T. A. Political, economic and environmental impacts of biodiesels: a review. Appl Energy 86, 2019, S108–17.