OPTIMIZATION OF SOLAR ASSISTED BIODIESEL PRODUCTION FROM LINSEED OIL

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Submitted by

NEERAJ BUDHRAJA
ROLL NO. - 2K16/RET/03

Under the supervision of

Prof. (Dr.) AMIT PAL

DEPARTMENT OF MECHANICAL, PRODUCTION & INDUSTRIAL AND AUTOMOBILE ENGINEERING
DELHI TECHNOLOGICAL UNIVERSITY
BAWANA ROAD, DELHI-110042

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I, **NEERAJ BUDHRAJA**, Roll No. **2K16/RET/03** student of **M. Tech. (Renewable Energy Technology)**, hereby declare that the work which is being presented in this thesis entitled "**OPTIMIZATION OF SOLAR ASSISTED BIODIESEL PRODUCTION FROM LINSEED OIL**" which is being submitted by me to the Department of Mechanical, Production & Industrial and Automobile Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of **Master of Technology**, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

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CERTIFICATE

I hereby certify that the work which is being presented in this thesis entitled "**OPTIMIZATION OF SOLAR ASSISTED BIODIESEL PRODUCTION FROM LINSEED OIL**" which is submitted by **NEERAJ BUDHRAJA**, Roll No. **2K16/RET/03** to the Department of Mechanical, Production & Industrial and Automobile Engineering, Delhi Technological University, Delhi in the partial fulfillment of requirement for the award of the degree of **Master of Technology**, is a record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Place: Delhi **Prof. (Dr.) AMIT PAL**

Date: SUPERVISOR

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NEERAJ BUDHRAJA
(2K16/RET/03)

ABSTRACT

The present explored crude oil reservoirs are depleting at a much faster rate than estimated at the end of 20th century. The higher energy demand for transportation, industrialization and luxurious life are the main consequences behind this fast rate depletion. To fulfill the everlasting demand of energy, we need to look for some alternative source of energy. Biodiesel being renewable and less polluting fuel can replace the conventional diesel fuel. But the higher energy and cost of biodiesel production is not allowing the industries to look biodiesel as a conventional diesel alternative. Thus, solar energy is implemented as heating source for transesterification process to reduce the cost of biodiesel production from conventional methods.

This study focuses on optimizing the yield parameters based on the Taguchi's approach, a powerful tool to maximize biodiesel yield. A full factorial design of 27 experiments, the signal-to-noise (S/N) ratio and analysis of variance (ANOVA) are employed to investigate the influence of yield parameters at different levels. The main objective of the study is to determine the effects of molar ratio, reaction time and catalyst concentration on the production of biodiesel from linseed oil. Different yield parameters have different influence on the production of biodiesel. The different levels for yield parameters recommended were 6:1, 7.5:1 and 9:1 for molar ratio; 90 min., 105 min. and 120 min. for reaction time; and 0.5 wt%, 0.75 wt% and 1.0 wt% for catalyst (KOH) concentration, respectively. The samples are processed under different level of parameters and percentage yield for each sample is measured. The result showed that the higher the molar ratio better the yield. The optimum yield parameters were 9:1 molar ratio, 105 min. reaction time and 0.5 wt% catalyst concentrations, which produced optimum yield of 82.48%. While the maximum yield of 82.82% is attained for molar ratio 9:1, reaction time 120 min. and catalyst concentration 0.75 wt%. According to the ANOVA analysis, molar ratio is the dominating factor with 63.01% contribution.

Keywords: Linseed oil methyl ester, Paraboloid solar dish, Taguchi, ANOVA and solar irradiation (or intensity).

CONTENTS

LIST OF FIGURES

LIST OF GRAPHS

LIST OF TABLES

CHAPTER 1

INTRODUCTION

The demand of energy for industries, transportation, communication; in short, living a luxurious life, is drastically gone up in the last few decades. Our conventional fuel sources are depleting very rapidly and their over exploitation is leading to an imbalance in the environment [1], which ultimately leading to severe environmental calamities such as global warming, green house, and non-seasonal droughts and heavy rain. To overcome these environmental problems without scarifying ever increasing demand of energy, has led us to explore renewable energy sources which may be reproduced in a very short span of time and can produce very less or no pollution, and thus, may also be called as environmental friendly fuel sources.

Renewable sources of energy are solar energy, wind energy, biofuel energy, tidal energy, geo-thermal energy, etc. Among these solar energy and wind energy is being utilized in the large scale for power production. While the utilization of other sources has also been increased significantly in the last few decades but still their contribution in power production is very less.

1.1 Renewable Sources of Energy.

The energy sources which can be renewed within a short time span are termed as renewable sources of energy. These energy sources are less or non-polluting sources, and thus, play a significant role in environment conservation.

1.1.1 Solar Energy.

The energy from the sun, amounting nearly 5,000 trillion kWh per day as solar intensity (electromagnetic radiation) is huge compared to the current energy demand of mankind. Energy from sun is over 10,000 times the annual global energy consumption, which is more than any other energy source present currently on the earth [2]. Solar energy is a plentiful, clean and safe energy source with a best option in replacement for the conventional fossil fuels.

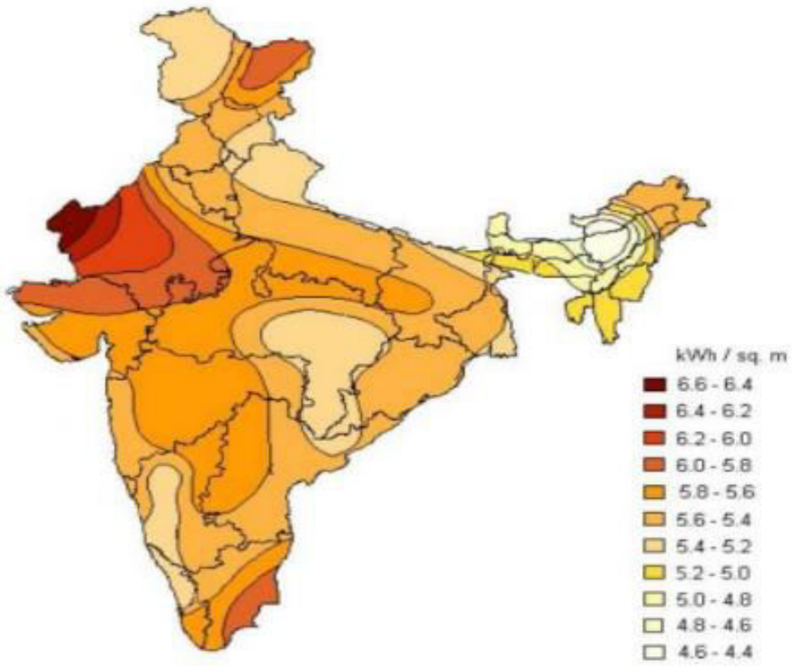


Figure 1.1: Average Solar radiations falling on India [3]

1.1.2 Wind Energy

The movement of air masses to produce energy which is basically in the form of kinetic energy is termed as wind energy. Wind energy is an eco-friendly renewable source being clean and cheap [4]. Very slow winds upto 5 m/s are useless for generation of power whereas very heavy stormy winds of more than 25 m/s can damage the wind turbine blade. The speed range between 5-25 m/s is considered best for exploring energy from wind.

1.1.3 Hydro Energy

The energy of falling water (termed Hydro Power) is used by humans since ancient time for grinding grain, sawing lumber and to do other tasks. The early upto 100 kW of hydraulic units were used which are relatively smaller than used currently. Hydroelectric power is a non-polluting energy source with reliable and flexible operation, and low cost of operation and maintenance [5]. The drawbacks are damages to the marine life, higher cost of construction, destroys natural habitat of surrounding area, and construction period is large.

1.1.4 Wave Energy

Transfer of energy from surface winds to the sea results in wave energy. Rate of energy transfer depends upon the speed of wind and the distance over which it interacts with water. The energy rate dissipation through friction at shore depends upon the characteristics of wave and depth of water. Large waves in deep sea lose energy quite slowly and effectively store it for many days and transmit it over longer distances [6]. The coastline has an estimated potential of a little in excess of about 2,000 GW energy resources. The main advantages are non-polluting source, the availability of large energy fluxes, and predictability of wave conditions over different interval of days. However, onshore wave energy installations may disturb marine live, visual landscape is affected and damages the beautiful ocean front views.

1.1.5 Tidal Energy

Tidal energy exploits the natural ups and downs of coastal tidal water caused principally by the interaction of the gravitational fields of the sun and the moon. The ocean level difference caused due to tides is good source for potential energy. The level from up tide to down tide is known as tidal range which varies greatly with location [7]. Only sites with large ranges (about 5 m or more) are used for power generation. The total combined potential at these sites is estimated is 120 GW. The barrage destroys the places that are home to many birds, fishes and aquatic animals.

1.1.6 Biomass

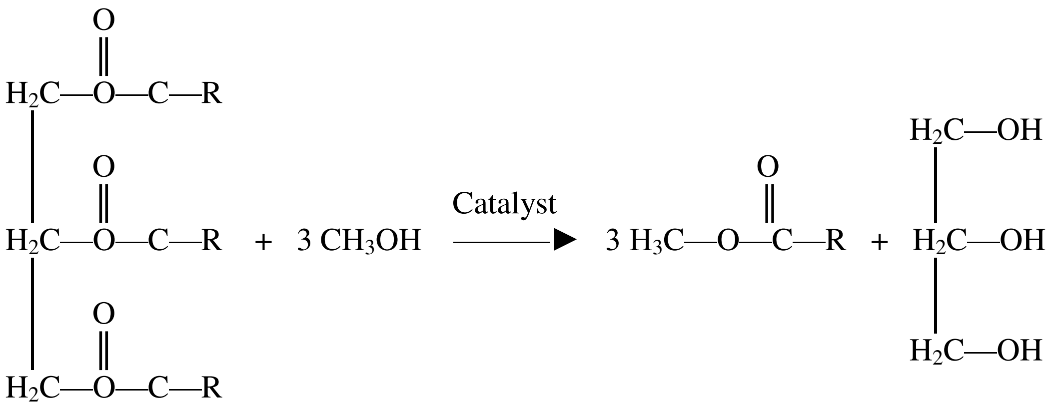
Biomass is produced from the living material of plants, animals, fungi, bacteria. All together, the earth's biomass has a very vast storage of energy. Biomass can be re-grown, thus it is an unlimited renewable resource of energy. It is also estimated that biomass, which comprises about 90% plant matter, is equivalent to the fossil-fuel reserves currently proven extracted globally [8]. The dry-matter mass of biological material cycling in the biosphere is about 250×10^9 ton/yr. The associated energy bound in photosynthesis is 2×10^{21} J/y (70,000 GW).

1.1.6.1 Ethanol as Biofuel

Ethanol produced for use as a fuel is almost exclusively through fermentation technology [9]. Almost each food containing starch is a potential source for ethanol production while sugarcane is used for ethanol production. A MPNG report says that 5% ethanol blending in gasoline would require around 500 million litres, which is presently available.

1.1.6.2 Biodiesel.

Vegetable oils and animal fats mainly consist of triglycerides. Triglycerides are esters of fatty acids (FA) with glycerol (also called glycerine). Transesterification reaction of vegetable oils is done to produce biodiesel [10]. In transesterification reaction, alcohol is mixed with vegetable oil and allowed to react catalytically at a temperature range of 60°C to 80°C.



Triglyceride Alcohol Alkyl Ester Glycerol

Transesterification Reaction [10]

The feedstocks include many non-edible vegetable oils (like jatropha, karanja, palm, mahua, caster bean, neem, linseed) and almost every edible vegetable oil (like soybean, sunflower, coconut, peanut) and also used cooking oil (WCO) from restaurants and hotels [11]. The main advantages are biodegradability, reduced engine exhaust emissions, safer handling and storage, and excellent lubricity. A few drawbacks of biodiesel being higher cost of production, which leads to offset from many countries by subsides, slight increase in NO_x exhaust emissions, unstable exposed to ambient air, and cold flow properties like high pour point and higher cloud point.

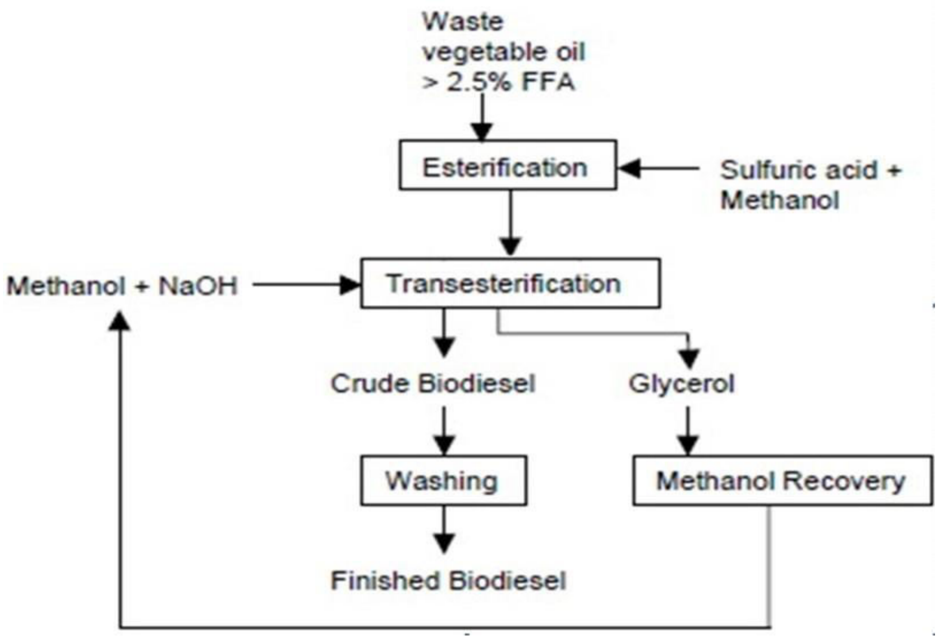


Figure 1.2: Block diagram for biodiesel production [12]

1.2 Solar Energy as Heating Source

As so far seen, the process of biodiesel production requires heat which is usually being utilized from the electric power coming from power plants running on conventional fuels. So, to reduce burden on these power plants solar energy for heating purpose is a good alternative. While the studies suggested that India is getting sufficient solar radiation which is about 5-7 kWh/m^2/day and that too for approximately 300 sunny days [2].

1.2.1 Box-type Solar Cooker.

These are designed for cooking purposes but they can be used as heating source and production the temperature upto 90-100°C. They are made up of box which is painted black from inside and open from the upper side, a glass covering the top of the box, a mirror attached to the upper side of the box to reflect sun’s ray inside the box, and one or two bowls (painted black from outside) placed inside the box for food storage. The demerits are requiring more time for cooking and the storage space is limited.

1.2.2 Concentrated-type Solar Cooker

The concept of concentrated-type solar cooker comes from the concentrating solar thermal (CST). They are better than box-type solar cookers in respect of quick cooking and storage space. The temperature reaches to 120-150°C and thus the cooking time is reduced considerably. Concentrated-type solar cooker consists of a paraboloid dish (with small pieces of mirrors or a material sheet having good reflective index), a stand usually of MS or cast iron for supporting the frame, and a receiver at the focus. The drawbacks are the focus is above the concentrating dish which makes the loading and unloading operation little complex, and the focus moves with the paraboloid dish.

1.2.3 Parabolic Trough Collector (PTC).

Another useful technology for utilising solar radiation for heating purposes is PTC. It contains a metal collector polished sheet (usually aluminium) with good reflecting index, and a receiver (painted black) surrounded by glass resulting in reduced convective heat losses. The temperature received upto 180-220°C while operation can be performed in a continuous manner.

1.2.4 Scheffler Reflector.

It is a dish with fixed focus collector and a lateral slice of a paraboloid. It consists of a dish as the shape of a lateral slice of a paraboloid and contains either small pieces of mirrors or the strips of polished metal sheet, receiver placed at focus with black painted outside, and a stand to support the frame and adapting seasonal changes to maintain the focus. The temperature attained upto 250°C and the focus is below the reflector dish. The fixed focus and lower receiver makes it simple in operation. The disadvantage is good manufacturing skills are required.

1.3 Biodiesel

As discussed above, biodiesel is alkyl ester produced by transesterification process of the triglyceride of oil. In 1893, the famous German inventor Dr. Rudolph Diesel designed the first ever diesel engine which originally operated by using vegetable oil. While in 1900, the engine designed by Dr.

Rudolph was run by peanut oil at Paris Exposition. Until the 1920s, just before the engine manufacturers modified the engines to run on lower viscosity petroleum diesel, vegetable oils were used as the fuels for diesel engines.

1.3.1 Factors affecting Biodiesel Production.

- Increased molar ratio (alcohol to vegetable oil) increases the alkyl ester yield considerably upto a particular limit. Further increase in molar ratio results in glycerol which is difficult to separate.
- Catalyst Concentration and type affects the conversion rate of biodiesel from triglyceride. For lower FFA (Free Fatty Acid), i.e. < 2.5% FFA content, a single stage alkaline transesterification is used and for higher free fatty acid (> 2.5%) content, a two stage acid transesterification is used.
- Stirring helps in higher alkyl ester yield from triglyceride.
- Impurities in vegetable oil decrease the conversion rate into alkyl ester.
- Moisture content results in soapification and thus reduces the yield.

1.3.2 Properties of Biodiesel.

Biodiesel and conventional diesel (or petroleum diesel) are generally characterized by different physiochemical properties like viscosity, density, calorific value, cetane number, flash point, moisture content, ash content, carbon residue, copper corrosion, etc [13]. Molar ratio (alcohol to oil ratio), catalyst concentration, reaction time, reaction temperature, and water content are parameters for biodiesel production. Few properties are:

- **Viscosity:** important in fuel injection operation, particularly at low temperatures. Higher viscosity affects on timings of fuel injectors causing improper fuel atomization inside cylinder. High viscous pure vegetable oil is the primary drawback for direct use as engine fuel. Transesterification process for conversion of triglyceride into alkyl esters reduces viscosity and molecular weight and this lower viscosity of biodiesel is close to petroleum diesel. While the rise in temperature decreases the viscosity of oil.

- **Density:** important criterion while blending of biodiesel with conventional diesel for CI engines fuel. Pure diesel is less dense than the pure biodiesel. It must be put at the top to ensure proper mixing of the blends of diesel and biodiesel.
- **Calorific Value (CV):** total heat released from a fuel during full combustion of fuel with oxygen. The SI unit is J/kg. The CV of biodiesel is somewhat between 38-42 MJ/kg and that of pure diesel is about 44 MJ/kg.
- **Cetane Number (CN):** measure of the ignition quality of fuel. High CN indicates shorter ignition delay. Longer FA chains and more saturation biodiesel content generally results in higher CN than pure conventional diesel.
- **Flash Point:** temperature at which a fuel ignites when comes in contact with a spark. Flash point has considerable affects on combustion quality of a fuel. Seals and fuel pumps are degraded by lower flash point fuels. Biodiesel has high flash point than the petroleum diesel which makes it good for engine health.
- **Cloud Point:** minimum temperature for wax formation (visibility of waxy substance) is called cloud point. Biodiesel has high cloud point than petroleum diesel thus care should be taken while using biodiesel in cold climates.
- **Pour Point:** temperature upto which the fuel flows continuously. Similar to the cloud point, biodiesel has high pour point than petroleum diesel and thus care should be taken for continuous flow of fuel in fuel pipes during cold climates.
- **Moisture content:** moisture content not only affects the production yield of alkyl esters during transesterification process but presence of moisture in the cylinder also degrades the engine. Thus, moisture content should be minimized in the fuel.

1.3.3 Advantages of Biodiesel.

The main advantages of using biodiesel over petroleum diesel fuel are given below:-

- It is renewable and biodegradable alternative for the petroleum diesel fuels.
- It has low aromatic and sulphur contents than petroleum diesel.
- It is a readily available fuel.
- It has higher flash point.
- Higher CN (cetane number) of biodiesel gives it better combustion efficiency.
- Lubricity of biodiesel is superior to petroleum diesel.
- Lower emissions like CO, HC, CO_2 and PM are measured in biodiesel than petroleum diesel fuels.

1.3.4 Demerits of Biodiesel Fuel.

Along with so many advantages, biodiesel has some disadvantages also which is given below:-

- Biodiesel has low energy density and higher viscosity than petroleum diesel.
- Pour point and cloud point of biodiesel is high.
- NO_x emissions considerable increases with biodiesel as engine fuel.
- Less engine power and speed also makes biodiesel inferior than petroleum diesel.
- For present motor vehicles biodiesel causes more engine wear than petroleum diesel.
- Presently, production cost is also high.
- Fuel consumption is also high in case of biodiesel than petroleum diesel.

1.4 Linseed Oil as Biodiesel

Linseed is an oil and fibrous crop used to produce linen. Linseed is cultivated as Rabi crop in India and is sown in the month of October and is harvested in April. It is a less water consuming crop and thus areas having annual rainfall from 45-75 cm are best for its cultivation [14]. The linseed seeds contain 33-44% of oil content by mass under optimum conditions. Low volatility and high viscosity are the main demerits [15]. The oil contains 47.4% 3-double bonds linolenic fatty acid, 24.1% two bonds linolenic FA and 19% 1-double bond oleic fatty acid, among these linolenic acid content is about 60% [16, 17]. The high content of linolenic acid affects the drying property of oil and makes it suitable for drying in alkyd paints [18].

1.5 Objectives of Present Work.

The proposed research has been completed with biodiesel production with the following objectives:

i. Measurement of solar intensity during interval of day in Delhi, India.
ii. Evaluation of best time day time interval for maximum solar radiation, which is used for heating source for transesterification.
iii. Optimization of parameters affecting the yield using Taguchi's approach of optimization.
iv. Determination of fuel properties of biodiesel produced by optimized conditions and comparing them with petroleum diesel standards.

LITERATURE REVIEW

A considerable number of studies have been done for the production of biodiesel from various edible and non-edible oils; and the general effects of the reaction temperature, reaction time, molar ratio, catalyst concentration and others have also been investigated. These studies have been briefly discussed under this section:-

- ***Agee et al.*** [17] discussed the production of biodiesel using solar energy for processing heat in transesterification. In this work, the mixture of soybean oil with alcohol and catalyst was placed on the focal point of the parabolic solar reflector in a black painted round bottom flask and then transesterification process takes place in approximately in 1 hour. For successful processing of transesterification, solar irradiation should be greater than 400-450 W/m^2. In this work, synthetic process of biodiesel took place without generating any chemical and electrical waste.

- ***Zheng et al.*** [18] evaluated solar utility and renewability evaluation for biodiesel production process. The simulation reduces 890 MJ/ h heating loads and 890 MJ/h cooling loads and no CO_2 is released. The exergy analysis of both processes shows that the renewability index of the new process with solar utility facilities is 99.9%, while that of the process with fossil fuel utility facilities is only 89.4%.

- ***Chen et al.*** [19] discussed production of biodiesel from waste cooking oil using a microwave heating system. The comparison of conventional and microwave assisted method was also done. The maximum yield of biodiesel produced from waste cooking oil under conventional heating was 96.6%. In microwave assisted system, the reaction time reduced to 1-6 minutes. The yield of biodiesel produced increased with reaction time from 1 to 3 min, but then decreased from 3 to 5 min. For the microwave assisted production, the maximum yield of biodiesel produced in microwave assisted method was 97.9%. The result showed that optimal condition in this work were use of 0.75 wt% CH_3ONa catalyst, a methanol to oil molar ratio of 6:1, microwave power of 750 W and reaction time 3min.

- ***Montero et al.*** [20] presented biodiesel process requiring a constant supply of thermal energy at temperature between 60°C and 120°C. In this work, the parabolic trough collectors array turned out to be the best option over the evacuated tube collectors to supply the power required for the solvent recovery stage in a biodiesel production process. This system provides 91% of the energy demanded by the biodiesel production process as such.

- ***Mihankhah et al.*** [21] studied biodiesel production from olive oil waste by transesterification reaction applied with solar energy. Whereas, electricity generated by photovoltaic panels was used to power a motor for mixing the reaction solution. The experiment gives the highest triglyceride conversion rate of 76.4% was achieved after 4 hours of reaction at 50°C, with a 1:4 weight ratio of olive oil waste to methanol and a 5wt% KOH as a catalyst.

- ***Hallenbeck et al.*** [22] presented microalgal bio-fuels as a sustainable alternative to fossil fuels. Microalgae being a fuel precurseur convert solar energy into many different types of bio-fuels, both gaseous and liquid. This improved sustainability will come from combining production with wastewater treatment, and the development of bio-fertilizers.

- ***Manisha et al.*** [23] gives the biodiesel production process by using a small parabolic dish type solar reflector, which is used for heating required in transesterification process, this avoids the use of electrical heating and magnetic stirring. In this work, Taguchi's software is used in the optimization of the process parameters. The maximum yield was obtained is 95.56% at optimum condition of molar ratio 6:1, reaction time 60 min, reaction temperature 70°C and catalyst concentration of 1.0wt%.

- ***Manisha et al.*** [24] analyses the biodiesel production from cotton seed oil using solar energy as a medium required for heating in transesterification process performed at small and medium scale. The results show that the conversion yield of CSOME (cotton seed oil methyl ester), 93.60%, is comparatively better than conventional methods. Thus, it is a cost-effective technique and can be commercialized in future.

- ***Khan et al.*** [25] analysized the various environmental impacts of biodiesel production from non-edible Jatropha oil and waste cooking oil (WCO). The result shows better performance of biodiesel production from Jatropha oil because WCO needs a large amount of energy for pre-treatment of raw WCO. Also, the collection of WCO from various sources contributes towards environmental impacts.

- ***Mohite et al.*** [26] optimized the process parameters of biodiesel production from Karanja and Linseed oil. Karanja biodiesel is produced by two steps, esterification/ transesterification process which is costly, health hazardous and corrosive due to use of concentrated acids. Whereas Linseed biodiesel can be produced by alkali-base transesterification, which is much faster and gives higher yield. The yields in the range of 68.2% to 78.9% have been achieved with varying different parameters.

- ***Guill´en-Gos´albez et al.*** [27] addressed the problem of reducing the environmental impact of biodiesel plants through their integration with a solar thermal energy system that generates steam. The approach presented was tested in the design of a 9,233,040 kg/year alkali-catalyzed biodiesel process using vegetable oil. The paper showed that is possible to achieve reductions in CO_2 emissions of up to 19.88% with respect to the maximum profitability design. This is achieved at the expense of reducing the net profit value (NPV).

- ***Dani Supardan et al.*** [28] studied biodiesel production from low cost feedstock of waste cooking oil (WCO) using hydrodynamic cavitation apparatus. The research showed the highest 89.4% yield of biodiesel production in transesterification process at reaction time of 150 minutes with methanol to oil molar ratio of 6. Hence, the experimental results clearly established the efficiency of cavitation as an excellent way of biodiesel production.

- ***Manisha et al.*** [29] discussed the various biodiesel production technologies such as microwave irradiation, ultrasonic cavitation and solar irradiation. The selection of biodiesel production is mainly depends on various parameters such as type of feedstock used, reaction time, reaction temperature, oil to alcohol molar ratio and amount of catalyst used. This enhances the quality and effectiveness of biodiesel production.

- ***Uddin et al.*** [30] presented a study on synthesis of biodiesel from waste cooking oil. A three-step method was used in which first step was the saponification of the oil, second was acidification to produce FFA and the third step was transesterification to produce biodiesel. In saponification process, the reaction time was noted as 2 hours when heated at 100˚C and the optimum molar ratio was 1:2 ratio of oil to NaOH. The molar ratio of soap to hydrochloric acid in acidification process was 1:2 and in the third step of esterification, the molar ratio of CH_3OH to FFA was 6:1. The concentration of HCl was 5wt% of FFA, the chemical reaction temperature was 60°C and the reaction time was 2 hour, with silica gel reaction time was reduced to 80 min and FFA content was reduced to 0.94%.A factorial design was applied which enabled the esterification reaction to occur in optimum conditions. The result showed that 79% conversion yield was found at optimum condition.

- ***Huang et al.*** [31] presented the process of biodiesel production using microalgae in place of conventional biodiesel feedstock. Microalgal oil has fatty acids content similar to common vegetable oils and it has short term growth cycle. Composition of microalgae is relatively single. Heterotrophic cultivation of microalgae is preferred for lipids production. The reaction temperature was maintained at 30˚C and 100% catalyst quantity was achieved. But for large scale production of biodiesel from microalgal oil is not successful due to high cost of production process, low lipid content and low biomass.

- ***Azcan*** and ***Danisman*** [32] used microwave technology for transesterification of cottonseed oil in the presence of methanol (CH_3OH) and potassium hydroxide (KOH). A Start S model microwave unit was used in this work. Both conventional and microwave irradiation assisted method of biodiesel production were compared by the estimation of critical reaction parameters such as the amount of catalyst, reaction temperature and reaction time. High conversion yield of biodiesel, produced from cotton seed oil, were obtained in the range of 89.3-92.8% at the reaction temperature of 333K for both types of methods. Also the optimal catalyst to oil ratio for both methods was same as 1.5% except the reaction time. Microwave irradiation technique consumes only 7 min in comparison of 30 min used for reaction in conventional biodiesel production.

- ***Berchmans et al.*** [33] discussed a technique of biodiesel production from high FFA containing oil. Use of alkali base catalyst in transesterification could reduce the yield of methyl esters of fatty acids by a considerable amount. In such cases of high FFA oil, Acid pre-treatment is done at first step. The FFA content of crude jatropha curcas seed oil is reduced to less than 1% after acid pre-treatment. In second step, transesterification process with alkali base catalyst gives 90% yield of jatropha oil methyl esters.

- ***Kamath et al.*** [34] studied the method of biodiesel production from Pongamiapinnata non-edible oil under batch microwave irradiation technique. The free fatty acid content in Pongamiapinnata oil is higher, so a two step method was adapted. The conversion yields were different for both one-step and two-step approaches. In one-step approach the yields was 80% while in two-step approach, the yield was 90% with a molar ratio of alcohol to oil equals to 10:1 and amount of catalyst KOH as 1wt%.

- ***Fattah et al.*** [35] studied influential factors affecting the oxidation stability of biodiesel derived from vegetable and animal based feedstocks. Effect of various antioxidants such as α-Tocopherol (α-T); Pyrogallol (PY); Butaylated hydroxyanisole (BHA); Propyl gallate (PG), Butaylated hydroxytoluene (BHT); Tert-butylhydroxyquinone (TBHQ); 2,5 –di-tert-butyl-1,4-dihydroxybenzene (DTBHQ), etc. has been studied. The result showed PY to be the best effective biodiesel stabilizer, whereas other antioxidants can be ranked for almost all vegetable oil biodiesel as OBPA ≈ DPD < BHT ≈ BHA < DTBHQ ≈ TBHQ < PG. However, for animal fat based biodiesel the rank is BHA ≈ BHT < PG < TBHQ. Also, metal deactivators such as citric acid; N,N′-dialicylidene-1,2-diaminopropane, etc. along with antioxidants helped in achieving better stability.

- ***Hsiao et al.*** [36] discussed the microwave-assisted biodiesel production from soybean oil using Nano powder calcium oxide as catalyst. The maximum conversion yield under optimum condition was 96.6%. The results indicated that combined use of microwave irradiation technique with nanopowder calcium oxide (nanoCaO) catalyst make the biodiesel production from soybean oil very efficient and qualitative.

- ❖ ***Kanitkar et al.*** [37] discussed transesterification process for rice bran oil and soybean oil using a batch microwave heating system. The conversion yields were compared for methanol and ethanol. The results showed that microwave technology reduce reaction time with both types of alcohols used and also reduce the catalyst demand in comparison with conventional production. It was observed that ethanol is better in terms of environmental issues and methanol is better in terms of effectiveness and performance.

- ❖ ***Yaakob et al.*** [38] presented the method of Fatty acid methyl ester preparation form jatropha curcas oil with the assistance of microwave oven for heating required in chemical process. In this experiment the maximum yield of biodiesel produced was obtained as 86.3% with excess oil to methanol molar ratio of 30:1. The catalyst used in this experiment was 4% NaOH at a reaction temperature of 55˚C. The quality of FAME prepared from Jatropha curcas oil using microwave assisted method was better and reaction time also magically reduced.

- ❖ ***Koberg et al.*** [39] reported the direct methods of biodiesel production from microalgae biomass of Nannochloropsis. Firstly, Microalgae was cultivated by the application of a biotechnological environmental system, so the cost of algae production was reduced significantly. Secondly, microwave and ultrasonic irradiation technique were compared with the assistance of SrO catalyst. For the second case, the result showed that direct transesterification using microwave oven technique is more simple and efficient than the ultrasonic assisted technique. The yield of biodiesel observed higher (37.1%) for microwave oven technique in reaction time of 5min, while ultrasonic technique could provide 20.9% yield in same reaction time.

- ❖ ***Singh et al.*** [40] produced biodiesel from microalgae Neochloris oleoabundans oil. N. oleoabundans is fresh water microalgae rich in oil content (42 %) but has high oil viscosity which requires transesterification. By ultrasonic transesterification method, the reaction time was reduced to 15 minutes which was 5 hours by conventional transesterification method. While the result showed maximum yield of 98 % biodiesel using ultrasonic assisted method, thus reducing overall biodiesel production cost.

- ***Yathish et al.*** [41] performed transesterification reaction of custard apple seed (Annona squamosa) oil using methanol, in the presence of KOH as catalyst at less than 65 °C of temperature. The various important properties of biodiesel are characterised by GC (gas chromatography) analysis. Thus, the biodiesel fuel properties obtained as such are kinematic viscosity at 40 °C is 5.712 centistokes; density is 865 kg/m^3; flash point 150 °C; calorific value 37510.8 kJ/kg-K; cloud point 2 °C; pour point 5 °C; ash content 0.02 % W/W; and carbon residue nil.

- ***Hajinezhad et al.*** [42] used Eurca sativa as a source of biodiesel production using methanol as alcohol and KOH as catalyser by means of transesterification process under ultrasound irradiation. The physiochemical properties of Eurca sativa oil and the related produced methyl ester were measured and profoundly discussed. Various fatty acid methyl esters were determined by Gas Chromatography and BF_3 method and the results showed 55.91% (highest) proportion of C18:1. Also, kinematic viscosity 37.06 mm^2/s; amount of FFAs 0.42%; density 0.915 g/cm^2; soap value 187.857 mg KOH/1g of oil; and acid value 1.533 mg KOH/1g of oil were measured, respectively. The conversion rate of 95.61% was measured using ultrasound technology.

- ***Buasri et al.*** [43] used Scallop waste shell for the production of a cheap catalyst for transesterification process required for biodiesel production from palm oil. Different experimental parameters, such as reaction time, reaction temperature, methanol/oil molar ratio and catalyst loading are used in Taguchi L9 (3^4) orthogonal array to evaluate the factors affecting the conversion of palm oil to FAME. The result showed 95.44% conversion yield of FAME under the optimal reaction condition of 10 wt% of catalyst, 9:1 methanol/oil molar ratio at a temperature of 65 °C and with reaction time of 3 hours. Thus, Scallop waste shell was found to be ecologically friendly heterogeneous base catalyst and can be used for biodiesel production effectively.

- ***Kumar et al.*** [44] reviewed the selection criteria for the heat transfer fluids that can be used in concentrated solar power plants with the drawbacks that incurred the use of older heat transfer fluids. A number of other possible heat transfer fluids with their properties were also compared.

- ***Demirbas et al.*** [45] discussed various non-edible plant oils for production of biodiesel. The cost as well as food crisis made non-feasible biodiesel production from edible oils. Thus, this work discussed the availability of non-edible oils such as jatropha, karanja, mahua, caster bean seed, neem, rubber seed, tobacco seed, etc. for production of biodiesel. Also, effect of different parameters on production of biodiesel is studied. The result showed that biodiesel produced from non-edible plant oils has good potential as an alternative fuel. However, high FFA content increases the biodiesel production cost. Hence, biodiesels containing high FFA content are not desirable under cost consideration.

- ***Mohan et al.*** [46] described various ultrasonic reactions for biodiesel production and studied Deodar biodiesel properties and stability. During the experiment horn, bath, double-frequency and triple-frequency ultrasonic reactors were used and optimum biodiesel yield is found are 98.5 % in 50 minutes, 99 % in 45 minutes, 99 % in 30 minutes and 99 % in 15 minutes, respectively, at 60 % of the maximum rated power conditions. It was also found that triple-frequency flow cell is the most energy efficient ultrasonic reactor for biodiesel with specific energy consumption (SEC) of 0.0312 kWh/kg and energy use index (EUI) of 336.70 respectively. Thus, triple-frequency flow cell have advantage over other ultrasonic rectors for biodiesel production.

- ***Kumar et al.*** [47] carried out a microwave-assisted transesterification of Pongamiapinnata using methanol as the alcohol and two types of alkaline catalyst, NaOH and KOH. The results indicated that optimum concentration for NaOH was 0.5 wt% and for KOH was 1 wt%. An appropriate amount of methyl esters were obtained as 97.5% using 1.0wt% KOH for 10 min and 96.0% yield using 0.5 wt% NaOH for 5 min. In both condition, the optimum reaction temperature remained at 60˚C. Finally, the fuel properties were investigated for all the reaction conditions and it was concluded that biodiesels produced from Pongamiapinnata oil met the ASTM standards for biodiesel. Microwave irradiation technique also reduced reaction time significantly from 3 hours in convention process to 5-10 min which makes the production process qualitative. Therefore, microwave-assisted transesterification could be a good technique for biodiesel production.

- ***Yadav et al.*** [48] compared ultrasonic transesterification and a magnetic stirrer method for biodiesel production from Nerium oleander (Thevetia peruviana) oil. A two-step transesterification process was carried out for optimum condition of 0.40 % V/V methanol to oil ratio, 1 % V/V H_2SO_4 catalyst, 55 °C temperature and 60 minutes reaction time followed by treatment with 0.2 % V/V methanol to oil ratio, 1 % W/V KOH alkaline catalyst, 55 °C temperature and 60 minutes of reaction time. The process is repeated with an ultrasonic method at the frequency of 28 kHz using ultrasonic horn type reactor (50 W) for about 10-15 minutes. The result showed that ultrasonic transesterification process is more effective method with a maximum yield of 97 % by weight of oleander biodiesel along with improved physiochemical characteristics.

- ***Yadav et al.*** [49] produced biodiesel from oleander (Thevetia peruviana) oil using ultrasonic transesterification process. The process is carried out for optimum condition of 0.45 V/V methanol to oil ratio, 1.2 % V/V H_2SO_4 catalyst, 45 °C temperature and 15 minutes reaction time followed by treatment with 0.25 V/V methanol to oil ratio, 0.75 % W/V KOH alkaline catalyst, 50 °C temperature and 15 minutes reaction time. Further, blends of oleander biodiesel with diesel are tested on a diesel engine. The result showed a 2.06 % increase in brake thermal efficiency for 20 % oleander biodiesel blend (B20), also upto 41.4 % and 32.3 % of decrease in CO and UHC emissions. Thus, biodiesel blends can be a good substitute for neat diesel.

- ***Kombe et al.*** [50] developed a low temperature glycerolysis process for lowering FFA in crude jatropha oil for alkali catalyzed transesterification. The response surface methodology (RSM) based on central composite design was used to model and optimize the glycerolysis efficiency under reaction time, temperature and glycerol to oil mass ratio. The highest glycerolysis efficiency was found to be 98.67 % under optimum condition of temperature 65 °C, reaction time 73 minutes and glycerol to oil mass ratio 2.24 g/g. A reduction from 4.54 % to 0.0654 % of FFA in crude jatropha oil is found. Thus, giving as high as 97.87 % conversion yield using homogeneous base transesterification. The fuel properties of jatropha biodiesel so obtained were comparable to those of ASTM D6751 and EN 14214 standards.

- ❖ ***Pal et al.*** [51] discussed two different technologies of biodiesel production from thumba oil and waste cooking oil (WCO). These two technologies are low frequency ultrasonic energy (28-33 kHz) and conventional mechanical stirrer method. The experiments were performed for alcohol to oil molar ratios of 4.5:1 and 6:1 respectively with different concentrations of KOH (0.5%, 0.75% and 1%). The results showed that the viscosity and density values of thumba and WCO biodiesel are within permissible limits but these values in comparison to petroleum diesel were slightly higher.

2.1 Conclusions from Literature Reviews

Recently, a number of papers on solar energy assisted biodiesel production processes are been studied and following conclusions can be drawn:-

- ► The papers suggested that solar energy can be a better option for the thermal energy required for biodiesel production processes.
- ► Reduction in the use of electrical energy will reduce the cost of biodiesel production.
- ► Applying solar energy for heating purposes will reduce the emissions from biodiesel production processes further making biodiesel environmental friendly.
- ► Further, Solar energy can also be used for solvent recovery process from the byproducts of transesterification reaction.
- ► Biodiesel production process requires a constant supply of thermal energy at temperature between 60°C and 120°C, which can be provided by solar irradiation.
- ► For successful processing of transesterification, solar irradiation should be greater than 400-450 W/m^2.
- ► The simulation of solar utility for biodiesel production process reduces 890 MJ/h heating loads and 890 MJ/h cooling loads and no CO_2 is released.
- ► Experiment showed that the PTC system provides 91% of the energy demanded by the biodiesel production process as such.
- ► The experiment gives highest triglyceride conversion rate of 74.5% after 4 hours of reaction at 50°C with 1:4 weight ratio and 5wt% KOH as catalyst using solar irradiation as heating source.

2.2 Research Gaps Identified

- ► So far, it was found that the commercial production of biodiesel is done using electrical energy for heating purposes.
- ► This electrical energy is ultimately coming from fossil fuel powered power plants which contribute in harmful emissions.
- ► A very few research is done in utilising Solar energy as heating source in biodiesel production processes.
- ► Solar energy can be effectively used as an energy source for the production of biodiesel commercially.
- ► This way not only fossil fuels are save but the environment is also saved from degradation.

OPTIMAIZATION METHOD

The technique of laying out the design of experimental situations involving multiple parameters was first carried out in 1920 by Sir R. A. Fisher, and called it, full factorial design. In this technique, all the possible combinations of parametric values are considered. For example, with an experimental situation of eight parameters, each at two levels, total number of experiments will be 256 (2^8).

3.1 Full Factorial Design

A full factorial experiment has two or more factors with distinct possible levels having all probable combinations of all these levels among all specified factors. The experiment is designed to study the influencing parameters on the response variable with effects of connections between the factors and the response variable. In general, the design of experiment involves all input parameters set at three levels each. If ‘n’ parameters have 3 levels each; a full factorial design will have 3^n runs. Thus, 3 different levels of 3 parameters each would take 27 trial runs.

3.2 Taguchi’s Method

Taguchi’s method is the efficient tool for getting optimal solution from a robust design in an easy and organised way at relatively low cost. It consists of all stages of product/process development for quality control. However, the significant element for obtaining optimum value is Design of Experiment (DOE). Taguchi’s (DOE) method is used to evaluate the influencing yield parameters like molar ratio, reaction time, catalyst concentration and type, and reaction temperature to obtain an optimal setting of these parameters resulting in the best yield [54, 55]. A three-step approach for optimization of a process or product consists of following steps namely, system design, parameter design, and tolerance design.

3.2.1 System Design

A basic functional prototype design is created using scientific and engineering knowledge of the engineer. This design consists of two stages namely, the product design stage and the process design stage. In the product design stage, involvement of the choice of materials, components, uncertain product parameter values is seen.

3.2.2 Parameter Design

The process parameter values are enhanced by the parameter design and the product parameter values are identified for refining the performance values. The parameter design is used to attaining best quality with reduced cost. Basically, Fisher designed the traditional parameter design which is complex to use. Increased number of parameters establishes a great number of experiments. To make it significant and easy an extraordinary design of orthogonal arrays is required to study the whole parametric space with very less number of experiments. Loss function computes the abnormality between the experimental value and the desired value. Taguchi suggests the employment of the loss function to compute the performance characteristic contrary from the anticipated value. S/N ratio is assessed by three types of the performance characteristic, that is, the lower-the-better, the higher-the-better, and the nominal- the-better. The S/N ratio for each level of process parameters is calculated based on the S/N assessment from equation 3.1 [56, 57].

Larger the Better (maximize):

$$S/N = -10\ log\ \left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \qquad (3.1)$$

3.2.3 Tolerance Design

Resources are focused on reduction and controlled deviation in the critical few dimensions with a positively accomplished parameter design, and an understanding of the consequence that the several parameters have on the performance.

3.3 Design of Experiment (DOE)

The influence of parametric process over some specific parameter like yield is determined by using design of experiment tool. DOE is specified for modelling and analyzing [58]. The DOE is considered as one of the most widespread approach in product or process developments. Table 3.1 is the DOE of three parameters with 3 levels.

Table 3.1: Design of experiments with three parameters at three-level for biodiesel production

Parameters	Levels		
	1	2	3
Molar Ratio	**6:1**	**7.5:1**	**9:1**
Reaction Time (min.)	**90**	**105**	**120**
Catalyst Concentration (wt. %)	**0.5**	**0.75**	**1.0**

3.4 Selection of Orthogonal Array

The selection of orthogonal array is done to formulate the experimental procedure for optimized solution required to be performed while selecting a particular orthogonal array. Table 3.2 shows the layout of 27 experiments performed at different parameters. Thus, L_{27} orthogonal array of Taguchi method was used.

Table 3.2: Array (L_{27}) for design of experiment by Taguchi's method

Experiment no.	**Parameters and their levels**		
	Molar Ratio	**Reaction Time (min.)**	**Catalyst Conc. (wt. %)**
1	**1**	**1**	**1**
2	**1**	**1**	**2**
3	**1**	**1**	**3**
4	**1**	**2**	**1**
5	**1**	**2**	**2**
6	**1**	**2**	**3**
7	**1**	**3**	**1**
8	**1**	**3**	**2**
9	**1**	**3**	**3**
10	**2**	**1**	**1**
11	**2**	**1**	**2**
12	**2**	**1**	**3**
13	**2**	**2**	**1**
14	**2**	**2**	**2**
15	**2**	**2**	**3**
16	**2**	**3**	**1**
17	**2**	**3**	**2**
18	**2**	**3**	**3**
19	**3**	**1**	**1**
20	**3**	**1**	**2**
21	**3**	**1**	**3**
22	**3**	**2**	**1**
23	**3**	**2**	**2**
24	**3**	**2**	**3**
25	**3**	**3**	**1**
26	**3**	**3**	**2**
27	**3**	**3**	**3**

CHAPTER 4

EXPERIMENTAL SETUP

4.1 Description of Equipments and Chemicals used

4.1.1 Solar Power meter

Figure 4.1: Solar power meter with solar intensity sensor

Solar power meter TM-207 shown in the figure 4.1 is used to measure the solar intensity falling on earth. W/m^2 and BTU are the measuring units of solar power meter. And it had wide range of applications such as meteorology applications, helpful to set up solar PV panels at optimum angles of incidence, solar power research, and many more.

4.1.2 AccWeather Mobile application

AccuWeather is a weather forecasting mobile application founded in November 15, 1962 by Joel Myers. It is a simple weather forecasting mobile application with GPS accessing. In this research, AccuWeather is taken as a reference metrological data provider. Atmospheric temperature, wind speed and direction, humidity percentage, and cloud cover percentage is determined by using AccuWeather with GPS access and the location was Shahbad Daulatpur, Delhi, India. The below figure 4.2 is the AccuWeather metrological data page.

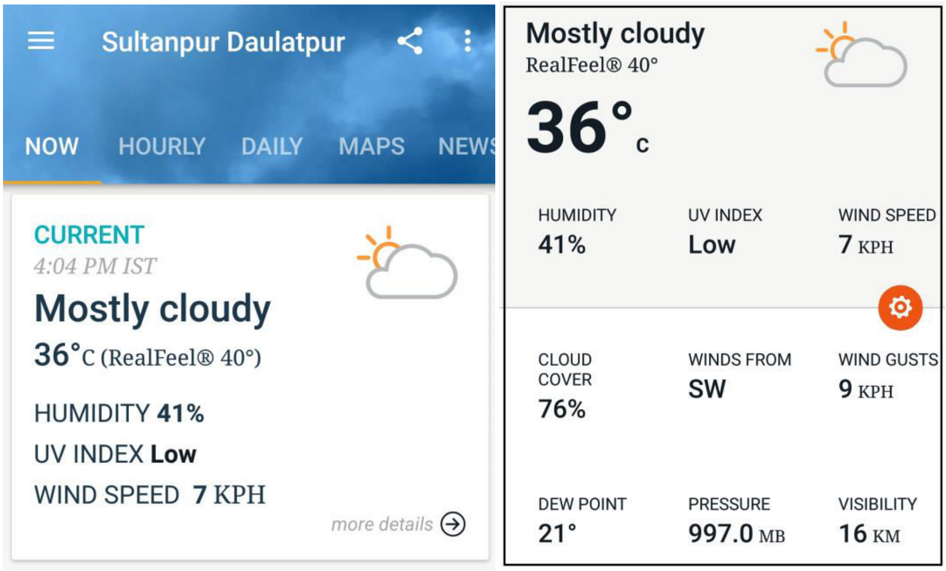


Figure 4.2: AccuWeather mobile application metrological data pages

4.1.3 Paraboloid solar dish collector


Figure 4.3: Front and Side view of paraboloid solar dish collector with receiver

The paraboloid solar dish (figure 4.3) with collector area about 1.2 m^2 is used as the heating source for transesterification process. The average temperature upto 120°C is attainable during 11am to 4pm with moderate to low cloud cover in a sunny day. This high temperature can be effectively used for transesterification process. The best thing is that it has no working cost with negligible maintance. Only the initial cost of the paraboloid dish collector is relative more.

4.1.4 Weighing machine

Figure 4.4: Digital weight machine

The weighting machine shown in the figure 4.4 is used during the research work. It is a high precision weighting machine manufactured by 'Globus'. The maximum limit of the weight is 600 grams while the minimum limit is 0.02 grams with the least count of 0.01 gram.

4.1.5 Beakers and Conical flasks

The capacity of the beakers used was 100 mL, 250 mL and 1000 mL while the conical flasks have the capacity of 250 mL. Beakers (as shown in figure 4.5) and conical flasks are manufactured by 'BOROSIL'.

Figure 4.5: Beakers containing biodiesel samples

4.1.6 Separating Flask

Figure 4.6: Two separating flask of capacity 500 mL and 2000 mL

Two separating flask measuring 500 mL and 2000 mL (as shown in figure 4.6) were used the water washing process of biodiesel. They are manufactured by 'BOROSIL'. The knob at the bottom of the separating flask is used to turn on and off the flow of the sample mixture from the flask.

4.1.7 Thermocouple

The instrument used for temperature measurement or thermometer (figure 4.7) is a thermocouple with the temperature measuring range of -50 °C to 300 °C. It was manufactured by 'III Instruments'.

Figure 4.7: Thermocouple used to measure sample temperature

4.1.8 Viscometer

To measure the viscosity and density of the biodiesel, viscometer is used. Figure 4.8 shows the Stabinger Viscometer-SVM 3000 manufactured by 'Anton Paar India Pvt. Ltd'. The ambient temperature or the reference temperature during the measurement of viscosity and density is 40 °C while the operating temperature range is from -60 °C to 135 °C with external cooling or heating. It can measure viscosity in the range of 0.2 mm^2/s to 30,000 mm^2/s. And the range of density which can be measured is from 0.6 g/cm^3 to 3 g/cm^3. The standards applicable are ASTM D7042, EN 16896, ASTM D4052, ISO 12185.

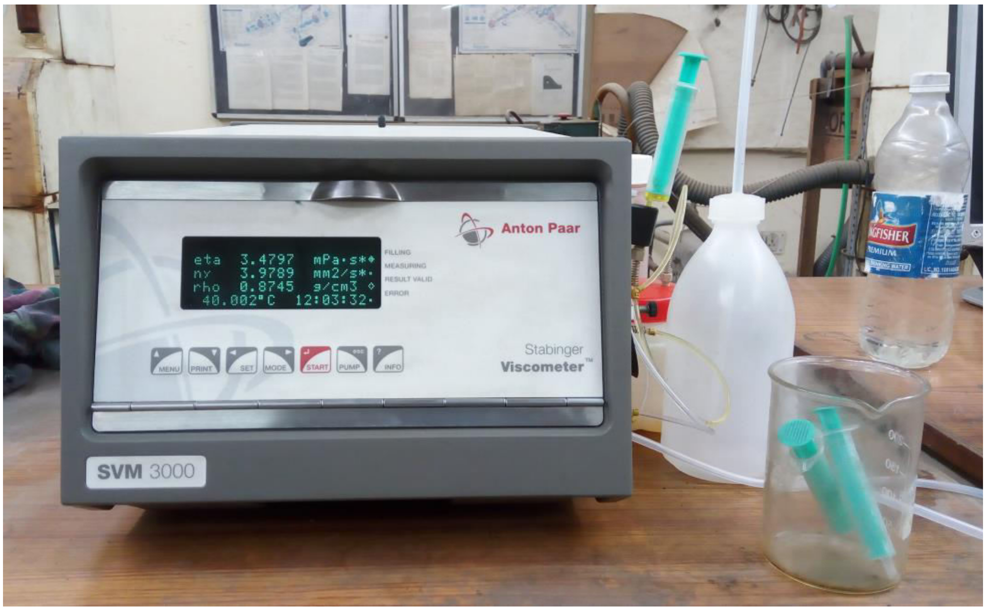


Figure 4.8: Viscometer used to measure kinematic viscosity and density of samples

4.1.9 Chemicals used

The catalyst used during the experiment is anhydrous KOH. And the sample size of linseed oil is taken as 100 grams with alcohol (methanol) as 22 grams (6:1 molar ratio), 28 grams (7.5:1 molar ratio) and 34 grams (9:1 molar ratio) respectively. While measuring the viscosity and density of the samples, toluene is used to wash viscometer after each property test.

4.1.10 Stop watch

A simple digital watch is used for the measurement of reaction time as the reaction times are 90 minutes, 105 minutes and 120 minutes, respectively.

4.1.11 Calorimeter

Calorimeter is a device used to measure the calorific value of a fuel sample, it may be raw oil or blend or any other liquid. The calorimeter used in this research work is ‘Parr 6100’ Calorimeter as shown in the figure 4.9.

Figure 4.9: Calorimeter used to measure calorific values of biodiesel sample

4.2 Procedure for Biodiesel production

The procedure for biodiesel production is available in many research papers. Initially, the free fatty acid (FFA) content is calculated for determining whether to go with two-step acidic transesterification process (when FFA >2.5) or single step transesterification process (when FFA <2.5). From literature reviews, the FFA content of linseed oil is found to be below 2.5 which is suitable for single step transesterification process. Thus, a homogeneous base catalyst (KOH) transesterification process with methanol is performed to produce methyl esters (or biodiesel). The following step wise demonstration of biodiesel production is as follows:

- Initially, the raw linseed oil is filtered for any impurities present in it.
- The filtered raw oil may contain moisture content which may lead to soapification process during the transesterification. Thus, the filtered raw linseed oil is heated upto 120 °C for about 5-10 minutes, this result in the evaporation of any moisture content present in it.
- Now, 100 gm of the filtered and dehumidified raw linseed oil is taken into a 250 mL beaker.

- Before the mixing of raw linseed oil and alcohol (methanol) is done, a mixture of methanol and catalyst (KOH) is formed since KOH dissolves in methanol effectively..
- This methanol-catalyst mixture is then transferred to the beaker containing raw linseed oil.
- The beaker content is then transferred to a receiver box, painted black outside and is air tight for not allowing methanol to evaporate outside, is to be placed at the focus of the paraboloid dish collector.
- Now, the paraboloid collector is adjusted in such a way that all the solar intensity falling on the dish is focused on the receiver as shown in the figure 4.10. Thus, rising the temperature and allowing the transesterification process to continue.

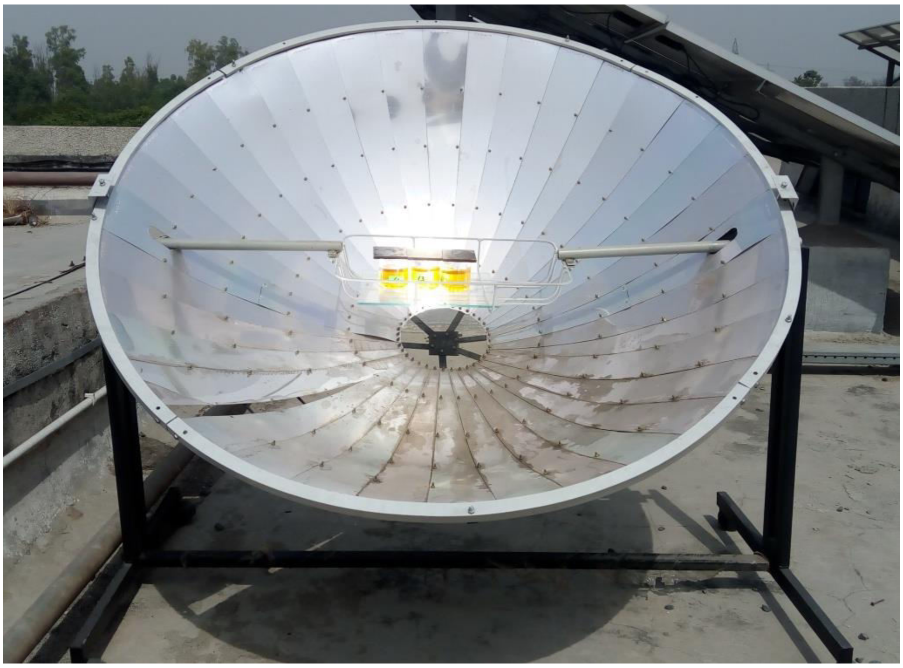


Figure 4.10: Experiment performed on paraboloid solar dish

- Once the reaction time of experiment finishes, the receiver content is transferred back to the beaker or directly poured into the separating flask.
- The sample is then stored undisturbed for about 24 hours. This leads to the settlement of glycerine (darker in colour) at the bottom of the beaker as shown in the figure 4.11.

Figure 4.11: Sample containing glycerine settled at the bottom

- The upper layer of biodiesel is transferred to a 250 mL conical flask. The sample still contains some catalyst dissolved in it. So, water washing is done to remove catalyst from the sample because the catalyst mixed biodiesel can contaminate the engine.
- For water washing, the water about 30-35 % of the sample is taken and heated above 50 °C. This hot water is then transferred to the conical flask containing biodiesel sample and mixed thoroughly.
- The mixture is then transferred to a separating flask and stored undisturbed for about 4 hours. The water-catalyst mixture comes at the bottom which is removed by bottom knob. The figure 4.12 shows water washed sample.

Figure 4.12: Separating flask with water washed biodiesel sample (upper layer biodiesel and lower layer water-catalyst mixture)

- Now, the remaining sample is poured into a beaker. Due to water washing some moisture content remains in this sample.
- So, to remove the remaining moisture content from the sample, again it is heated to 110-120 °C for about 5-10 minutes.
- The sample is then weight and the sample thus remained is the pure biodiesel as shown in figure 4.13.

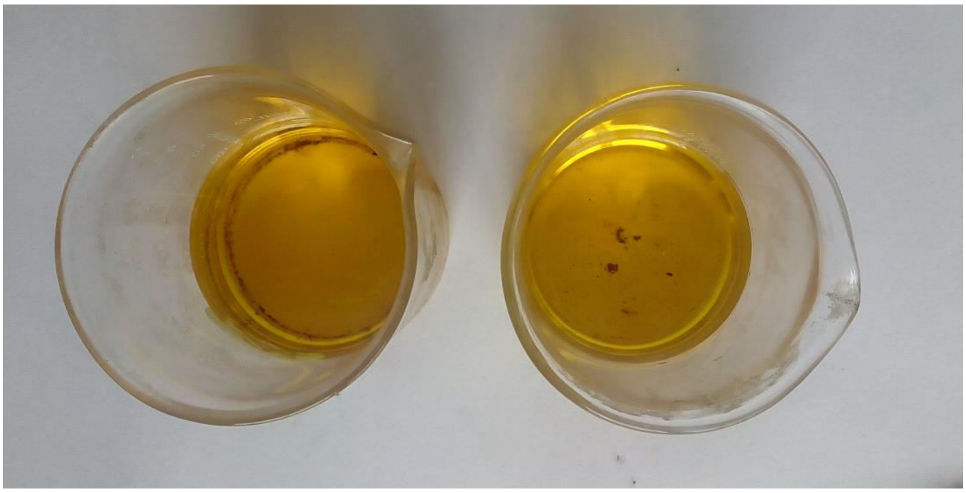


Figure 4.13: Beakers containing pure linseed oil biodiesel

- Lastly, the various physiochemical properties such as viscosity, density is measured to compare with the conventional diesel fuel.

CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 Experimental Results

The results of the experiments are categorized in the following groups as given below:-

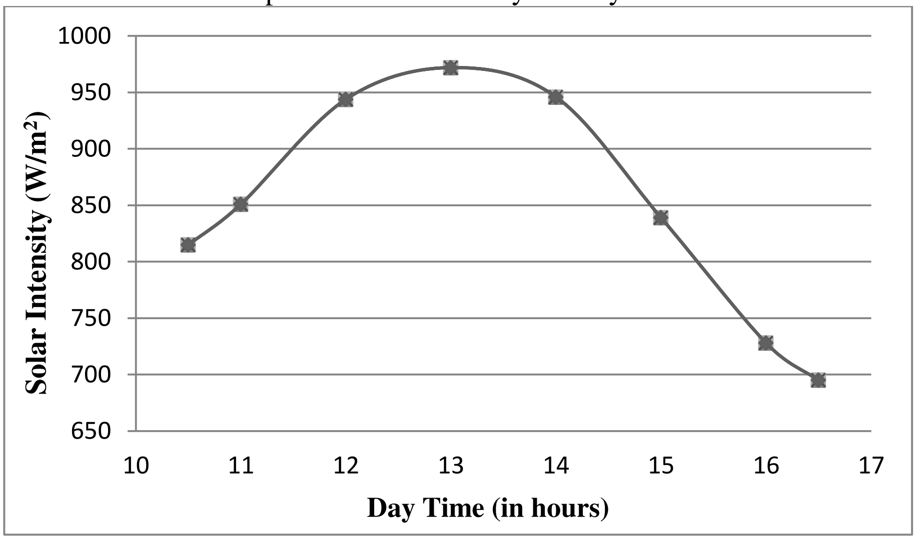
- ► Measuring the solar irradiation throughout the day and evaluating the best time period for performing experiments considering all parameters.
- ► Optimizing the parameters which may affect the yields of biodiesel production using Taguchi's approach.
- ► Evaluating the optimum yield of alkyl ester production through transesterification process of linseed oil under most favourable condition using Taguchi's approach.
- ► Using ANOVA for validation and studying the effects of different control parameters on linseed methyl ester production.
- ► Measuring and comparing the physiochemical properties of linseed methyl ester.

5.2 Measurement of solar irradiation

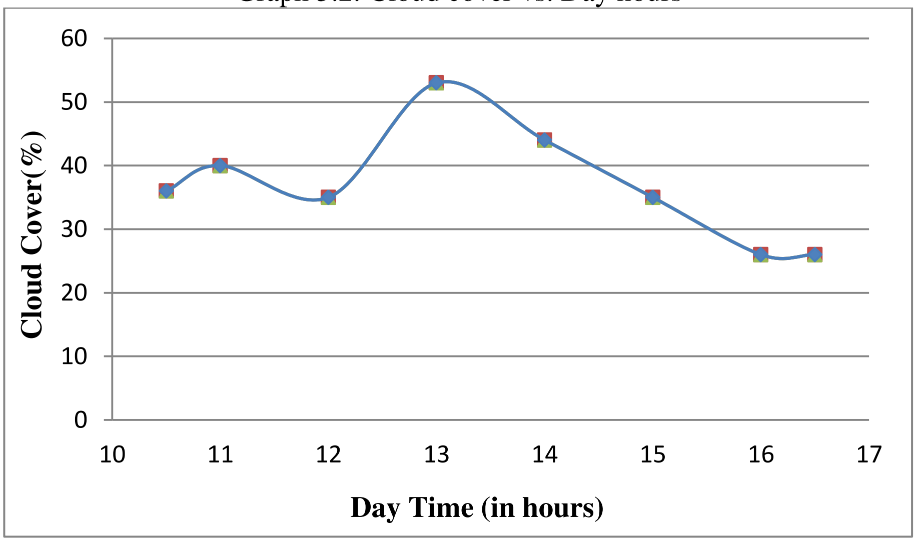
Solar irradiation (or solar intensity) is the amount of solar energy falling on the earth. And the amount of solar irradiation falling on unity sq. meter of area in a day is termed as Solar constant. The values of the solar intensity and other meteorological parameters were measured at the terrace of Mechanical Engineering Department, Delhi Technological University, Delhi, India during the month of May-June 2018.

The average wind speed recorded for 23rd and 29th May 2018 was 7 m/s; for 30th May 2018 was 14.2 m/s; for 31st May 2018 was 7.3 m/s, and 1st and 4th June 2018 recorded with 9.2 m/s and 12.3 m/s, respectively. In general, the average wind speed from 23rd May 2018 to 5th June 2018 was recorded as 9.6 m/s. The wind direction normally from East or East-South East was seen. The results for solar intensity, cloud covers and temperature with day hours are as follows:

Graph 5.1: Solar Intensity vs. Day hours



Graph 5.2: Cloud cover vs. Day hours



Graph 5.3: Temperature vs. Day time

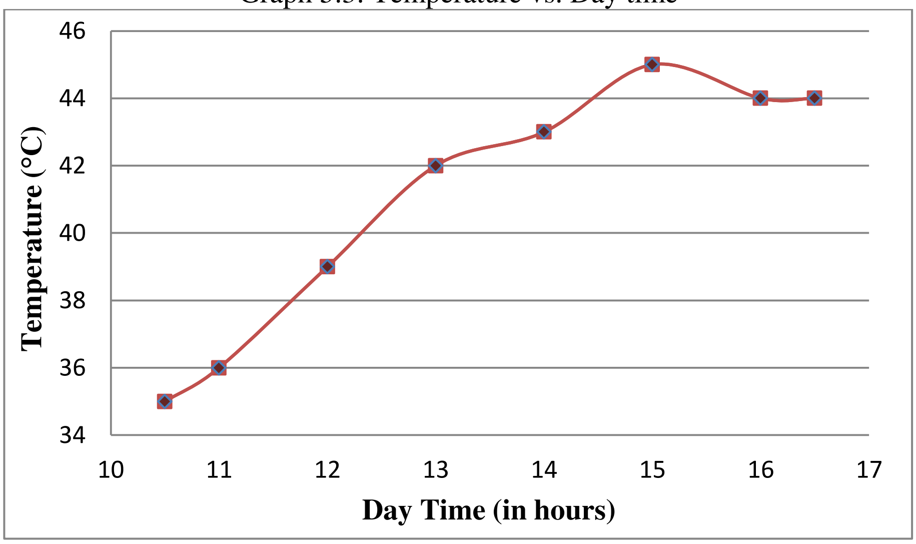


Figure 5.1: Graphs showing meteorological parameters for 23rd May 2018

Figure 5.1 shows the meteorological parameters for 23rd May 2018. Graph 5.1 gives the variation of solar intensity during the sunny day of 23rd May 2018. From the graph, it was seen that the solar intensity rises from morning to noon and at 13:00 hour's solar intensity reaches at its peak value of 972 kW/m^2. Then again a fall is seen in solar intensity as the day proceeds and at about 1630 hours 695 kW/m^2 of solar intensity is measured. Cloud cover throughout the day is depicted by graph 5.2. This graph shows that the sky was slight cloudy during 23rd May 2018 with a cloud cover range between 26 % (at 16:00 hour) to 53 % (at 13:00 hour). Whereas the average cloud cover throughout the day is seen as about 36.9 %. And thus, considerable amount of solar intensity is reduced. Graph 5.3 gives the variation of atmospheric temperature. From the graph, a continuous raise of temperature is seen from 10:30 hours to about 15:00 hours (with peak temperature 45°C of the day). But the average atmospheric temperature from 13:00 hours to 16:30 hours is seen about 44 °C which is quite high. Thus, from 11:00 hours to 16:00 hours gives the required solar intensity for using solar energy as heating source for biodiesel production.

Figure 5.2 shows the meteorological parameters for 29th May 2018. The variation of solar intensity during the sunny day of 29th May 2018 is given by graph 5.4. From the graph, it was found that the solar intensity reaches at its peak value of 1080 kW/m^2 at about 13:30 hours. Then the fall starts in solar intensity as the day proceeds and at 15:30 hours it reaches to 841 kW/m^2. A minor reduction in solar intensity is seen at 15:15 hours due to cloud cover. Graph 5.5 gives the data for Cloud cover throughout the day. This graph shows that the clouds cover during 29th May 2018 were scattered with minimum cloud cover of 0 % at 15:30 hour and maximum 45 % at 15:15 hour. Whereas if the average clouds cover throughout the day is determined, then about 16 % can be seen. This low clouds cover percentage does not block the solar intensity. Thus, solar intensity reaches above 1000 kW/m^2 mark. The variation of atmospheric temperature is understood by graph 5.6. The peak temperature is 44 °C at 15:30 hours when 0% clouds cover was observed. While the average atmospheric temperature from 12:00 hours to 15:30 remained at about 41.5 °C. Inspite of cloud covers the time from 11:00 hours to 16:00 hours gives the required solar energy (solar intensity) as heating source for biodiesel production.

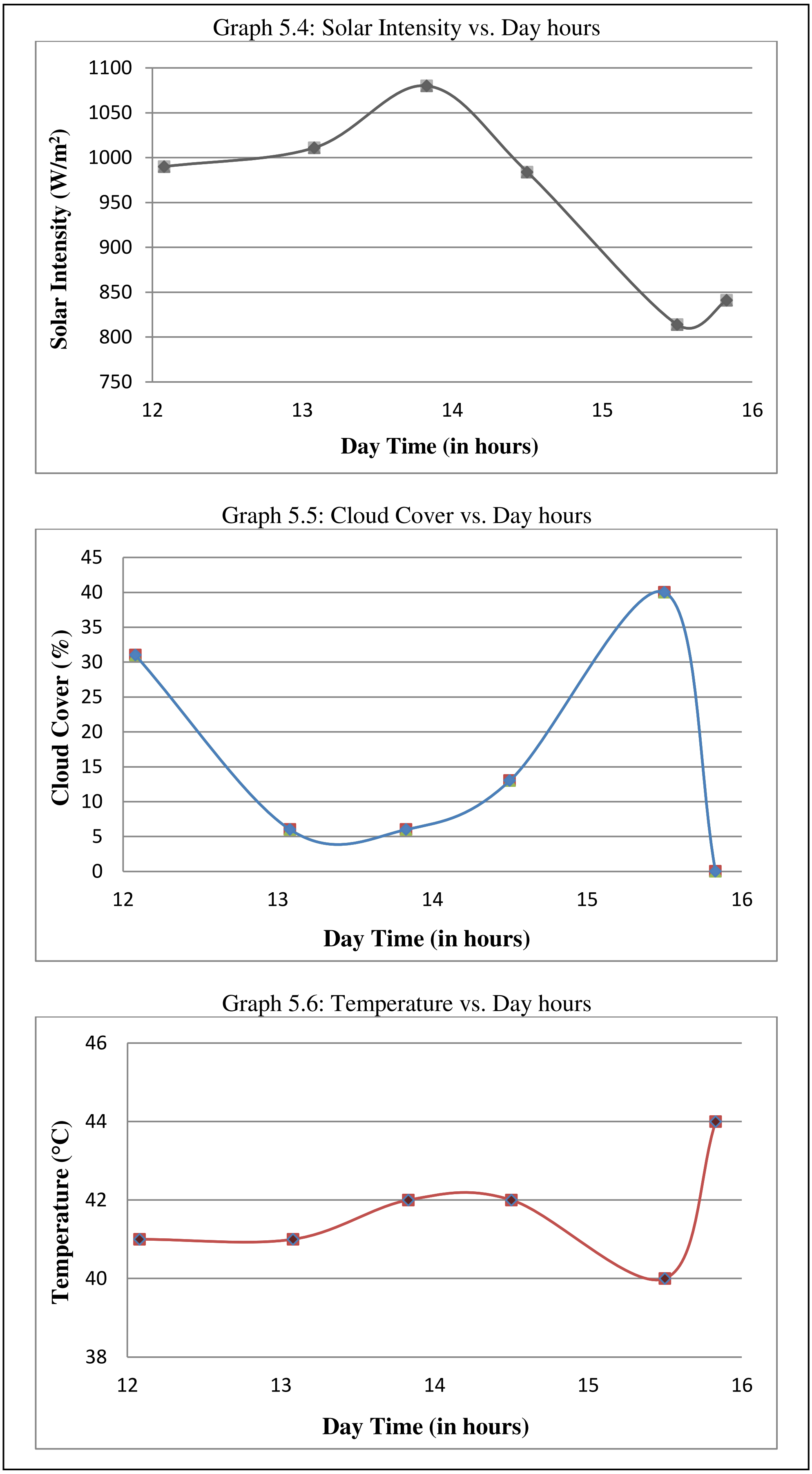
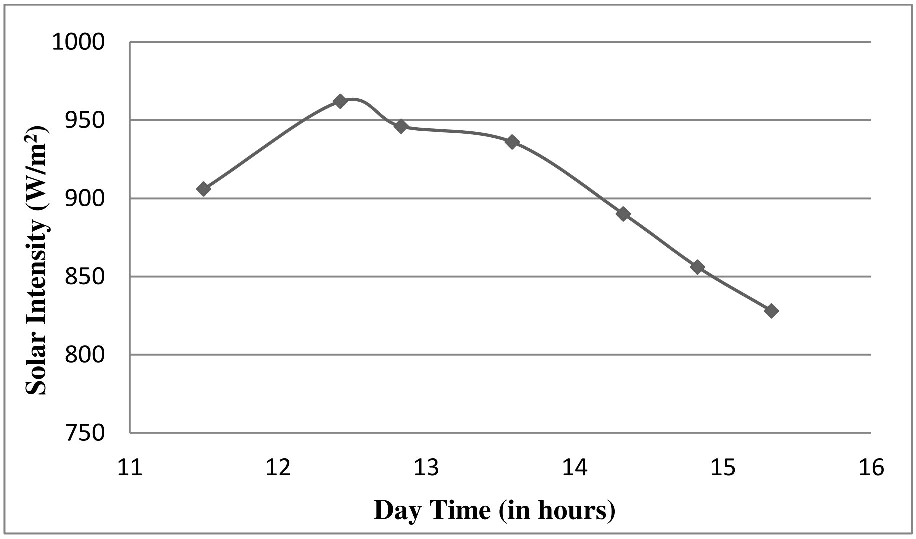
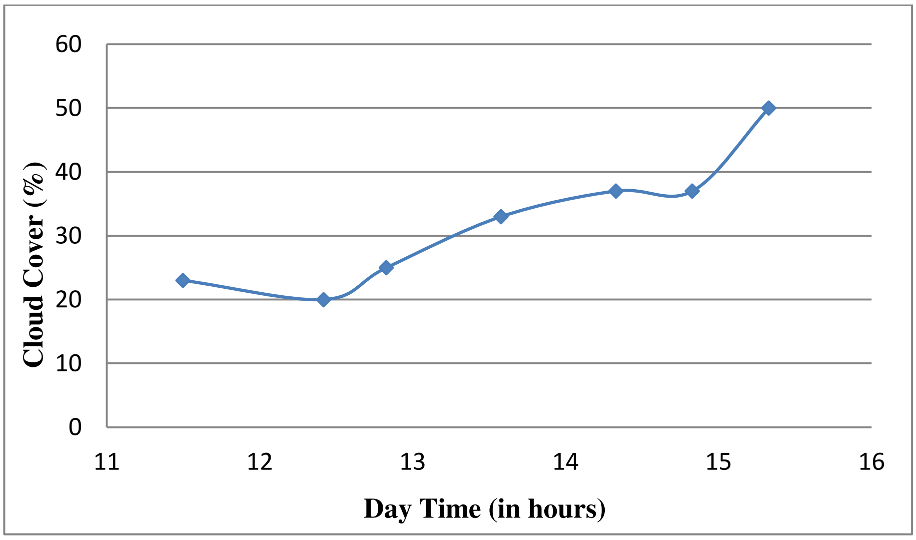


Figure 5.2: Graphs showing meteorological parameters for 29th May 2018

Graph 5.7: Solar Intensity vs. Day hours



Graph 5.8: Cloud Cover vs. Day hours



Graph 5.9: Temperature vs. Day hours

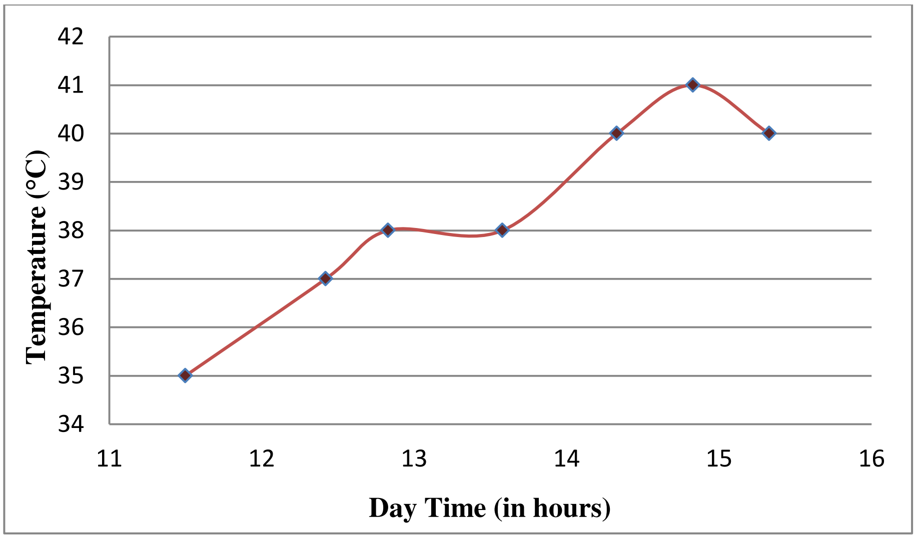
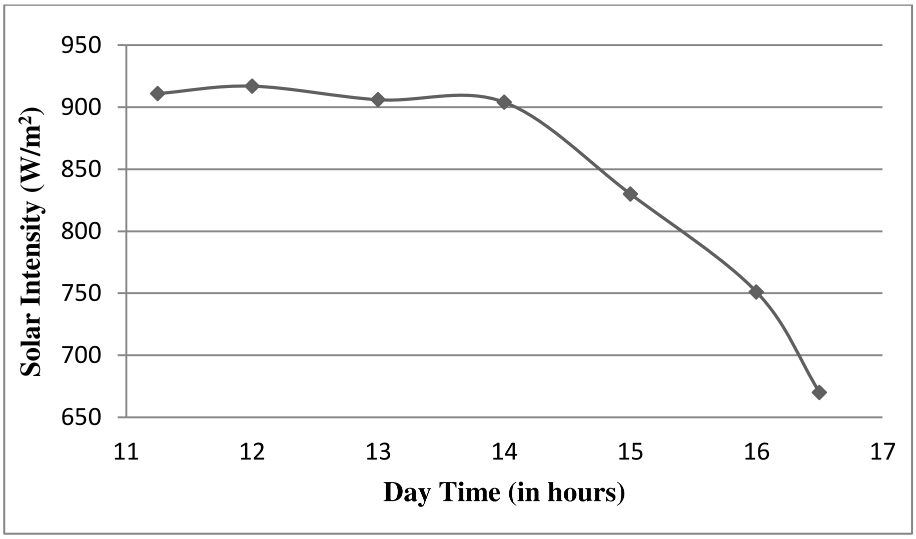


Figure 5.3: Graphs showing meteorological parameters for 30th May 2018

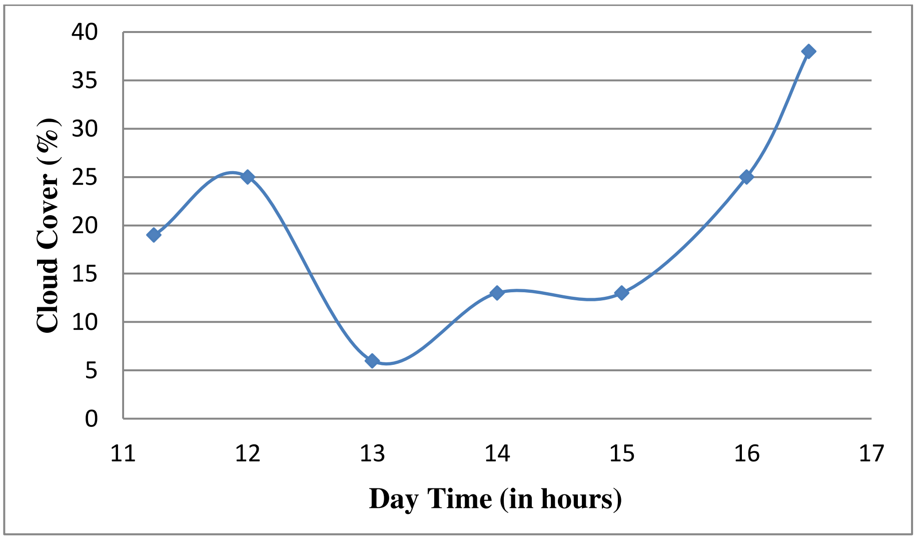
Figure 5.3 shows the meteorological parameters for 30th May 2018. Graph 5.7 is the curve of the variation of solar intensity during 30th May 2018. It was found that the solar intensity at about 12:30 hour reaches to its peak value of 962 kW/m^2. Then the downfall can be detected in solar intensity as the day proceeds. At about 15:20 hour, the solar intensity becomes 828 kW/m^2 as measured by the solar power meter. Graph 5.8 depicts the cloud cover. The graph clearly shows that the sky was cloudy during 30th May 2018 with a cloud cover range between 20% at 12:30 hour to 50% at 15:20 hour. Whereas the average cloud cover throughout the day was determined to about 32.1% which reduces solar intensity upto a considerable amount. Graph 5.9 gives the variation of atmospheric temperature. A continuous raise of temperature was seen from 11:30 hour to 15:15 hour with the peak temperature 45°C of the day at 14:50 hour. The average atmospheric temperature was measured as 38.2 °C from 11:30 hours to 15:15 hour. With cloudy sky during 11:00 hours to 16:00 hours again the required solar energy (intensity) as heating source is received for biodiesel production.

Figure 5.4 shows the meteorological parameters for 31st May 2018. The variation of solar intensity during the sunny day of 31st May 2018 has been given by the graph 5.10. From the graph, it can be examined that the solar intensity reaches at its peak value of 917 kW/m^2 at 12:00 hour and remains above 900 kW/m^2 from 11:00 hour to 14:00 hour. Then the fall in solar intensity can be seen as the day proceeds and becomes 670 kW/m^2 at 16:30 hour. Graph 5.11 gives the data for Cloud cover. The graph clearly shows that the uneven cloudy sky during 31st May 2018 with a minimum cloud cover of 4% at 13:00 hour and a maximum 40% at 16:30 hour. While the average clouds cover throughout the day is determined to be about 19.9%. The variation of atmospheric temperature was given by graph 5.12. The peak temperature reached was 42 °C and remained constant from 15:00 hour to about 16:30 hour. While the average atmospheric temperature measured from 11:15 hour to 16:30 hour remained at about 40.6 °C. Thus, uneven cloudy sky during 11:00 hours to 16:00 hours was the brightest interval of the day giving the required amount of solar intensity for using solar energy as heating source for biodiesel production.

Graph 5.10: Solar Intensity vs. Day hours



Graph 5.11: Cloud Cover vs. Day hours



Graph 5.12: Temperature vs. Day hours

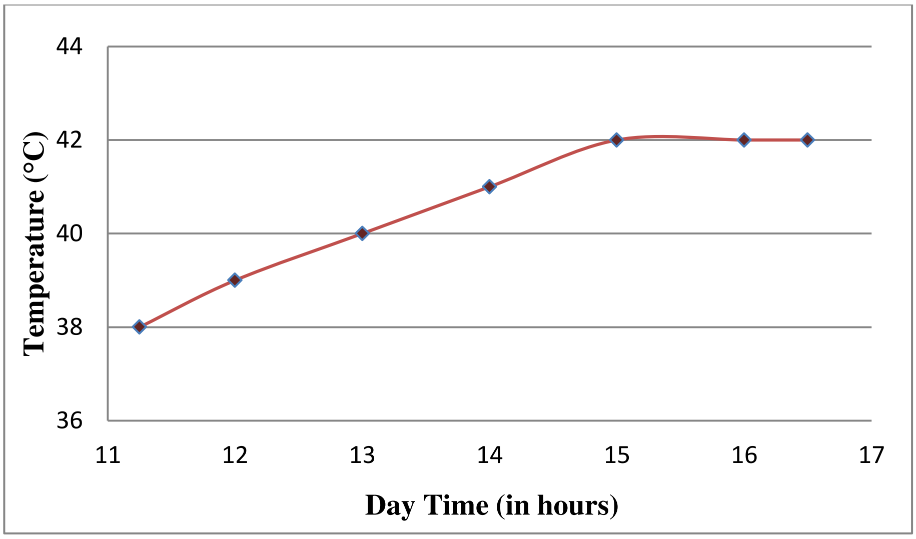
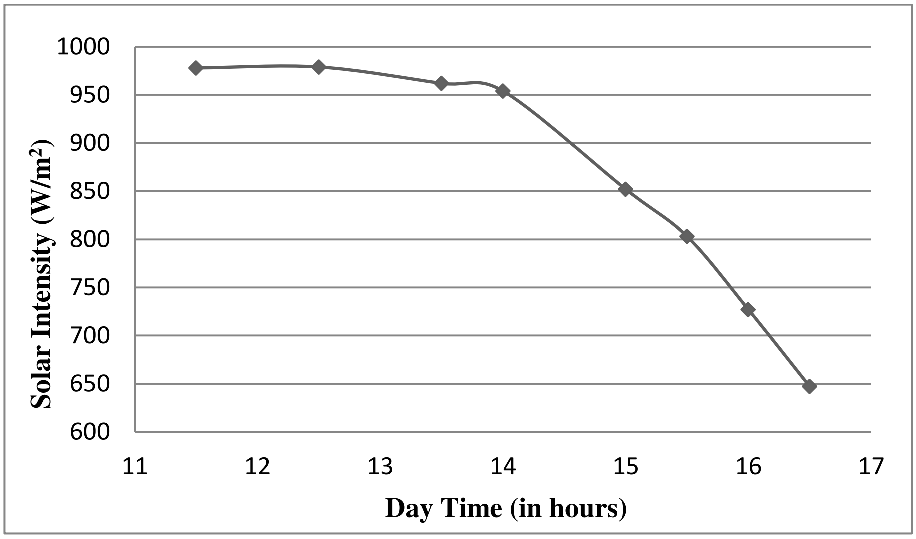
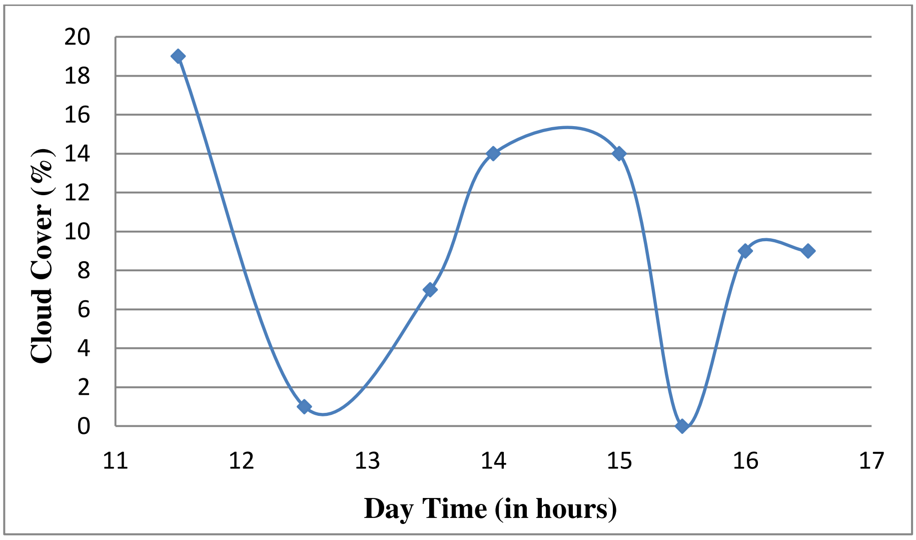


Figure 5.4: Graph showing meteorological parameters for 31^{st} May 2018.

Graph 5.13: Solar Intensity vs. Day hours



Graph 5.14: Cloud Cover vs. Day hours



Graph 5.15: Temperature vs. Day hours on 1st June 2018

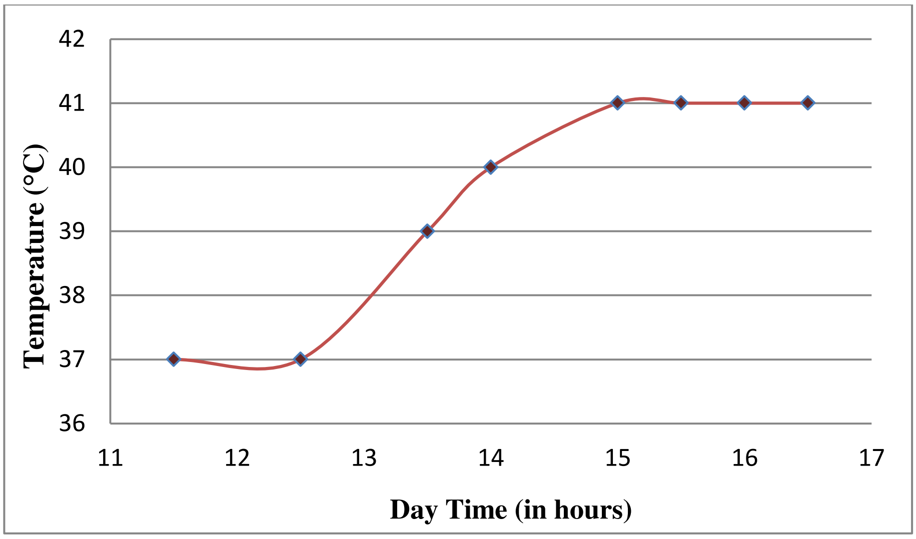
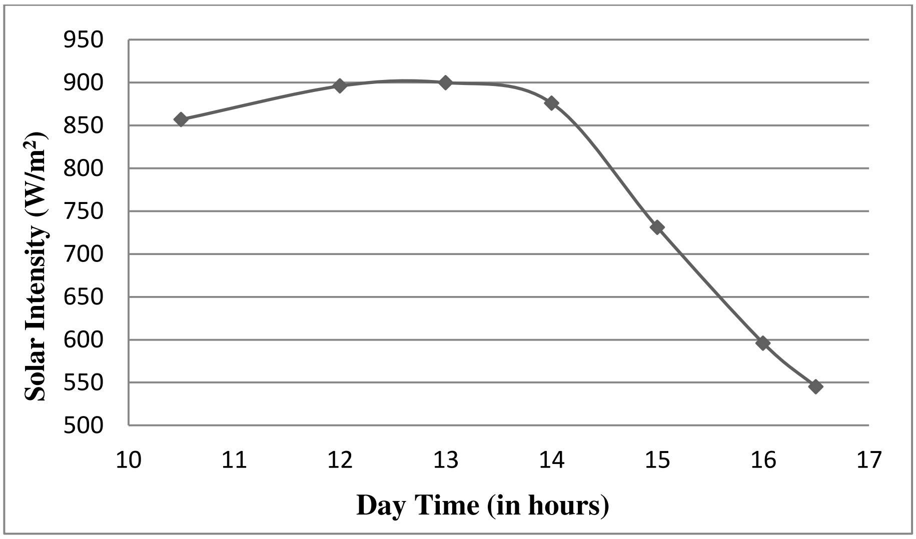


Figure 5.5: Graphs showing meteorological parameters for 1st June 2018

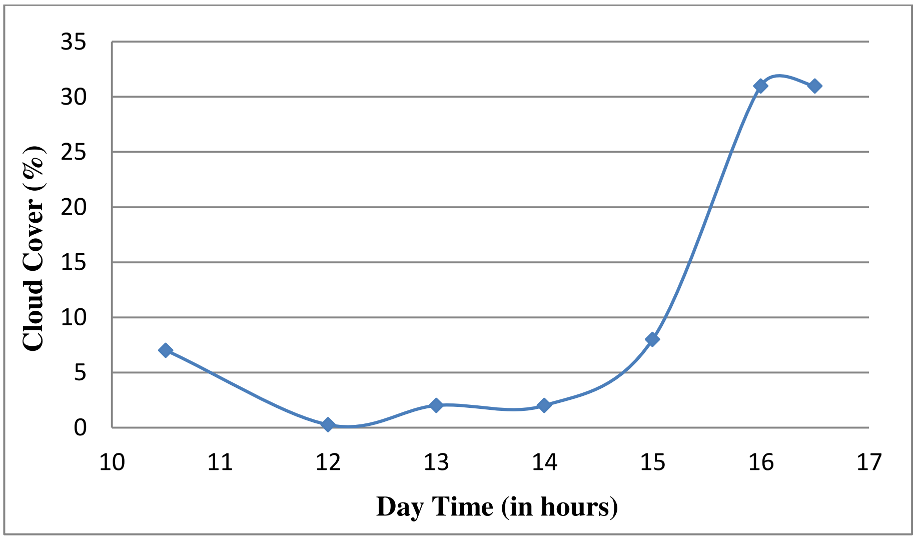
Figure 5.5 shows the meteorological parameters for 1st June 2018. Graph 5.13 gives variation of solar intensity during sunny day of 1st June 2018. It was found that the solar intensity at about 12:30 hour reaches to its peak value of 979 kW/m^2. Then, the solar intensity decreases when the day proceeds. At about 16:30 hour, the solar intensity becomes 647 kW/m^2 as measured. The graph 5.14 depicts the cloud cover. The sky was quite clear during 1st June 2018 with a cloud cover range between 0% to about 19%. And the average cloud cover throughout the day was measured to about 9.1% which gives a very steady solar intensity throughout the day. Graph 5.15 gives the variation of atmospheric temperature. A continuous raise of temperature was seen from 11:30 hour to 15:00 hour and once the peak temperature of 41°C is reached, it remained at peak for 16:30 hour. While the average atmospheric temperature was measured as 39.6 °C. Uneven cloud cover with very less cloud cover percentage during 11:00 hours to 16:00 hours giving the required amount solar intensity for using solar energy as heating source for biodiesel production.

Figure 5.6 shows the meteorological parameters for 4th June 2018. Graph 5.16 gives variation of solar intensity during sunny day of 4th June 2018. The graph shows rise in solar intensity from morning to noon and at 13:00 hour solar intensity reaches at its peak value of 900 kW/m^2. Then the fall can be seen in solar intensity as the day proceeds and at 16:30 hours the solar intensity measured was 545 kW/m^2. The cloud cover was depicted by graph 5.17. The graph gives the clear picture that the sky was quite clear during 30th May 2018 most of the time being below 8%. Only after 16:00 hour clouds came and the cloud cover reached about 31%. While the average cloud cover throughout the day still remained about 11.6%. The variation of atmospheric temperature is shown by the graph 5.18. A continuous raise of temperature was seen from 10:30 hour to 14:00 hour and once the peak temperature of about 41°C is reached, it remained at peak for about 16:30 hour. While the average atmospheric temperature was measured was 40.3 °C. The sky was quite clear with very little cloud cover during 11:00 hours to 16:00 hours giving the required amount solar intensity for using solar energy as heating source for biodiesel production.

Graph 5.16: Solar Intensity vs. Day hours



Graph 5.17: Cloud Cover vs. Day hours



Graph 5.18: Temperature vs. Day hours

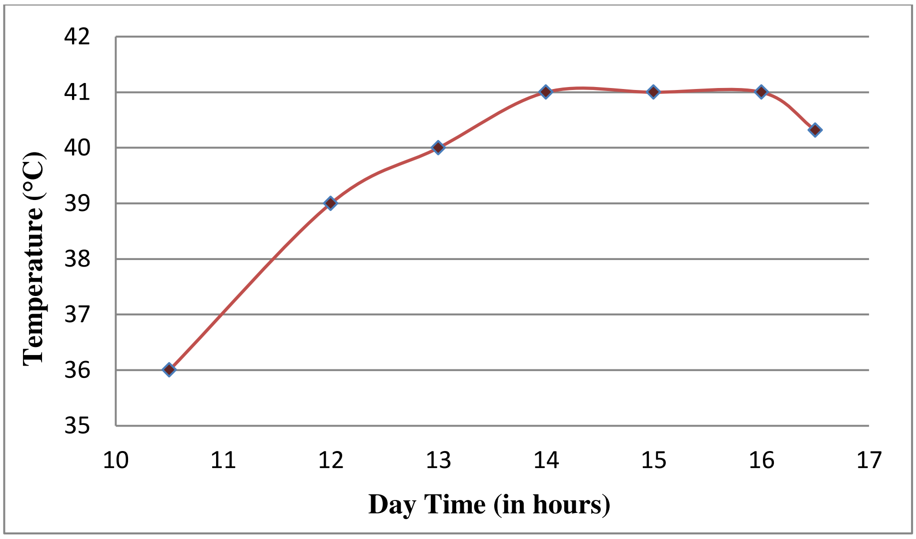


Figure 5.6: Graphs showing meteorological parameters for 4th June 2018

5.3 Optimization of the parameters effecting the yield of biodiesel

Table 5.1 shows the percentage yield with the parameters and S/N (Signal to Noise ratio) ratios of the selected experiment, respectively. Among the three characteristic types of S/N ratio, here larger the better is used to measure the optimum condition.

Table 5.1: Methyl ester yields from Linseed Oil and S/N ratios of 27 performed experiments

Experiment no.	Molar Ratio	Reaction Time (min.)	Catalyst Concentration (wt %)	Yield (%)	S/N ratio
1	6:1	90	0.50	74.59	37.4541
2	6:1	90	0.75	75.48	37.5564
3	6:1	90	1.00	71.96	37.1421
4	6:1	105	0.50	78.62	37.9109
5	6:1	105	0.75	76.35	37.6564
6	6:1	105	1.00	73.28	37.3001
7	6:1	120	0.50	78.98	37.9507
8	6:1	120	0.75	75.91	37.6065
9	6:1	120	1.00	72.40	37.1947
10	7.5:1	90	0.50	78.11	37.8540
11	7.5:1	90	0.75	75.92	37.6076
12	7.5:1	90	1.00	77.23	37.7552
13	7.5:1	105	0.50	80.30	38.0947
14	7.5:1	105	0.75	76.79	37.7059
15	7.5:1	105	1.00	78.90	37.9413
16	7.5:1	120	0.50	77.67	37.8053
17	7.5:1	120	0.75	76.35	37.6564
18	7.5:1	120	1.00	76.43	37.6650
19	9:1	90	0.50	80.00	38.0614
20	9:1	90	0.75	82.07	38.2832
21	9:1	90	1.00	79.29	37.9839
22	9:1	105	0.50	82.48	38.3274
23	9:1	105	0.75	80.97	38.1667
24	9:1	105	1.00	80.64	38.1314
25	9:1	120	0.50	80.80	38.1481
26	9:1	120	0.75	82.82	38.3628
27	9:1	120	1.00	78.53	37.9007

The equation for the mean square deviation (MSD) for the case larger the better is as follows:

$$MSD = \frac{1}{n} \sum_{i}^{n} \left(\frac{1}{y_i} \right)^2 \quad (5.1)$$

Where *n* represents the repetition of the experiments

and y_i represents the methyl ester yield

Also, the S/N ratio is calculated as:

$$S/N\ ratio = -10\ \log\ (MSD) \qquad (5.2)$$

From the table 5.1, the highest yield of biodiesel is about 82.82% for molar ratio 9:1, reaction time of 120 minutes and the catalyst concentration of 0.75 wt% with a highest S/N ratio of 38.3628, whereas the mean S/N ratio is measured to be 37.8231 for all experiments.

The mean S/N ratios for each parameter and for each level are given in table 5.2. The mean S/N ratio for any given level of a given parameter is the average value of all the S/N ratios of that parameter on all particular levels at the given experimental conditions. For example, the mean S/N ratio for molar ratio at level 1 (i.e. at 6:1 ratio) is the average of the S/N ratios of the experiment no. 1, 2, 3, 4, 5, 6, 7, 8 and 9 since the molar ratio is 6:1 for all considered experiments. Similarly, the mean S/N ratio for reaction time at level 2 (i.e. at 105 minutes) is the average of the S/N ratios of the experiment no. 4, 5, 6, 13, 14, 15, 22, 23, 24 as all the experiments has reaction time of 105 minutes.

Table 5.2: Response table for S/N ratio of each Level, Delta value and Rank of each parameter

Parameters	Level			Delta	Rank
	1	2	3		
Molar Ratio (oil/methanol)	37.53	37.79	38.15	0.62	1
Reaction Time (minutes)	37.74	37.91	37.81	0.17	3
Catalyst Concentration (wt %)	37.96	37.84	37.67	0.29	2

Using the mean S/N ratios for each parametric level from the table 5.2, the Delta values can be calculated for each parameter. Delta values determine the ranking of parameters effects. Here, the ranks are 1st rank is for molar ratio followed by catalyst concentration and reaction time with 2nd rank and 3rd rank.

Similarly, effects of means for each parameter and for each level can be used to rank from table 5.3. As seen from the table, the molar ratio has 1st rank, then the catalyst concentration and reaction time comes with 2nd and 3rd ranks respectively.

Table 5.3: Response table for Means of each Level, Delta values and Rank of each parameter

Parameters	Level			Delta	Rank
	1	2	3		
Molar Ratio (oil/methanol)	75.29	77.52	80.84	5.56	1
Reaction Time (minutes)	77.18	78.71	77.77	1.52	3
Catalyst Concentration (wt %)	79.06	78.07	76.52	2.55	2

5.4 Validation of the effects of various control parameters by ANOVA

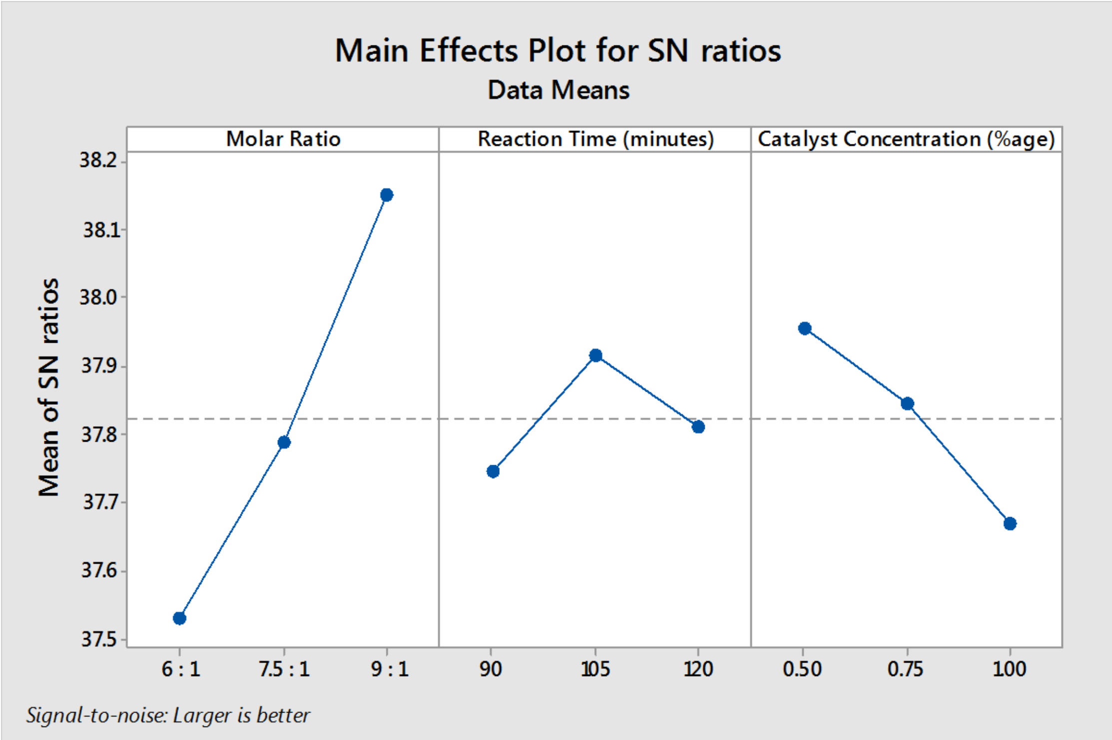
Table 5.4: ANOVA table to determine influence of parameters

Parameters	Degree of Freedom	Sum of Squares	Mean Square	F-Value	P-Value	Contribution (%)
Molar Ratio	2	140.72	70.358	33.22	0.000	63.01
Reaction Time	2	10.62	5.312	2.51	0.107	4.76
Catalyst Conc.	2	29.64	14.819	7.00	0.005	13.27
Error	20	42.36	2.118			18.96
Total	26	223.34				100

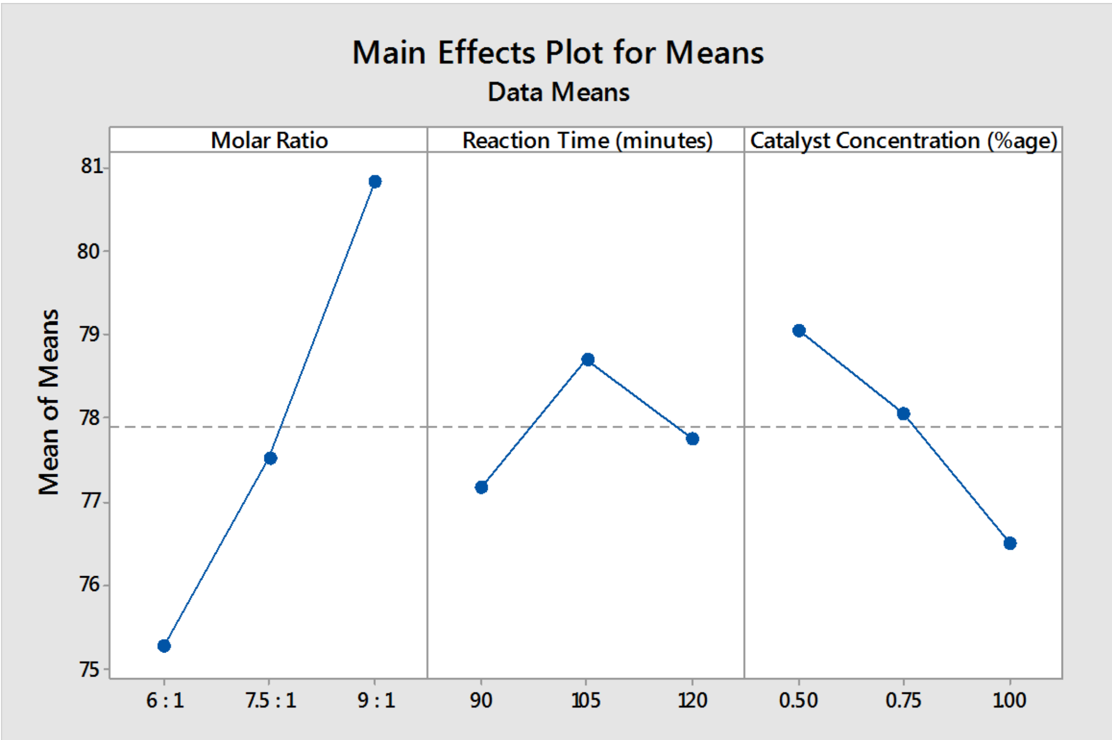
From table 5.4, the influence of various parameters on alkyl ester yield can be determined using ANOVA. As given in the table, degree of freedom for each parameter is found to be 2, then sum of squares and mean squares are also available. Through the table, F-value and P-value with percentage contribution can be easily determined. F-value determines the contribution of a parameter. Bigger the F-value, larger will be the contribution. In this case, molar ratio has the highest F-value of 33.22 which means the contribution of molar ratio is highest with 63.01%. Next come P-value, which should be closer to zero. Closer the P-value of a parameter to zero higher will be the contribution of that parameter. Also, P-value should not exceed 0.5, parameters with >0.5 P-value has no influence on results. From the table clearly seen that molar ratio with P-value 0.000 has highest contribution percentage and reaction time with 0.107 P-value has the least contribution percentage. While it is clear that none of the parameters has P-value greater than 0.5. As discussed earlier, the highest contribution percentage of molar ratio with 63.01%, followed by catalyst concentration and reaction time with 13.27% and 4.76% contribution percentages respectively.

5.5 Effects of parameters on alkyl ester production

Graph 5.19: Effects of S/N ratios (Larger is Better) on Minitab by Taguchi's approach



Graph 5.20: Effects of Means calculated on Minitab by Taguchi's approach



5.5.1 Effect of Molar ratio (methanol/oil)

First graphs in graph 5.19 and 5.20 shows the effects of mean S/N ratio (larger is better) and the effects of mean for the molar ratio (alcohol to oil ratio). As determined from the graphs, the maximum mean S/N ratio is found to be 38.1517 for 9:1 molar ratio, followed by 37.7873 and 37.5302 for 7.5:1 and 6:1 molar ratios respectively. Similar results were seen in main effects plot of mean with molar ratio, giving the highest value of 80.8441 for 9:1 molar ratio, followed by 77.5221 for 7.5:1 molar ratio and 75.2875 for 6:1 molar ratio, respectively.

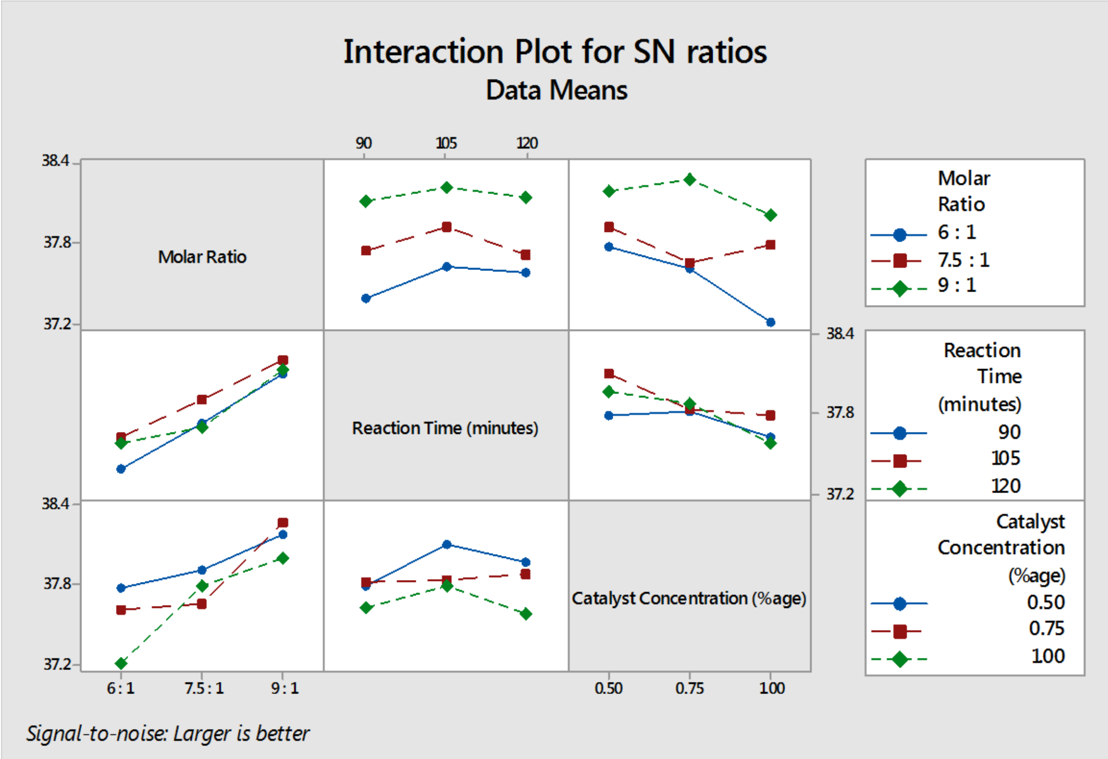
5.5.2 Effects of Reaction time (in minutes)

Next graphs in graph 5.19 and 5.20, i.e. 2nd graphs in both S/N ratios plot as well as mean plot gives the main effects of S/N ratio and mean for reaction time. The graph 19 measures the highest mean S/N ratio of 37.9150 for 105 minutes of reaction time, then comes 120 minutes of reaction time with mean S/N ratio of 37.8100 and mean S/N ratio of 90 minutes reaction time stands at last with 37.7442. While talking about the main effects of mean plot (graph 20) on reaction time, somewhat similar results are obtained as 78.7051 for 105 minutes reaction time, 77.7664 for 120 minutes of reaction time, and 77.1823 for 90 minutes of reaction time.

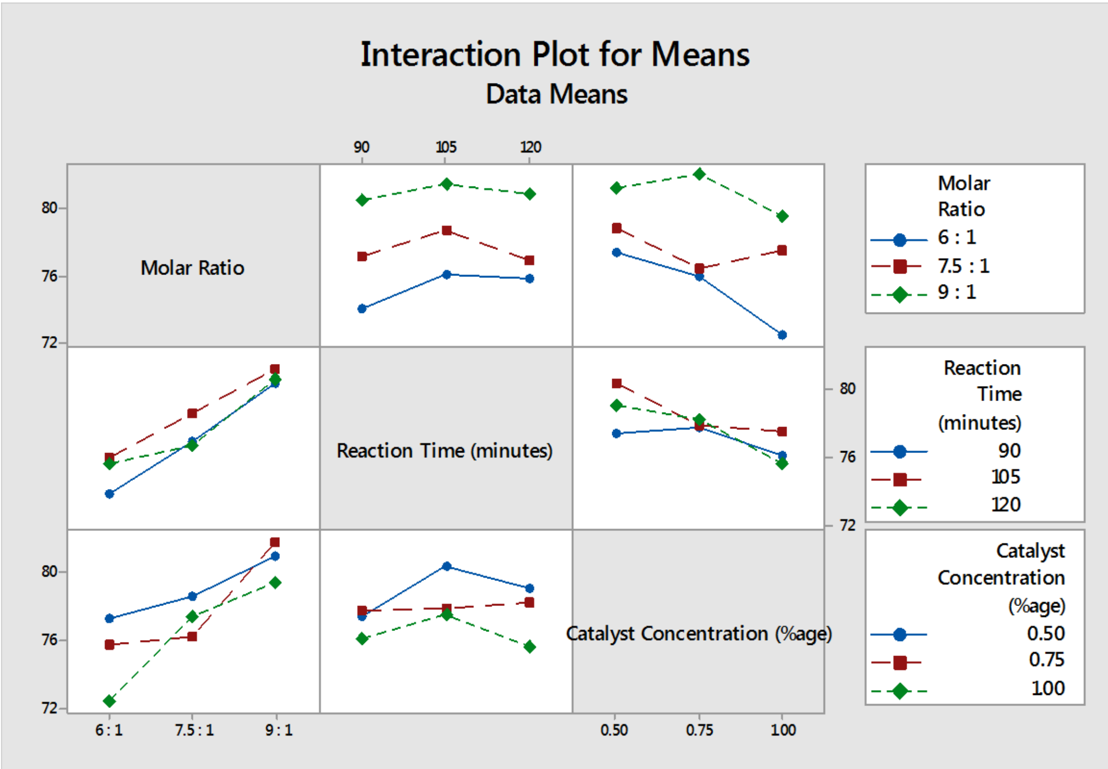
5.5.3 Effects of Catalyst concentration

3rd graphs of graph 5.19 and 5.20 show the main effects of S/N ratio and mean for catalyst concentration. As clearly determined from the graphs, the highest mean S/N ratio of 37.9563 is given by catalyst concentration of 0.5 wt%, followed by mean S/N ratio of 37.8446 by 0.75 wt% catalyst concentrations, and least mean S/N ratio of 37.6683 by 1.0 wt % of catalyst concentration, respectively. Similar, trend is seen in main effect plot of mean for catalyst concentration, where highest mean value of 79.0626 is given by 0.5 wt% catalyst concentrations, then 78.0739 by 0.75 wt % catalyst concentrations and lowest 76.5172 by 1.0 wt% catalyst concentrations.

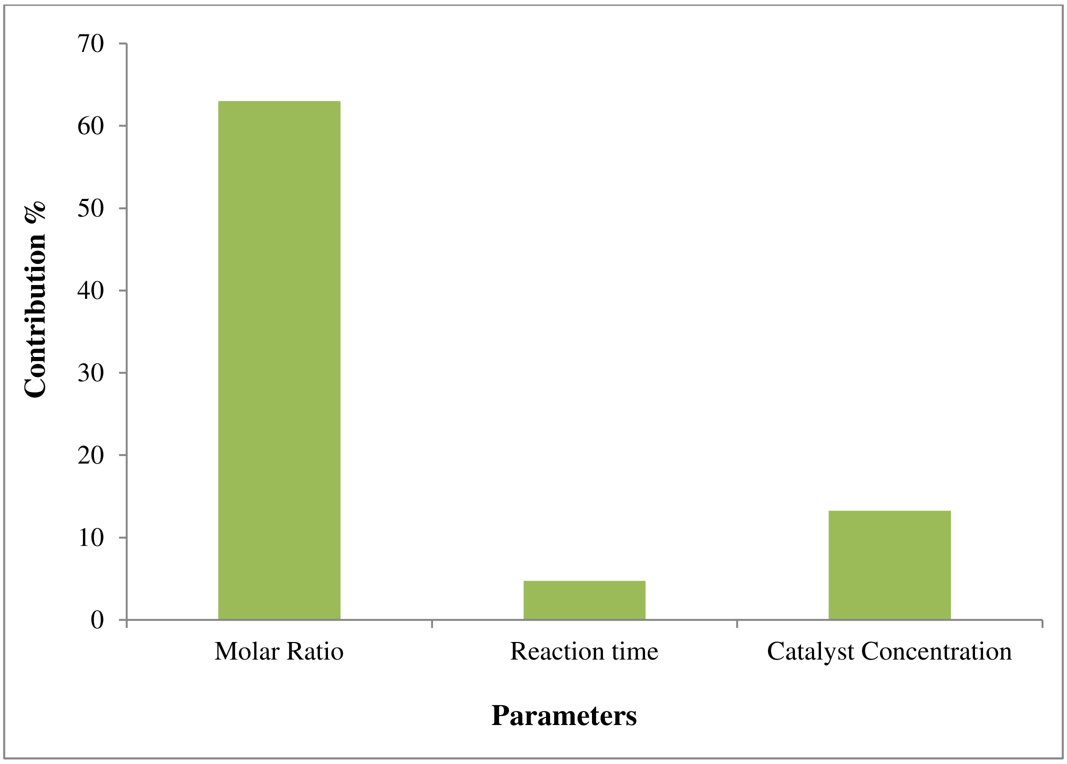
Graph 5.21: Interaction plot for S/N ratio (Larger is better)



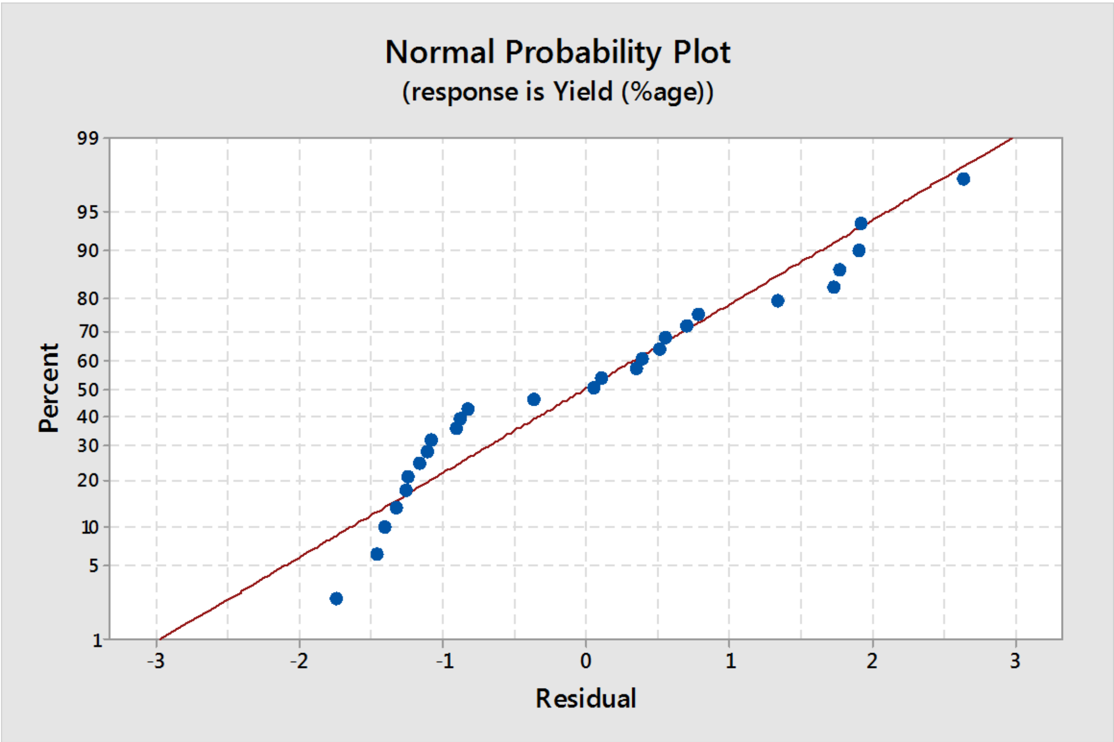
Graph 5.22: Interaction plot for Mean



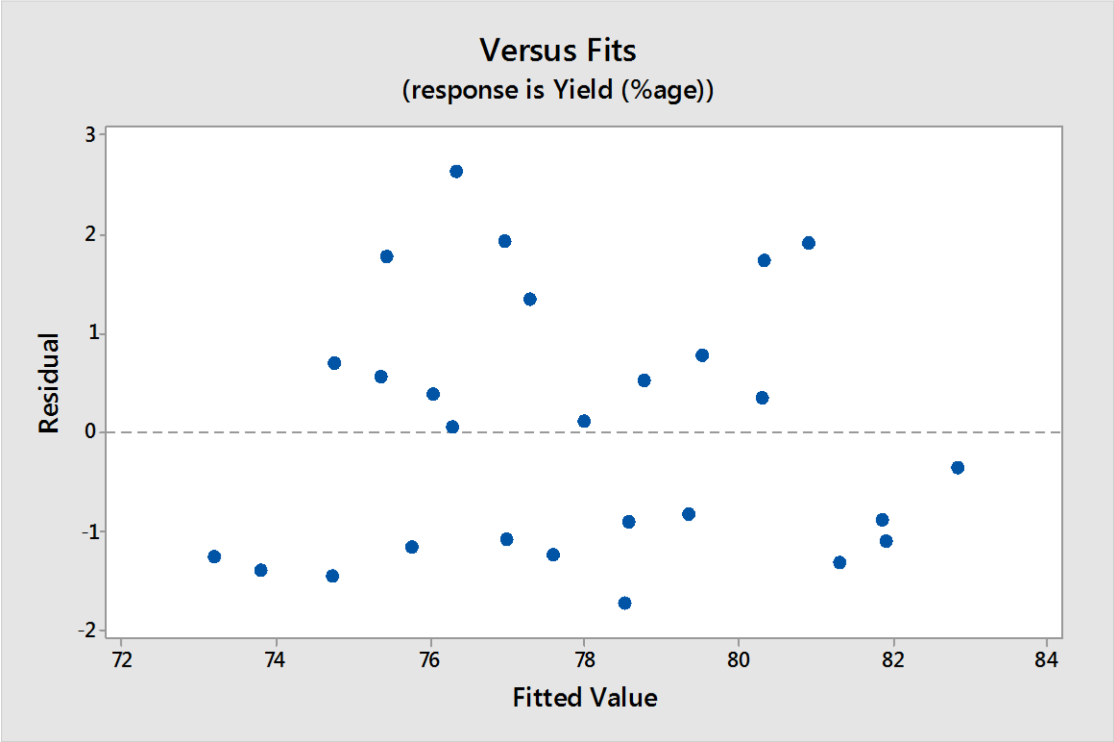
Graph 5.23: Percentage contribution of different parameters on Biodiesel production



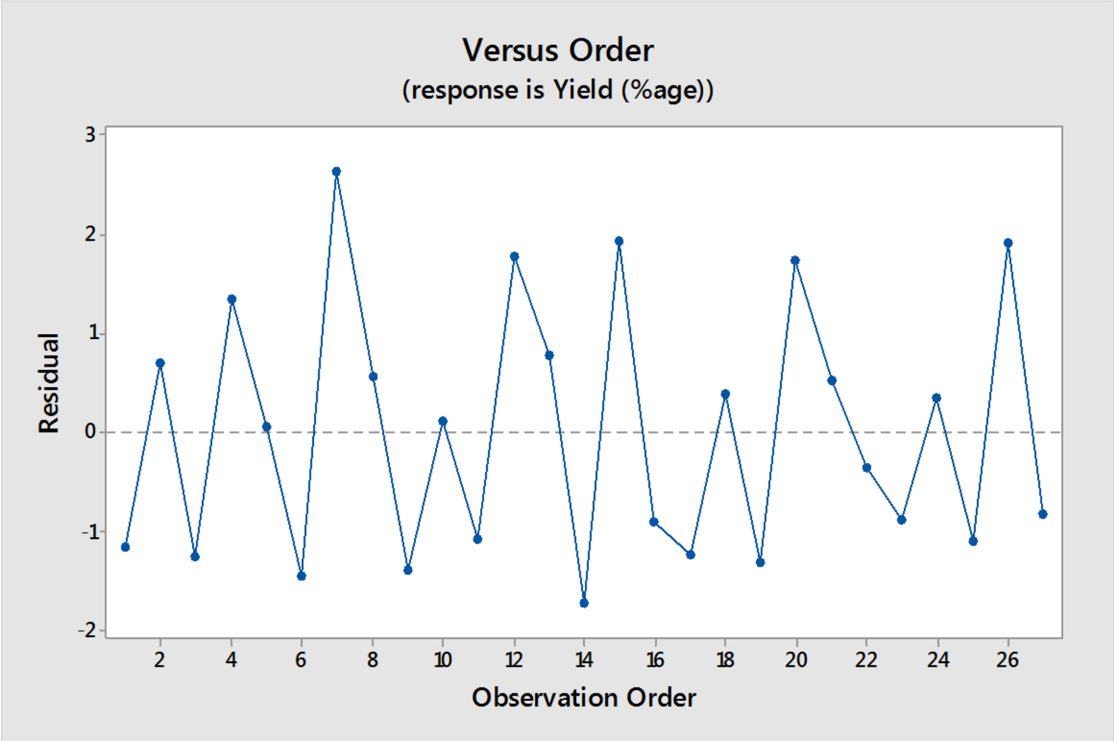
Graph 5.24: Percent Yield vs. Residual Plot



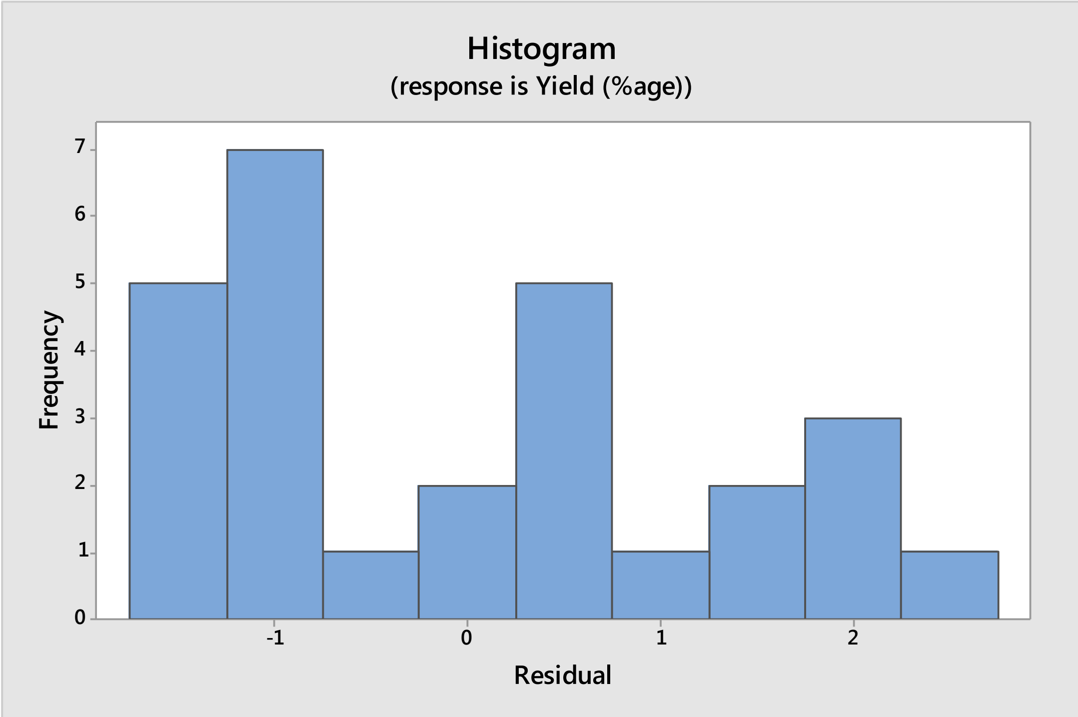
Graph 5.25: Residual vs. Fitted Value plot



Graph 5.26: Residual vs. Observation Order plot



Graph 5.27: Frequency vs. Residual plot



5.6 Comparison of physiochemical properties of Linseed oil biodiesel with Diesel

Table 5.5: Comparison of the fuel properties according to ASTM Standards

Properties	Density (kg/m^3)	Kinematic Viscosity (centistokes)	Calorific Value (MJ/kg)
ASTM Standards [51]	-	1.9-6.0	>33.0
Conventional Diesel fuel	809.6	2.815	43.5
Raw Linseed Oil	914.0	27.317	35.2
Linseed oil methyl ester (B100)	887.5	6.585	38.7
Blend (B20)	826.1	3.511	42.5
Blend (B30)	831.7	3.705	42.1
Blend (B40)	840.9	4.152	41.6
Blend (B50)	849.9	4.696	41.1

The table 5.5 above gives a comparison between conventional diesel, raw linseed oil, linseed oil methyl ester, and different diesel and biodiesel blends for the various properties such as kinematic viscosity, density and calorific value. It was clearly determined that linseed oil methyl ester has slight higher values for each properties as ASTM standard. From table 5.5, blends upto 50% are acceptable according to the ASTM standards. Thus, blends B20 to B50 can reduce the use of conventional diesel upto 20% to 50%.

CHAPTER 6

CONCLUSIONS AND FUTURE SCOPE

6.1 Conclusions

This research work includes the measuring of metrological parameters of the day during the month of May-June 2018 at Delhi Technological University, Delhi, India and measurement of corresponding solar intensity for the particular area. The following conclusions are made:

- Meteorological parameters recorded day with their effects on solar intensity. The average solar intensity is about 965-990 W/m^2 during 12:30 hours to 14:30 hours and the percentage cloud cover shows main effect. The cloud cover upto 35% during 13:30 hours can reduce the solar intensity upto 890 W/m^2.
- Also, the solar intensity was low during the morning (815 W/m^2 at 10:30 hours) and rises as the day continues, reaches the peak value from 12:30 hours to 13:30 hours. Then the solar intensity again start falling in the evening (545 W/m^2 at 16:30 hours).
- The average wind speed of 8.34 m/s and wind direction either from East or East-South East has very less convective losses from the receiver throughout the experiments.
- Atmospheric temperature measured shows a raise from morning and at about 13:00 hours reach the peak (42-45 °C) and then start falling.
- Thus, heat from the solar intensity during 11:00 hours to 15:30 hours is used to carry out transesterification process for linseed biodiesel production. The raw linseed oil having FFA content less than about <2.5 is used for a single step transesterification process.
- Optimization of yield parameters considered are molar ratio (6:1, 7.5:1, 9:1), reaction time (90 min., 105 min., 120min.) and catalyst KOH concentration (0.5 wt%, 0.75 wt%, 1.0 wt%).

- The highest S/N ratio is found to be 38.3628 for molar ratio 9:1, reaction time 120 min. and catalyst concentration 0.75 wt%. While the optimum condition was molar ratio 9:1, reaction time 105 min. and catalyst concentration 0.5 wt% with 38.3274 S/N ratio.
- The optimum parameters for optimum yield of 82.48% are 9:1 molar ratio, 105 min. reaction time and 0.5 wt% catalyst concentrations. While the highest yield obtain is 82.82% with 9:1 molar ratio, 120 min. reaction time and 0.75 wt% catalyst concentrations.
- Molar ratio has highest contribution of 63.01% followed by catalyst concentration 13.27% and reaction time 4.76%, resp.
- Density of the biodiesel is 887.5 kg/m^3 and the viscosity of biodiesel is 6.585 centistokes whereas the calorific value is 38.7 MJ/kg which is comparable with the conventional diesel.
- A blend of upto biodiesel 50% and conventional diesel 50% has comparable physiochemical properties as conventional diesel fuel.
- Using solar heat for biodiesel production will considerable reduces the cost.

6.2 Future Scope

This research work can be further extended to produce biodiesel from other non-consumable oil. The following are the future scope of work:

- High biodiesel yield obtained is 82.82% using solar energy as heating source while the other conventional biodiesel production methods gives about 90-94% yield. Thus, solar technology may be improved to increase the yield.
- New ideas for using more and more solar energy for biodiesel production in large scale have to be found to reduce the burden on conventional electricity sources and reducing the cost of production.
- Methods for methanol recovery process from the by-product glycerine are to be determined and the solar energy should be used for high heating requirement of methanol recovery.
- Since the temperature from solar energy can reach upto 150 °C, thus good pressurised vessels should be used for less evaporation of methanol.

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