“EXPERIMENTAL INVESTIGATIONS ON PYROLYSIS OF DIFFERENT BIOMASS USING SOLAR ENERGY”

A thesis submitted to the
University of Petroleum and Energy Studies

For the award of
Doctor of Philosophy
in
Power Engineering

BY
Surajit Mondal

February 2020

SUPERVISOR (s)
Dr. Jitendra K Pandey
Dr. Suresh Kumar

Research and Development
School of Engineering
University of Petroleum and Energy Studies
Dehradun-248007; Uttarakhand

“EXPERIMENTAL INVESTIGATIONS ON PYROLYSIS OF DIFFERENT BIOMASS USING SOLAR ENERGY”

A thesis submitted to the
University of Petroleum and Energy Studies

For the award of
Doctor of Philosophy
in
Power Engineering

BY
Surajit Mondal
(SAP ID 500048367)

February 2020

Internal Supervisor

Dr. Jitendra K Pandey
Professor
Department of Chemistry
University of Petroleum and Energy Studies

External Supervisor

Dr. Suresh Kumar
Professor & Director
Tula’s Institute

UPES
UNIVERSITY WITH A PURPOSE

Research and Development
University of Petroleum and Energy Studies
Dehradun-248007; Uttarakhand

ACKNOWLEDGEMENT

I would first like to thank my PhD advisors, Dr. JK Pandey and Dr. Suresh Kumar, for the past four years at UPES. Their passion and persistence in science have constantly encouraged me during my PhD study. In my first year, they spent enormous efforts guiding me on research and never lost their patience when my experiment was not going well. They would seek every chance to train my paper writing and presenting skills that help build my confidence and become a qualified researcher. Without their constant support, I would never be able to accomplish my PhD study. All the knowledge and merit that they passed on me, has made me today and will continue benefiting my future life.

I am grateful to R&D team at UPES for their support in every manner and further acknowledge the continuous encouragement received from Dr. Kamal Bansal for supporting this work in all its stages. I specially want to thank Mr. Ankit Dasgotra and Mr. Vishal Kumar Singh for helping me in formatting, etc.

I am also grateful to the lab staff and their support at our Institute (UPES) and at the Indian Institute of Technology, Rookie (IIT-R) for facilitating SEM-EDX analysis.

I would like to thank my parents for their constant support and love at every stage of my life. Completing this degree would never be possible without their love and encouragement. Finally, a gratitude to all my dear colleagues for their continuous help and support.

February 2020

DECLARATION

I declare that the thesis entitled **"Experimental Investigations on Pyrolysis of different Biomass using Solar Energy"** has been prepared by me under the guidance of Dr. Jitendra K Pandey, Professor of Chemistry, University of Petroleum and Energy Studies, Dehradun and Dr. Suresh Kumar, Professor and Director, Tula's Institute, Dehradun. No part of this thesis has formed the basis for the award of any degree or fellowship previously.

Surajit Mondal

Surajit Mondal
Research and Development
University of Petroleum and Energy Studies
Dehradun
Date: 17.02.2020

UPES
UNIVERSITY WITH A PURPOSE

Great Place To Work. Certified
APR 2019 - MAR 2020
INDIA

CERTIFICATE

I certify that Surajit Mondal has prepared his thesis entitled **"Experimental Investigations on Pyrolysis of different Biomass using Solar Energy"** for the award of PhD degree of the University of Petroleum & Energy Studies, under my guidance. He has carried out the work at the Department of Research and Development, University of Petroleum & Energy Studies.

Internal Supervisor

Dr. Jitendra K Pandey
Professor
Department of Chemistry
University of Petroleum and Energy Studies
Dehradun, Uttarakhand, 248007
Date: 17th Feb, 2020

TULA'S
DEHRADUN INSTITUTE

• Approved by AICTE, Ministry of HRD, Govt. of India • ISO 9001:2015
Affilated to: • Uttarakhand Technical University • Sri Dev Suman University • Uttarakhand Board of Technical Education

Date: 17.02.2020

CERTIFICATE

I certify that Surajit Mondal has prepared his thesis entitled **"Experimental Investigations on Pyrolysis of different Biomass using Solar Energy"** for the award of PhD degree of the University of Petroleum & Energy Studies, under my guidance. He has carried out the work at the Department of Research and Development, University of Petroleum & Energy Studies.

External Supervisor

Director
Tula's Institute
Dhoolkot,Dehradun

Dr. Suresh Kumar
Professor & Director
Tula's Institute Dehradun
Uttarakhand-248007

Mission:
- Promote intellectual and skilled human capital generating employment and entrepreneurship.
- Be educational centre of excellence of multi ethnicity and diversity.
- Establish as technology driven teaching learning institution.
- Provide world class platform for research and innovation.

Dhoolkot, P.O. Selaqui, Chakrata Road
Dehradun - 248011 (U.K India)

www.tulas.edu.in

UPES
UNIVERSITY WITH A PURPOSE

THESIS COMPLETION CERTIFICATE

This is to certify that the thesis on **"Experimental Investigations on Pyrolysis of different Biomass using Solar Energy"** by Surajit Mondal in partial completion of the requirements for the award of the degree of doctor of philosophy (in engineering) is an original work carried out by him under our joint supervision and guidance.

It is certified that the work has not been submitted anywhere else for the award of any other diploma or degree of this or any other university.

Internal Supervisor

Dr. Jitendra K Pandey
Professor
Department of Chemistry
University of Petroleum and Energy Studies
Dehradun, Uttarakhand, 248007

External Supervisor

Director
Tula's Institute
Dhoolkot,Dehradun

Dr. Suresh Kumar
Professor & Director
Tula's Institute
Dehradun, Uttarakhand, 248007

TABLE OF CONTENTS

ABSTRACT

The increasing energy demand of a rapidly growing population has rekindled the interest of humankind in the use of biomass as a source of energy. The main factors behind this resurgent interest in biofuels are the fast-depleting fossil fuel reservoirs and concerns regarding climate change. The proper choice of technology for conversion of biomass into clean-burning fuel is essential for sustained use of biomass as a source of energy. Various thermo-chemical conversion processes such as combustion, hydrogenation, liquefaction, gasification and pyrolysis have been utilized to extract various energy products from biomass. Even though pyrolysis, of all the thermo-chemical processes, is still in a preliminary stage of development, but it has received special attention in our present energy scenario as it can convert biomass into various liquid, solid and gaseous products. The use of solar energy provides a renewable source for pyrolysis, which gives it an edge over use of thermal energy from conventional fuels. Today dearth of energy is one of the biggest concerns in front of human. Increasing population demands more energy, hence burden on presently used non-renewable sources of energy. These non-renewable sources such as fossil fuel, coal are expectedly to deplete in near future. Environment pollution is also one the major problem while extracting the energy from these sources. Higher carbon foot print on the environment is one such examples of pollution. Vast majority of research is being carried out for meeting energy demand from ~~of~~ renewable sources of energy and still going on. Solar energy, wind energy, hydrothermal energy, nuclear energy etc. have been an alternative option for renewable energy.

Biomass is another substitution of energy dependence on non-renewable source. Probably it has capacity to overcome present requirement of energy. Bio-fuel from non-conventional oil containing seeds is one of major search area of biomass energy. Extraction of oil from these seeds is possible via thermochemical and biochemical ways. One of the major advantages of biomass is negligible amount of sulfur content in the fuel or oil. These fuels are CO_2 neutral fuels as the generated CO_2 after burning used by plants for their growth. Hence these are better and with very less amount of carbon foot print on the environment.

List of Tables

List of Figures

Nomenclature:

θ : Degree crank angle

$\dot{m}$: Mass flow rate of fluid/species/fuel, kg/s

$\frac{\partial q}{\partial x_1}, \frac{\partial q}{\partial x_2}, \ldots, \frac{\partial q}{\partial x_n}$: Partial differential of calculated parameter q which depends On different measured variables x1, x2,……,xn.

B : Bore, diameter of engine cylinder

BTE : Brake thermal efficiency, %

C : Carbon

C_2H_6 : Ethane

CA : Crank angle

CH_4 : Methane

CI : Compression ignition

CO : Carbon monoxide

CO_2 : Carbon dioxide

CR : Compression ratio

DTG : Differential thermo-gravimetric analysis

EGT : Exhaust gas temperature

FITR : Fourier Transform Infrared

Fspecies : Mole fraction of exhaust gas species (CO, HC and NOx)

GC-MS : Gas chromatography–mass spectrometry

H : Hydrogen

H_2 : Hydrogen molecule

HC : Hydrocarbon emission, g/kWh

HRR : Heat release rate, J/degree CA

MW : Molecular weight

N : Engine speed, rpm

NDIR : Non-dispersive infrared

NOx : Oxides of nitrogen, g/kWh

O : Oxygen

p : In-cylinder pressure
P : Rated power, Kw
PO : Pyrolysed oil
PODB20 : Blend of 20% Pyrolysed oil and 80% diesel
PODB40 : Blend of 40% Pyrolysed oil and 60% diesel
PODB60 : Blend of 60% Pyrolysed oil and 40% diesel
Q : Heat release rate, kJ
S : Sulphur
SEC : Specific energy consumption
SFC : Specific fuel consumption
T : Temperature, K or ^{o}C
TGA : Thermo-gravimetric analysis
Vg : Volume of gaseous products inside the combustion chamber
DNI : Normal Direct Irradiance

Chapter 1: Introduction

Energy prerequisite is emphatically constrained by the requests of the cultivating populace. According to the reports submitted by the World Renewable Energy Council (WREC), the total populace will increment to twelve billion continuously and as per the present situation the overall energy request will expand steeply to around multiple times [1, 2]. A turn of endeavors are being built to control the developing energy shortfall [3, 4]. Scientists are endeavoring to find elective types of energy, and this mission is emphatically constrained by the expanding stress over planetary temperature increase and environmental modification. The different assortments between the various energy sources, biomass has the particular bit of leeway of carbon being unbiased. For vital yield the carbon which is released into the environment during its activity is perused in return during the use of biomass. As of now, world's essential energy supply in the form of biomass is given around 13% and over 75% as a sustainable power source [5]. As per the report submitted by World Energy Council the Bioenergy could contribute between 25-33% of the total worldwide vital supply by 2050 [6]. For the appropriate nourishment and fiber the biomass will require efficient transformation rate and shirking of rivalry.

Of the various ways open for change of biomass in fuels, process of pyrolysis changes over bio-fuels from nice assortment of makers, counting agrarian and officer administration developments into liquid, solid and vaporous fills [7]. Every one of the three yield parts used alternatively as forces, immediately or later succeeding improvement. Pyrolysis fluid has capability to be used in IC and EC engines, particularly in Internal Combustion systems having CI. Solid scorch is significant for warming or co-firing of plants having coal manufacturing, and as topsoil manure and conditioner by which it furthermore gives aloofness of climatically carbon. Scorch can in like manner be applied to convey synthesis gas by methods for gasified strategies. The pyrolysis gaseous fluid possibly be employed in gaseous fired boilers, gaseous turbines, Spark ignition or double fuel trains. The ongoing records featured chances to deliver feasible IC motor fills by pyrolysis using biomass [8]. An overwhelming de crease of ozone harming substance (GHG) outflows is conceivable substitution of petroleum products des-tinned for IC motors with sustainable alternatives, for example, powers from pyrolysis using biomass. Great thought has been given to biofuels creation as a choice rather than oil, diesel [9–18].

Not a lot of research practices are in progress on biofuel thermal decomposition and its implifications for what it's worth yet in earliest times of advancement. To speed progress, it’s critical to solidify and spread the out happens to front line investigate. The point of this survey is subsequently to exhibit the ebb and flow status and future innovative work (R&D) possibilities of elective fills for IC motor applications, for the benefit of specialists associated with the generation and upgradation of pyrolysis energizes.

The requirement for energy is expanding because of the growing population, advancement in technology and urban development. By beginning of 22nd century, generally speaking energy request is guess to be various occasions bigger than that of today. We are seeing a steady up-ward design in energy costs. Government organizations and scientists are seeking after various choices to fulfil the moving toward energy hole realized by development sought after per capita, creating populace, and the need to limit discharges of ozone harming substance i.e. GHG started from traditional wellsprings of energy. Among the sum of different alternatives, biofuel is novel in that its carbon dependent, produce empowers like non-sustainable power sources. The utilization of biomass assets for energy generation has already begun to be notable: current biomass supply roughly 13 percentage of global essential energy and over 75 percentage of global bio energy.

Without a doubt, it's evaluated that biofuel would come up with 25–33 percentage of worldwide energy production till 2050. World Energy Council published a report concluded that the contemporary growth will carry on for many decades. Current acquiring of biomass sources needs an effective rate of conversion and evasion of competitiveness with food and fiber. Conversion of biomass from various resources can be taken place by pyrolysis, having forest and agricultural residuals into solid, liquid and gases phases. The entirety of the came about stages have possibilities energizes (straight away or after progression) in random assortments of central player for transporter, power creation, consolidated warmth and force (CHP) or joined cooling warmth and force (CCHP). Both external and internal combustion engines can use pyrolysis liquid (PL), especially internal combustion (IC) engine having compression ignition specification. The solidified sear is valuable for heat up purpose, co terminating in a coal plants, and for soil manure and conditioners where by its addition gives few sequestration of environmental based carbon. Scorch could likewise utilized to create syngas by means of gasified procedures. Pyrolysis gas could be utilized in gas-ended boilers, Turbines, SI indicated motors or Double fuel motors. Current records hyped chances to create manageable internal combustion engine sources from biofuel pyrolysis. In addition, the United Kingdom Carbon Trust had recognized bio source pyrolysis as a fascinating choice to give future fuel for conveyance purpose. IC locomotives, particularly CI specified engines, are utilized broadly global for blend of energy sources, for example, shipping, fish boats, water supply, energy creation, CHP-CCHP. Generally, they would stay well known for a period of ten years because of their higher productivity (i.e. in part and full loading) and diversity in marking (i.e. little to huge), higher capacity to weight proportion, lower capital venture and running expenses, fuel adaptability. Till 2005, complete assessed global Green House Gas emission was 44153 Mt CO_2 eq. (66.5% related to energy resources). Segment with transportation, warmth and force was 39.2 percentage approx. (considerable number of discharges) and 59% (of complete energy related), with generally IC motors (checking turbines), steam turbine filling in as primary. Right now amazingly immense abatement in GHG discharges is possible by the substitution of non-renewable energy sources energy sources headed for IC motors to restore able alternatives, for instance, fuel sources from bio-mass pyrolysis. In spite of the fact that there exists few pyrolysis review transformation procedures, variables and product varieties, generally few have been riveted on the pyrolysis fuel applications. Chiaramontia [106] issued a review paper on utilization of speedy PL in IC and EC engines for production of power, however didn't follow the utilization of PG in Internal Combustion engine. Pyrolysis of bio fuels and their implementation are in any case in the pre time of advancement. For accelerating the progress, results of cutting edge research should essentially be combined and disseminated. The objective of this examination work is right now shows the level of running and further Research and Development potential outcomes of PL and PG as substitute fuel sources in Internal Combustion motors, to help investigators connected with creation and upgradation of pyrolysis fills. This type of study will also be beneficial to those engaged in testing and improvement of engines, including manufacturers from related field.

1.1.Motivation/Need for research:

- Potentiality of renewable sources to replace fossil fuels.
- Fill the worldwide condition worry about environmental change, energy assurance, expanding oil imports.
- Limited work on solar thermal pyrolysis technology.
- Long term study of storage stability and economic viability.
- Evolution of new dedicated pyrolysis oil and gasoline engines.

1.2.Aim:

- Building up an integrated access to produce, store and use of solar thermal energy by using waste biomass of any nature.
- Design, installation and demonstration of an integrated solar thermal based biomass pyrolyser to produce fluid and gaseous biofuels.
- Performance, emission and combustion analysis of these pyrolysed biofuels on IC engines (Petrol & Diesel).

1.3.Potentiality of various types of biomass:

India makes around 450 to 500 MT of biomass for each year [19]. Biomass gives 32 percentage of all the essential energy usage in the nation currently. Energy Alternatives India checks that the potentiality right now for energy from biomasses in our nation changing by approx. 18,000 Mega Watt, although the degree of biomasses are usually defined, to a higher value of approx. 50,000 MW on the off chance that one by one way or another figured out how to enlarge the degree of explanation of biomass. [20]. The present degree of biofuel in full scale fuels use is unbelievably of lower value and is cramped generally to 5 percent mixing of ethanol in gas, where the framework has done its requirement in 10 states [21]. At this moment, biodiesel is not traded on the national fuel grandstand, yet the framework expects to gather 20 percent of the national diesel demand till 2020 using biofuel. There are roughly sixty three Million hectare badlands in state, from which around 40 MHA regions can be evolved by attempted installing jatropha. Our nation utilizes few motivating force schemes to get townspeople to reinstate squander arrival by the development of jatropha. Basic bottlenecks for biofuel plant (in view of any innovation) is the inventory network bottlenecks that results in non-accessibility of feed-stock, as showed in Fig 1. Here related issue is the unpredictability, or all the more exactly increment, in the feedstock cost. At that place are other concerns and bottlenecks as well, such as:

- Absence of sufficient approach structure and successful funding instruments;
- Absence of compelling administrative system;
- Absence of specialized limit;
- Nonattendance of powerful information dispersal;

- Constrained fruitful business exhibit model understanding.

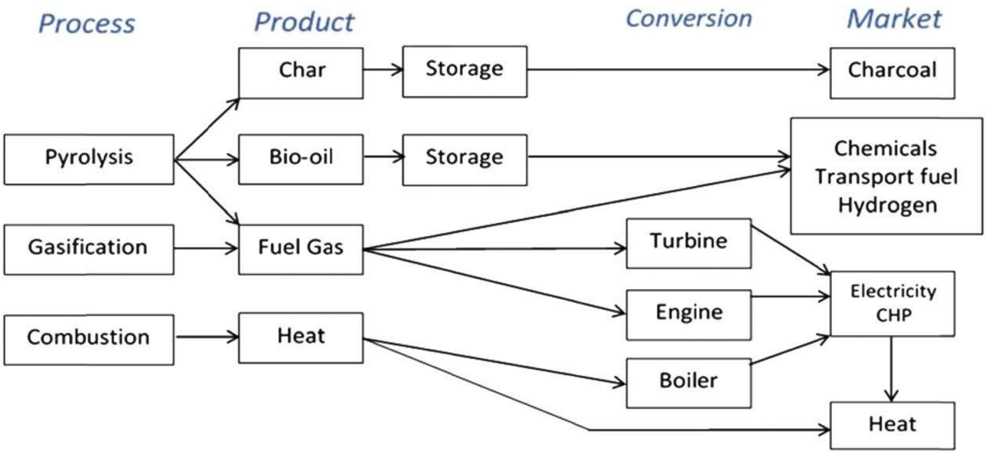


***Fig 1**: Thermochemical procedure and its output*

In the context of biomass for energy, biomass are often employed to mean plant-based textile, but biomass can equally apply to animal or veggie-derived material [22–24]. The reference to ‘recent’ living organisms is brought out to exclude fossil-derived material. It can be split into two broad categories: natural and derived materials. All organic materials such as stems of plants, trees and algae could be the input for energy output. Biomass energy is gained from plant and animal material, such as wood from natural forests; waste from farming and forestry processes; and industrial, human or animal wastes. So, biomass resources can be classified into three main categories [25,26]:

- Agricultural waste, Industrial waste, Medical waste, Electronic waste etc.
- Forest products; and
- Energy crops.

The ability of different biofuel raw material used in the pyrolysis method to convey biomass is condensed (as shown in Table I). It can be observed from the table that the bio-oil yield varies from 21.9% to 75%, depending on the type of biomass used, type of reactor and reactor temperature.

Table I: *Diverse biomass raw materials used for producing biofuels by pyrolysis*

Biomass type	**Reactor types**	**Temperature (○C)**	**Bio-oil yield (weight %)**	**Type of pyrolysis**	**Ref.**
Grape bagasse	Stainless steel fixed-bed reactor	550	27.6	Fast pyrolysis	[27]
Hardwood and softwood from pine tree	Tubular vacuum pyrolysis reactor	450	55.0	Fast pyrolysis	[28]
Municipal, livestock and wood waste	Internal is circulating fluidized-bed (ICFB) reactor	500	39.7	Fast pyrolysis	[29]
Plant thistle, *Onopordum acanthium* L.	Fixed-bed reactor	550	27.3	Slow pyrolysis	[30]
Potato skin	Stainless steel fixed-bed reactor	550	24.8	Steam pyrolysis	[31]
Pinewood sawdust	Conical spouted bed reactor	500	75.0	Flash pyrolysis	[32]
Pine wood	Auger reactor	450	50.0	Fast pyrolysis	[33]
Waste furniture sawdust	Fluidized-bed reactor	450	65.0	Fast pyrolysis	[34]
Rice husks	Fluidized-bed reactor	450	60.0	Fast pyrolysis	[35]
Sugar cane waste	Fixed-bed fire-tube heating reactor	475	56.0	Fast pyrolysis	[36]

Comparative analysis of elemental composition and physical properties of biomass feedstocks:

1.4.Typical biomass components

Typically, biomass contain varying amounts of cellulose, hemi-cellulose and lignin, as shown in Figure 2

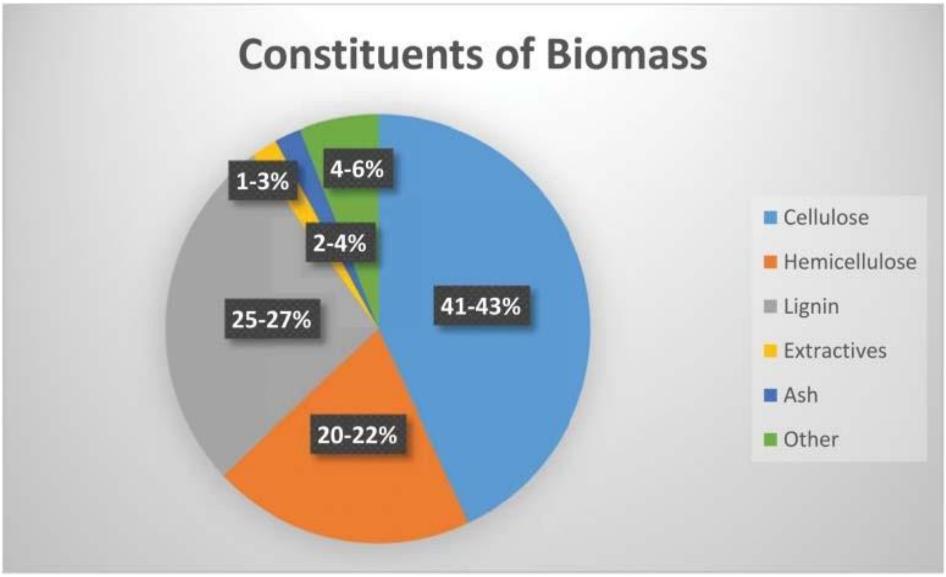


Fig 2. *Typical Biomass Components* [45]

Cellulose is an existing composite of nature with composition $(C_6H_{10}O_5)_n$; it's a polysaccharide containing of a straight fetter of hundreds to a large value (b (1→4)) attached with D-glucose. [43,44].

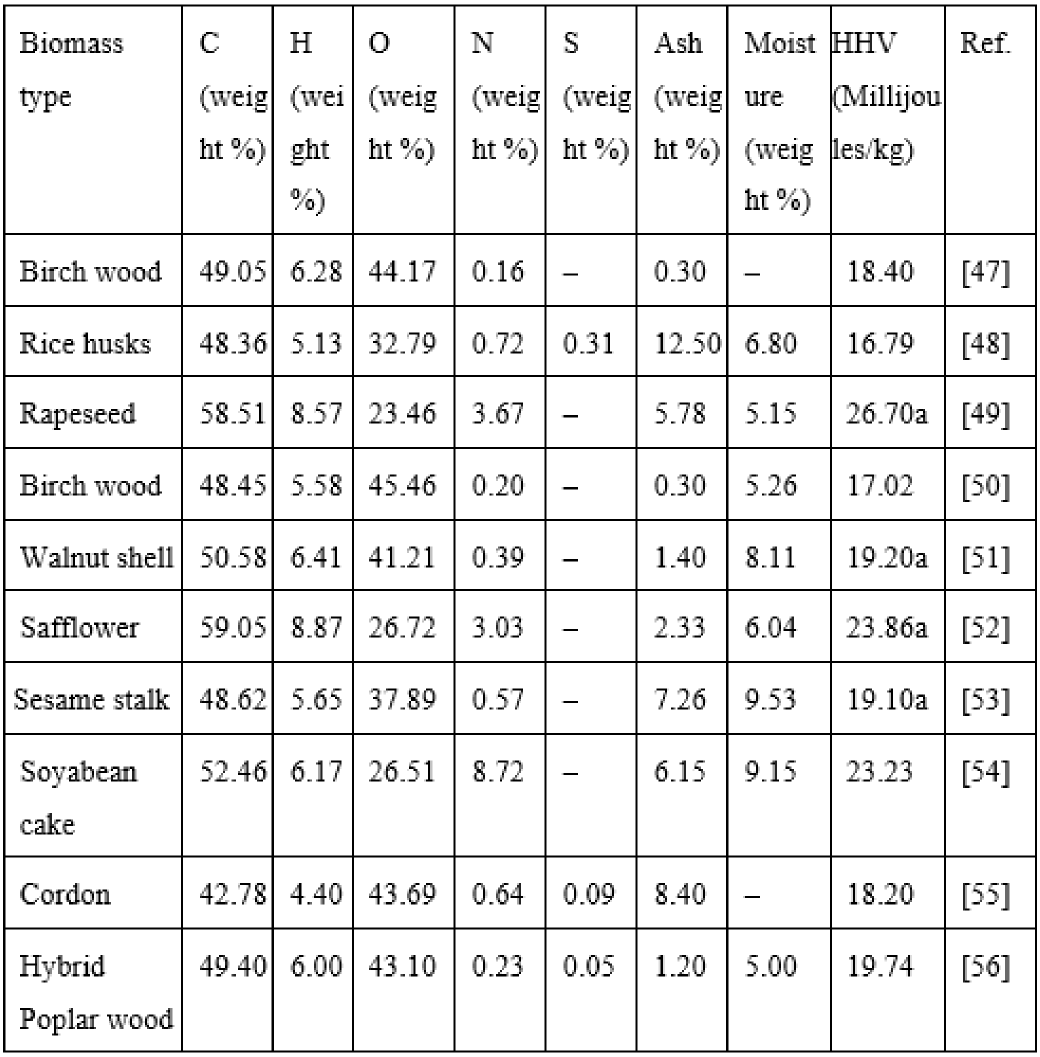
Chapter 2: Literature Survey

2.1. Elemental configuration and physical attributes of diverse biomasses

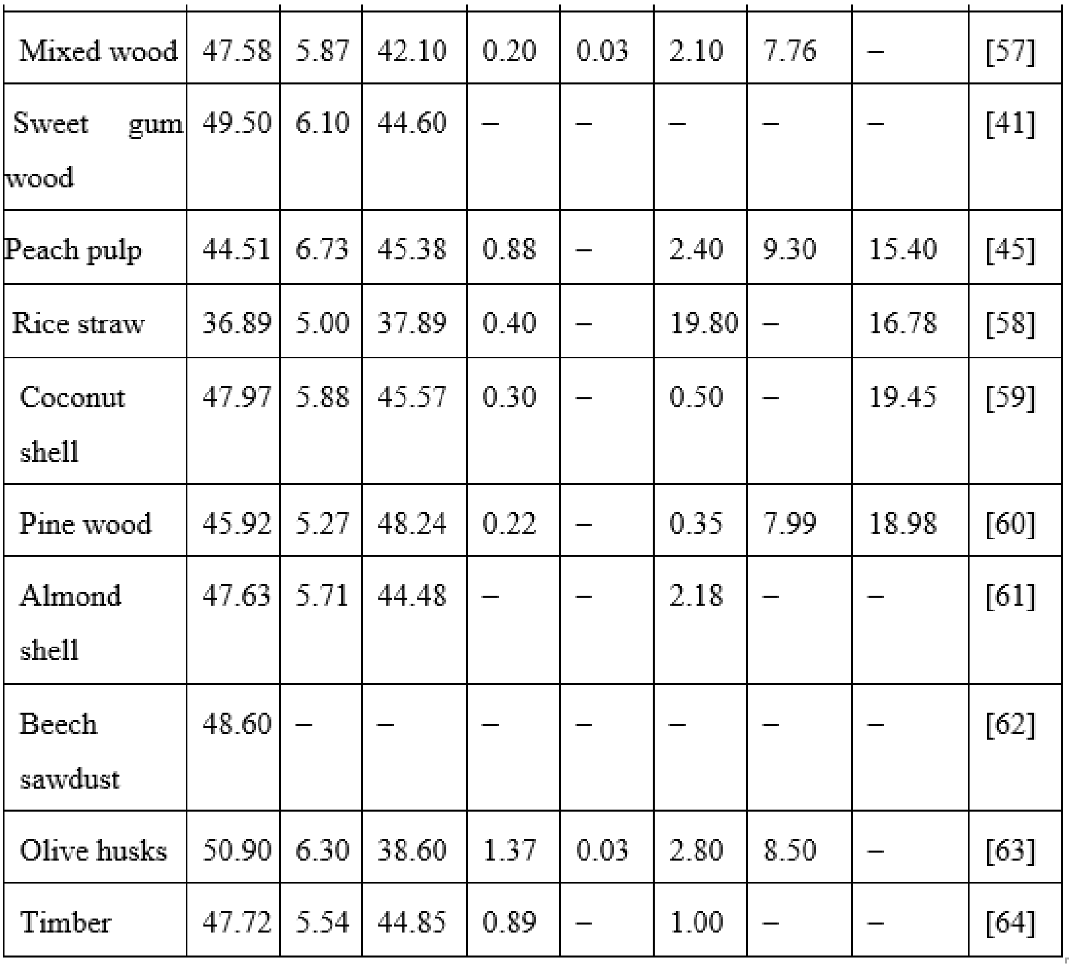
The elemental composition and physical properties of various biomasses can be observed from Table II.

Ultimate and proximate analyses were carried out in earlier studies to assess the elemental composition of various biomass feedstock's. It can be stated that the characterization of oils depends on temperature, and they can be used as liquid fuel due to their high energy content [46]

Table II: *Elemental components and physical attributes of diverse biomasses*:



Biomass type	C (weight %)	H (weight %)	O (weight %)	N (weight %)	S (weight %)	Ash (weight %)	Moisture (weight %)	HHV (Millijoules/kg)	Ref.
Birch wood	49.05	6.28	44.17	0.16	–	0.30	–	18.40	[47]
Rice husks	48.36	5.13	32.79	0.72	0.31	12.50	6.80	16.79	[48]
Rapeseed	58.51	8.57	23.46	3.67	–	5.78	5.15	26.70a	[49]
Birch wood	48.45	5.58	45.46	0.20	–	0.30	5.26	17.02	[50]
Walnut shell	50.58	6.41	41.21	0.39	–	1.40	8.11	19.20a	[51]
Safflower	59.05	8.87	26.72	3.03	–	2.33	6.04	23.86a	[52]
Sesame stalk	48.62	5.65	37.89	0.57	–	7.26	9.53	19.10a	[53]
Soyabean cake	52.46	6.17	26.51	8.72	–	6.15	9.15	23.23	[54]
Cordon	42.78	4.40	43.69	0.64	0.09	8.40	–	18.20	[55]
Hybrid Poplar wood	49.40	6.00	43.10	0.23	0.05	1.20	5.00	19.74	[56]



Mixed wood	47.58	5.87	42.10	0.20	0.03	2.10	7.76	–	[57]
Sweet gum wood	49.50	6.10	44.60	–	–	–	–	–	[41]
Peach pulp	44.51	6.73	45.38	0.88	–	2.40	9.30	15.40	[45]
Rice straw	36.89	5.00	37.89	0.40	–	19.80	–	16.78	[58]
Coconut shell	47.97	5.88	45.57	0.30	–	0.50	–	19.45	[59]
Pine wood	45.92	5.27	48.24	0.22	–	0.35	7.99	18.98	[60]
Almond shell	47.63	5.71	44.48	–	–	2.18	–	–	[61]
Beech sawdust	48.60	–	–	–	–	–	–	–	[62]
Olive husks	50.90	6.30	38.60	1.37	0.03	2.80	8.50	–	[63]
Timber	47.72	5.54	44.85	0.89	–	1.00	–	–	[64]

From the above mentioned table, various biomass was taken and their ultimate and proximate analysis had performed by various authors based on their experiments. The elemental analysis was performed to get the idea of the elemental compositions and their end point uses. The temperature and the pyrolysis types will give the final output i.e. oil which will be used in various applications.

2.2. Energy transformation expressway of diverse biomass:

Different thermo-chemical conversion processes include combustion, gasification, liquefaction, hydrogenation and pyrolysis. Pyrolysis is still in its developing stages but has received special attention as it can convert biomass directly into solid, liquid and gaseous products by thermal decomposition of biomass in the absence of oxygen. Pyrolysis offers efficient utilization, which is of special importance for agriculture- based economic systems, with vast quantities of available biomass by-products. Table III summarizes conversion steps for various feedstock's and their corresponding products.

Elements of different thermo-synthetic activities are appeared in Fig 1, although steps associated with the change of biomasses into valuable items are appeared in Fig 3. Table IV condenses the main discoveries of research work on biomasses transformation, by various authors [65–68].

From Table IV, a thought can be produced dependent on the yield of different biofuels by different techniques. Analysts have used various kinds of feed-stocks, and has added catalysts of different characters to determine better yielding processes.

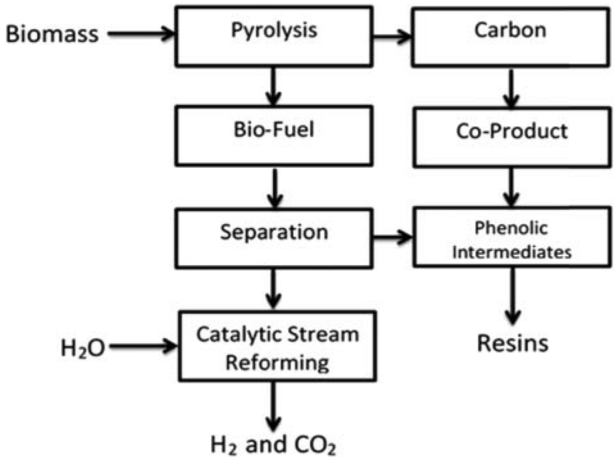
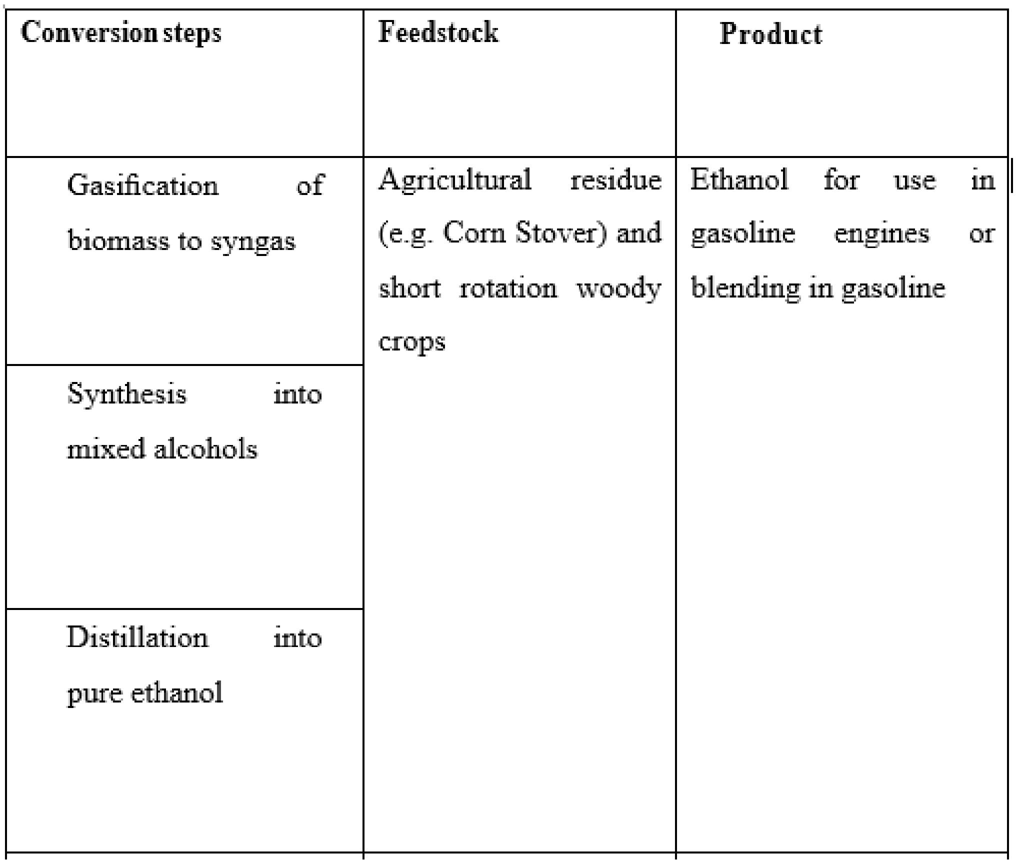


Fig 3: *Diverse biomass expressways and their productions*

Electrical energy is employed worldwide and it is energy efficient also. In parliamentary law to keep the energy efficiency of a system, if renewable energy could put back the conventional energy then it would offer a great benefit to society in the hereafter. Based on all conventional energy sources, solar thermal energy is one of the most promising technologies. But some generalizations are too present in solar thermal engineering.

Table III: *Diverse converging steps in thermal-chemical operation based on the raw material*

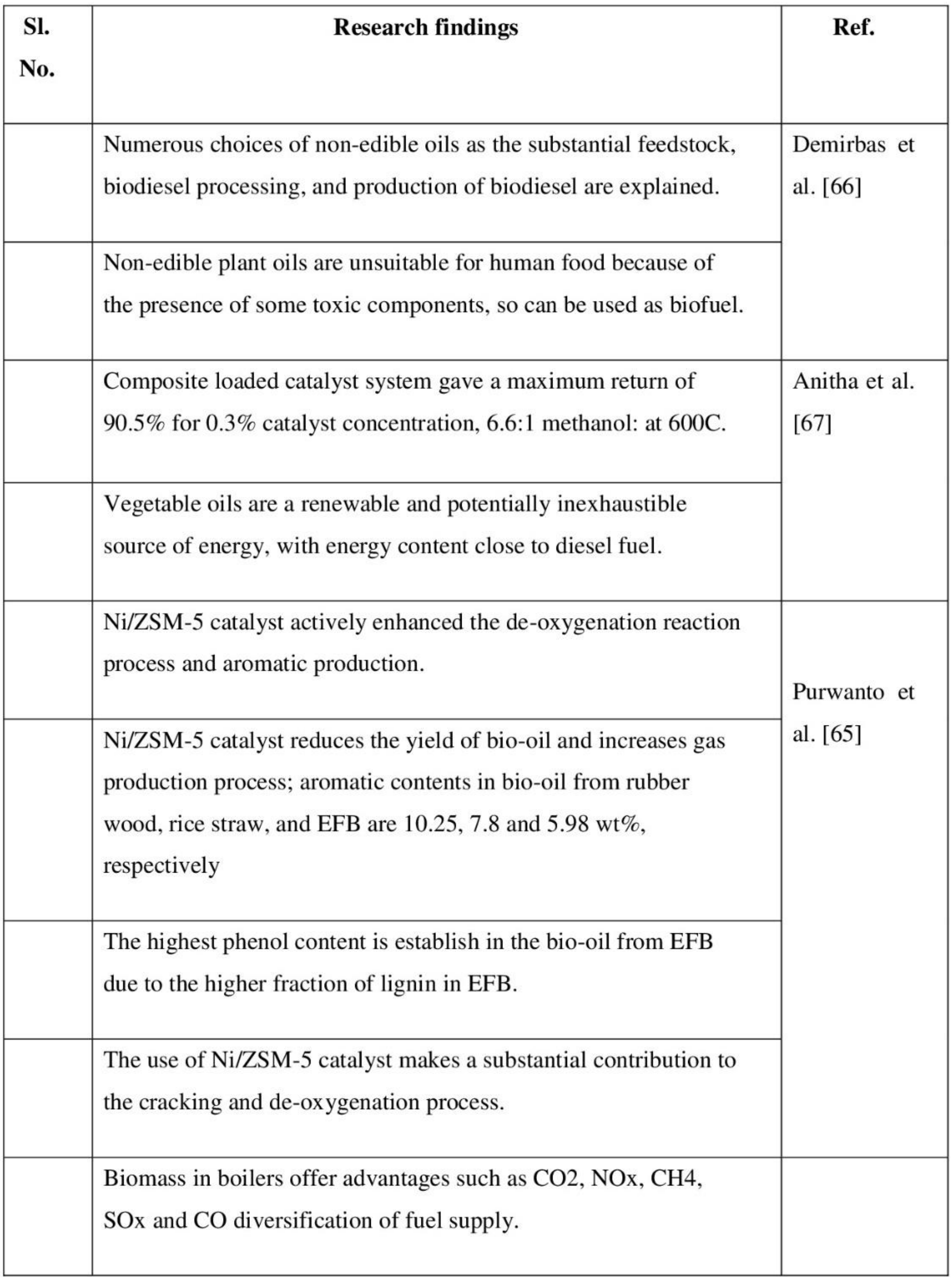
This table demonstrates the various conversion steps and products as an output based on the feedstock chosen. In various atmospheric condition, the product's result has been given.



Conversion steps	**Feedstock**	**Product**
Gasification of biomass to syngas	Agricultural residue (e.g. Corn Stover) and short rotation woody crops	Ethanol for use in gasoline engines or blending in gasoline
Synthesis into mixed alcohols		
Distillation into pure ethanol		

Gasification of biomass to syngas	Wood, agricultural residue, switch grass	Fischer-Tropsch liquids (synthetic hydrocarbons) for use in diesel And jet engines
Catalytic conversion into hydrocarbon fuels		
Refining into ‘clean diesel’ and naphtha fractions		
Pyrolysis of biomass to bio-oil	Wood, agricultural residue, grass	
Stabilization of bio-oil		Renewable gasoline and diesel for use in gasoline, diesel, and jet Engines; renewable fuel oil for heat and power
Upgrading to gasoline/diesel fuels		

Table IV: *A synopsis of biofuels creation by several procedures*



Sl. No.	Research findings	Ref.
	Numerous choices of non-edible oils as the substantial feedstock, biodiesel processing, and production of biodiesel are explained.	Demirbas et al. [66]
	Non-edible plant oils are unsuitable for human food because of the presence of some toxic components, so can be used as biofuel.	
	Composite loaded catalyst system gave a maximum return of 90.5% for 0.3% catalyst concentration, 6.6:1 methanol: at 600C.	Anitha et al. [67]
	Vegetable oils are a renewable and potentially inexhaustible source of energy, with energy content close to diesel fuel.	
	Ni/ZSM-5 catalyst actively enhanced the de-oxygenation reaction process and aromatic production.	Purwanto et al. [65]
	Ni/ZSM-5 catalyst reduces the yield of bio-oil and increases gas production process; aromatic contents in bio-oil from rubber wood, rice straw, and EFB are 10.25, 7.8 and 5.98 wt%, respectively	
	The highest phenol content is establish in the bio-oil from EFB due to the higher fraction of lignin in EFB.	
	The use of Ni/ZSM-5 catalyst makes a substantial contribution to the cracking and de-oxygenation process.	
	Biomass in boilers offer advantages such as CO2, NOx, CH4, SOx and CO diversification of fuel supply.	

Biomass is another switch of energy dependence on non-renewable sources. Probably it has a capacity to overcome the present prerequisite of energy. Bio-fuel from nonconventional oil containing seeds is one of the largest search areas of biomass energy [103]. Origin of petroleum from these sources is possible via thermochemical and biochemical ways. One of the major advantages of biomass is a negligible quantity of sulfur content in the fuel or oil. These fuels are CO_2

neutral fuels as the generated CO_2 after burning is used by plants for their development. Hence, these are better and with very less quantity of carbon footprint on the surroundings. The designed capacity of biomass is about 1.08 ×1011 toe (tons of oil equivalent), that's far more than the present need of energy [107]. The commonly used procedures for extraction of oil by biomasses are pyrolysis, combustion and high pressure condensation [108].

Here are some advantages of utilizing solar energy for biomass production, according to [109]:

a. Upgradation of calorific value of the feedstock's.

b. Decontamination of the gaseous product by the by-product of combustion.

c. The environment seems to be cleaned due to the reduced emission of pollutants in the gentle wind.

d. Use of unmixed oxygen via air for the energy concentrated procedure has been done away with. The above 4 points add more advantages to solar thermal pyrolysis of bio-oil generation. Thither are a circumscribed number of surveys that have been performed using this technology, which are talked about infra.

Gasification of biomasses are well known renewable resources for transport fuel; when the heat supply to this process is served by concentrating solar system it turns yet more efficient process [104]. Mainly biomass contains carbon, hydrogen and oxygen as CH1.4O0.6, that is carbon 52.2%, hydrogen 6.1%, oxygen 41.8% as per weight. Combustion, which takes space in the presence of oxygen, generates carbon dioxide and water as products. These products are then converted to synthetic fuels. It has described very well about engineering a commercial solar gasification system [110].

Concentrated visible light radiation was used by Hopkins [111] for flash pyrolysis of cellulosic material. Clear crystal sparkled bed reactor was used for the study and flux was delivered by an arc represented furnace, that uses xenon bulb as a light source. Flechsenhar & Sasse [112] used settled bed reactor including 0.05 gram of biomass under argon atmosphere. The irradiation power was derived by means of solar simulator containing essentially a xenon lamp positioned in the focal point of a parabolic reflector. Image furnace technology also has been used for flash pyrolysis of cellulose [113]. Stuffed bed sun based reactor for the steaming gas phasing for the carbonaceous matter was studied by

Piatkowski et al. [114]. The reactor was subjective to radiation flux concentration up to 2953 suns, creating temperature up to 1490 K, yielding high quality of the syngas. Solar-to-chemical conversion efficiency varied between 17.3% and 29%.

Li et al. [115] reviewed production distribution from solar pyrolysis of agriculture and forestry biomasses residue using a solar furnace setup. Morales et al. [116] investigated orange-peel pyrolysis using parabolic-trough concentrator. The mean irradiation of the pyrolitic reactor covering was 15.65 of that of sun. Reflectivity by biomass was one of the reasons for heat loss in the process, which was around 38%, and around 36% was because of the thermal parametric difference among reactor and the environment. Peak temperature value for the reactor at the middle of the focal line was 465°C. Reported weight reduction of orange peeling was 79 weight % at an irradiation of 12.55 kW/m^2. Yield of biological oil was 77.64% and 1.43% were non condensable gases to 20.93% of char. This proves better efficiency of solar thermal pyrolysis with 465°C of temperature achieved, which is in the range for the pyrolysis of biomasses.

Use of solar furnace for pyrolysis procedure is also one of the methodologies other than CSP. Zeng et al. [117] reported sun based pyrolysis of wood on a laboratory extent by solar assisted pyrolysis reactor setup. In this study, they used beech wood and calculated the effectiveness for temperature and sweeping gaseous flowing rate on the production yield. In this study, they had control on heating range and temperature under solar concentration. Around 51% yield of gas was obtained by pyrolysis at 2000°C with heat rating of 50°C/minute and argon flowing rate of 6 NL/minute. At higher temperature gas yields were higher. This group is continuously working on wood pyrolysis using this technology with computational studies and modelling.

When water content increases, it reduces the tar decomposition, carbon monoxide and hydrogen decreases. Char decomposition plays a major role in yield of product biogas.

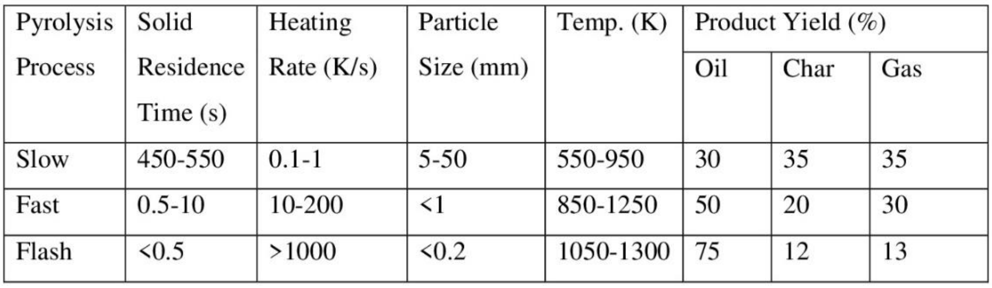
Solar tracking helps to remain focused with high temperature needed for the process. In whole, the sun changes its position using solar tracker Fresnel, continuously adjusted with the position of the sun. This Fresnel system has been built in-house by Zeaiter et al. [118]. They studied scrap rubber catalytic pyrolysis using this system.

Chintala et al. [100,101] designed a Scheffler parabolic dish with 16 m^2 of reflected area. The dish usage was to make focus on the sunlight radiation on the pyrolysis reactor and bio-oil is produced. An automatic tracker system was also attached with it. The system was designed for various types of biomass feedstock, however, in this study, they used Jatropha biomass for oil production. The average range of temperature was around 250-320°C and exploring maximum 20% of bio-oil yield. Temperature was pretty much ranging of required temperature for the pyrolysis of biomass. Further studies and characteristic studies for char, liquid oil and gas were done. Oil was utilized in compression ignition engine after upgradation and blending with diesel at 20%, 40% and 60% shares.

2.3. Glimpse of Pyrolysis Technology:

In pyrolysis procedure, reaction is taking place not in the presence of oxygen. Various kinds of pyrolysis dependent on reaction time, temperature and other atmospheric condition. Based on the reaction nature and temperature zone it has been classified as: Slow pyrolysis, Flash Pyrolysis and Fast Pyrolysis.

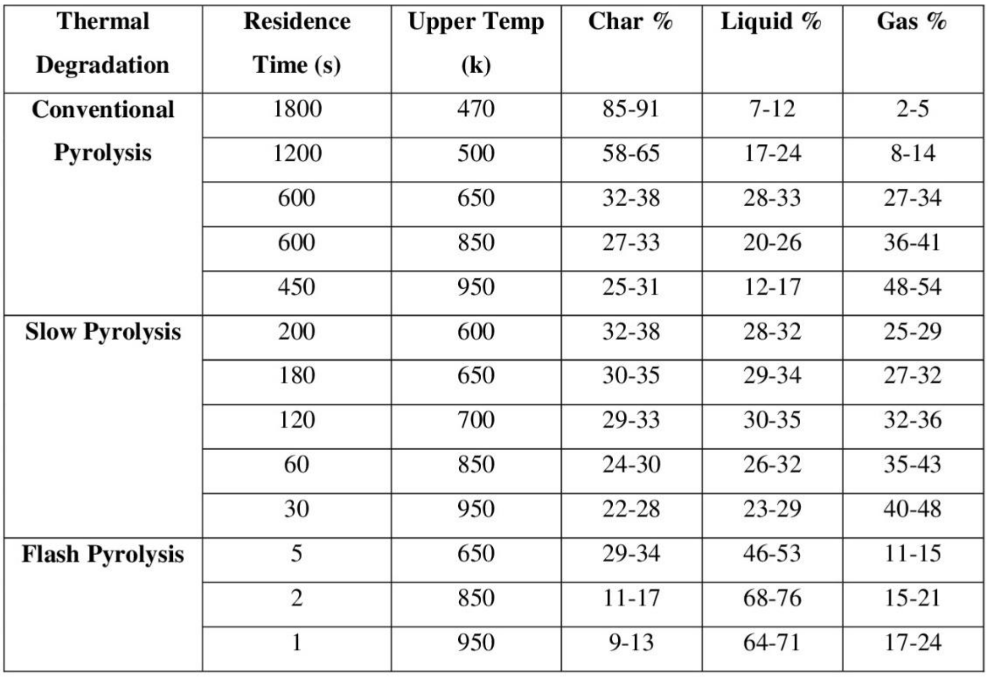
Table V: *Typical operational variables and outcomes for pyrolysis procedure*



Pyrolysis Process	Solid Residence Time (s)	Heating Rate (K/s)	Particle Size (mm)	Temp. (K)	Product Yield (%)		
					Oil	Char	Gas
Slow	450-550	0.1-1	5-50	550-950	30	35	35
Fast	0.5-10	10-200	<1	850-1250	50	20	30
Flash	<0.5	>1000	<0.2	1050-1300	75	12	13

Now the typical operational variables and outcomes from pyrolysis procedure can also be represented the table no VI. Based on the various thermal degradation the liquid, gas and solid compound's composition can be shown.

Table VI*: Typical operational variables and outcomes for pyrolysis procedure*



Thermal Degradation	Residence Time (s)	Upper Temp (k)	Char %	Liquid %	Gas %
Conventional Pyrolysis	1800	470	85-91	7-12	2-5
	1200	500	58-65	17-24	8-14
	600	650	32-38	28-33	27-34
	600	850	27-33	20-26	36-41
	450	950	25-31	12-17	48-54
Slow Pyrolysis	200	600	32-38	28-32	25-29
	180	650	30-35	29-34	27-32
	120	700	29-33	30-35	32-36
	60	850	24-30	26-32	35-43
	30	950	22-28	23-29	40-48
Flash Pyrolysis	5	650	29-34	46-53	11-15
	2	850	11-17	68-76	15-21
	1	950	9-13	64-71	17-24

The pyrolysis liquid and the conventional fuel can also be segregated based on various properties like ultimate and proximate analysis. By doing that we may assume the elemental composition of each and every fuels. In table no VII, it has been classified based on their composition.

Table VII: *Comparability of pyrolysis phase and standard fuel oil*

	Pyrolysis liquid	Diesel	Heavy fuel oil
Density kg/m³ at 15°C	1220	854	963
Elementel Composition			
% C	48.5	86.3	86.1
% H	6.4	12.8	11.8
% O	42.5	---	---
% S	---	0.9	2.1
Viscosity cSt at 50°C	13	2.5	351
Flash point °C	66	70	100
Pour point °C	-27	-20	21
Ashwt.%	0.13	0.01	0.03
Sulphur %wt	----	0.15	2.5
Water %wt	20.5	0.1	0.1
LHV(MJ/kg)	17.5	42.9	40.7
Acidity	3	---	----

2.4. Solar Thermal Pyrolysis Technology

It is critical to comprehend that sun powered warm innovation isn't equivalent to sun oriented board, or photovoltaic (PV) innovation [74]. Sun based warm electric energy age focuses the lighting from the solar source to produce heating, and heat is utilized to start heating motor, that turn-on a generator to create power. Working liquid, which is warmed via concentrated daylight could be a fluid or in gaseous phase. Distinctive placed liquids incorporate water, oil, salts, air, nitrogen, helium, and so on. Various motors sort includes steam engines, gaseous turbines and so forth. These engines can be much efficient, regularly with efficiencies somewhere in the range of 30 and 40%, and are fit for creating tens to several megawatts of intensity. PV energy change, then again, legitimately changing over daylight into energy. This implicit that sun powered boards are just viable during sunlight hour in light of the fact that puts power is definitely not a particularly productive procedure. Warmth stockpiling is a far simpler and increasingly effective technique, that’s the thing which make sun oriented warm so appearing for larger extent energy generation. Warmth can be putter away during the sunlight and afterward flipped over into power around evening time. Sun oriented warm plants (having capacity) limits can radically improve the financial matters and dispatch capacity of sunlight based power.

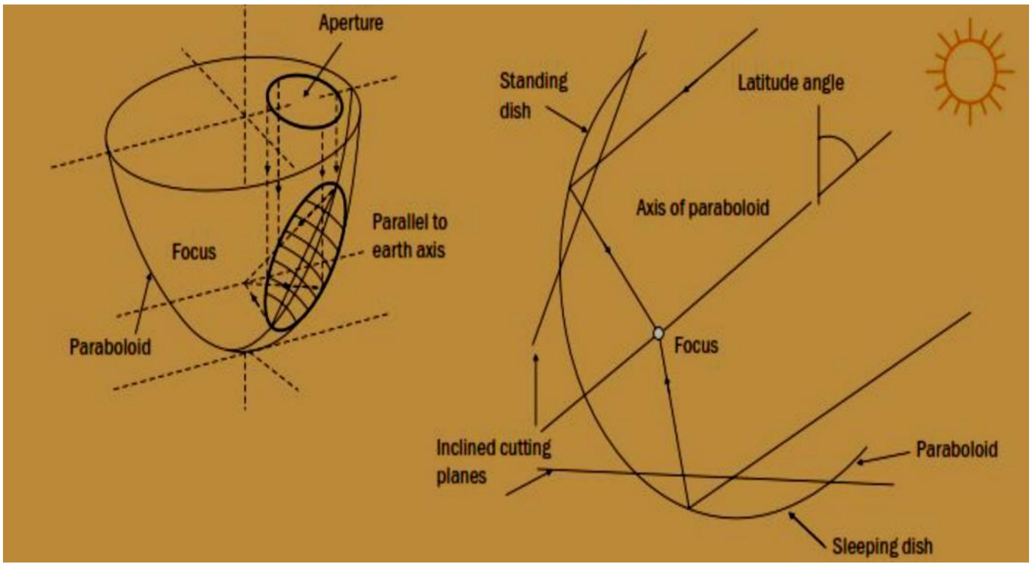


Fig 4: *Schematics of Scheffler Reactor*

2.5. Ongoing scenario of solar thermal power having competition with fossil fuel:

Sunlight based warm force as of now drives the path as the most practical sun powered innovation on a huge extent. It right now beat photo Voltaic frameworks, and it additionally could beat expensive power from petroleum products, for example, flammable gas. Regarding minimal effort and high negative ecological effects, nothing contends with coal. In any case, major sunlight based warm industry players, for example, E-Solar, lighting source and Abengoa has just beaten the cost for Photo Voltaic and petroleum gas, sooner rather than later they will beat the cost of coal [75]. With an undeniably industrializing planet, the pioneers in sun powered warm innovation have an ever-developing business sector. The issue is, and will consistently be, the manner by which making sun oriented warm innovation increasingly prudent. There are as of now two strategies for sun powered warm assortment. The first is a line center assortment (explanatory trough frameworks [76], straight Fresnel frameworks) and the second is a point center assortment (sun powered pinnacle frameworks [77], Stirling sunlight based dish frameworks [78]). Line center is more affordable and in fact less troublesome, however not as productive as pointing center. The reason for this innovation is a parabola-formed mirror, which turns on a solitary pivot for the duration of the day, following the sun. The point center strategy requires a progression of mirrors encompassing a focal pinnacle, otherwise called a force tower. The mirrors center the sun's beams onto a point on the pinnacle, which at that point moves the warmth into progressively usable energy. Point center, however at first costlier and actually more nuanced, eclipses line center when results are concerned. The purpose of center in a line center mirror cluster can just arrive at temperatures around 200^0C [79]. That is an adequate temperature to run a steam turbine, however when contrasted with the 500^0C and higher temperatures that point center can come to, the additional exertion and cost is offset by its more noteworthy proficiency capacity. High productivity matters since it drives down both the land use, and the powerful expense per kWh of the plant. Instructions to create the power from the sun, with and without a sun oriented concentrator can be appeared in fig 5.

Regardless of the sun's colossal size, and in light of its good ways from the Earth, it isn't exactly a point source. It really involves 1/20 in the sky. When making a concentrator, the design of the framework needs to consider this subtended edge of the sun. The presentation and monetary feasibility of sun based warm gatherers rely upon numerous elements including fabricating innovations, methods, structure, kind of parts (liquids and materials, for example, the concentrator, beneficiary, following frameworks, stockpiling frameworks, and so forth. [80–87]) and application areas (power generation [88], heat pump [89], cooking [90], baking [91], desalination [92], water supply in building [82], solar heater to industrial processes [93,94], refrigeration systems. [87], distillation [95,96]), location [97]. Detailed findings are presented by Hafez et al. [76].

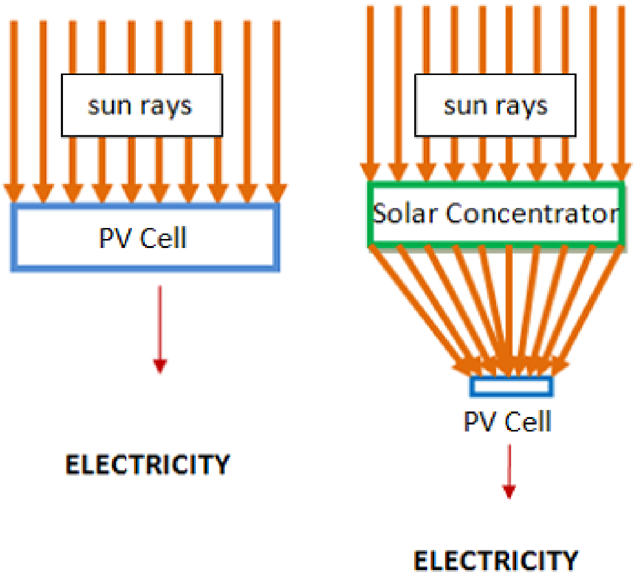


Fig 5: *Generating electricity from the sun, with and without a solar concentrator*

Existence of advantages and disadvantages of diverse pyrolysis procedures in term of environmental impact:

Advantages:

- It is a renewable energy;
- It is cheaper in comparison with fossil fuels;
- It minimizes dependence over traditional fuels;
- It can be utilized to produce diverse products, that's beneficially to society because of surrounding impact;
- It minimizes dependence over fossil fuels.

Disadvantages:

- No direct usage in automotive motors;
- It is not effective as comparison with fossil fuel.

2.6. Potentially usage of pyrolysis bi-products:

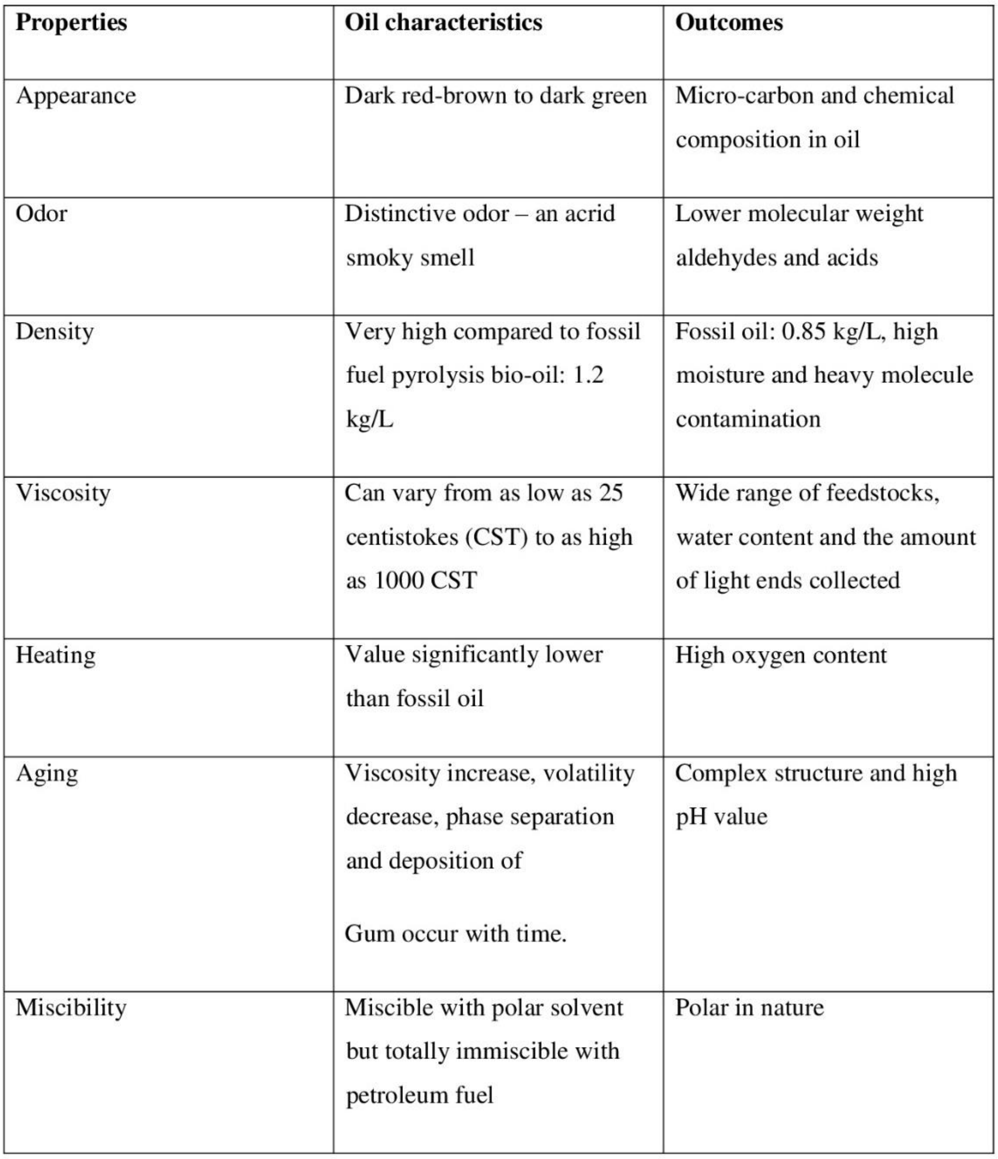
Altogether there are three essential items acquired from pyrolysis of biomass, for example non-condensable gases, scorch and fumes. At encompassing temperature, the fumes have been consolidated to dim dark colored fluid. The ideal temperature is 350^0C to 500^0C [98,99] where greatest fluid generation happens. The test examinations directed by Chintala et al. [100,101] on sun oriented thermochemical pyrolysis affirmed that thermochemical responses will begin at about 350^0C, and the response productivity will improve with expanding temperature. They achieved a greatest temperature of 500^0C with the work of a Scheffler dish. At higher temperatures atoms present in the fluid are separated to deliver little particles, which advances the vaporous division. The yield of items coming about because of biomass pyrolysis can be augmented as follows:

Charcoal – a lower temperature, lower heating rate procedure;

- Liquid products – lower temperature, higher heating rate, short gaseous residence time procedure; and
- Fuel gas – Higher temperature, lower heating rate, long gaseous residence time procedure.

Pyrolysis items rely on the water content in the biomass, which delivers huge amounts of condensate water in the fluid stage [25]. This adds mainly removal of water-dissolvable mixes from vaporous, tar stages, and in this way a more noteworthy lessening in vaporous and strong items [102]. Table V shows the oil attributes that are great for use as energizes in various applications.

Table VIII: *Favoring physical properties of bio oil used as fuels*



Properties	**Oil characteristics**	**Outcomes**
Appearance	Dark red-brown to dark green	Micro-carbon and chemical composition in oil
Odor	Distinctive odor – an acrid smoky smell	Lower molecular weight aldehydes and acids
Density	Very high compared to fossil fuel pyrolysis bio-oil: 1.2 kg/L	Fossil oil: 0.85 kg/L, high moisture and heavy molecule contamination
Viscosity	Can vary from as low as 25 centistokes (CST) to as high as 1000 CST	Wide range of feedstocks, water content and the amount of light ends collected
Heating	Value significantly lower than fossil oil	High oxygen content
Aging	Viscosity increase, volatility decrease, phase separation and deposition of Gum occur with time.	Complex structure and high pH value
Miscibility	Miscible with polar solvent but totally immiscible with petroleum fuel	Polar in nature

From the above mentioned table a basic idea can be generated on the properties of bio-oil that is used as a fuel in any reaction. Based on various properties the oil characteristics are different and as a result the outcomes have described.

Table IX: *Different types of pyrolysis output by using Karanja as a biomass*

Sl. No.	Research Findings	Authors
1	The conversion of karanja fruit hulls by fast pyrolysis was investigated using a drop-type two-stage reactor. The ex-situ catalytic fast pyrolysis of karanja fruit hulls over a silica-alumina catalyst was performed at 500 °C and at a catalyst loading of 0.1 g. The obtained bio-oil yield was 41.09 wt%.	Y.L.Tan et al [119]
2	Thermal pyrolysis of Karanja seed was performed in a semi batch reactor at different temperatures in order to find out the optimum temperature (550 °C) for utmost liquid yield (55.17%, weight basis).	Krushna PrasadShadangi et al [120]
3	Karanja (Pongamia glabra) seeds were pyrolyzed in semi-batch mode at a temperature range of 450–550 °C and at a heating rate of 20 °C/min. Suitability of liquid product obtained after thermal pyrolysis of karanja seed as an alternate fuel.	Niraj KumarNayan et al [121]
4	Fuel properties of pyrolytic and co-pyrolytic oil was compared. Co-pyrolysis of waste polystyrene enhanced the yield of pyrolytic oil. Co-pyrolysis increased the calorific value, decreased the viscosity and pH of oil. High calorific value co-pyrolytic oil obtained at 2:1 ratio.	Krushna PrasadShadangi et al [122]

	Co-pyrolysis resulted in increasing the aromatic content of pyrolytic oil.	
5	Characteristics of Roselle and Karanja biodiesel are studied and compared it with diesel. Blend LA20 and KB20 perform better engine performance than with other biodiesel blends. Shows the tremendous potential to decrease CO2 emission with increasing engine load. Biodiesels fuel emits lower NOx and smoke emission than with diesel fuel.	Pankaj Shrivastava et al. [123]
6	A maximum liquefaction conversion of 99% was obtained at a reaction temperature of 240°C, a residence time of 120 min and a Karanja PSC to PBO ratio of 1:6. In contrast, ~94% conversion was obtained for the same residence time but at significantly lower temperature of 160°C when phenol and sulphuric acid were used in the ratio of Karanja PSC, phenol and H_2SO_4 as 1:2:0.6. It was observed that aromatic structure with less oxygen was evident in bio–crude compared to PBO.	Kotaiah Naik Dhanavath et al [124]
7	Biodiesel is produced from renewable resources like vegetable oils and animal fats. It can use as a fuel in diesel engine by blending with diesel or in pure form. Biodiesel blended diesel fuel emits less harmful gasses compare to diesel fuel. India	Rupesh L.Patel et al [125]

	is developing country where more than 70% of petroleum products are import.	

Chapter 3: Experimental Set-up

Solar Thermal is an emerging technology now a days, which can focus upon a lot of new aspects of emerging ideas. Out of various new technologies based on the sun based thermal technology, sun based thermal pyrolysis is a effective technology. In this doctoral research work the primary and main aim was to extract bio-oil by using solar thermal energy in a vivid manner. The utilization of heat can produce bio-oil from the extraction of non-edible plant seeds in the absence of oxygen. The reaction chamber has been built in such a way so that the chamber may be air tight and no gas can be entered. A schematic diagram (Figure 6) has been drawn to understand the basics of the experiment.

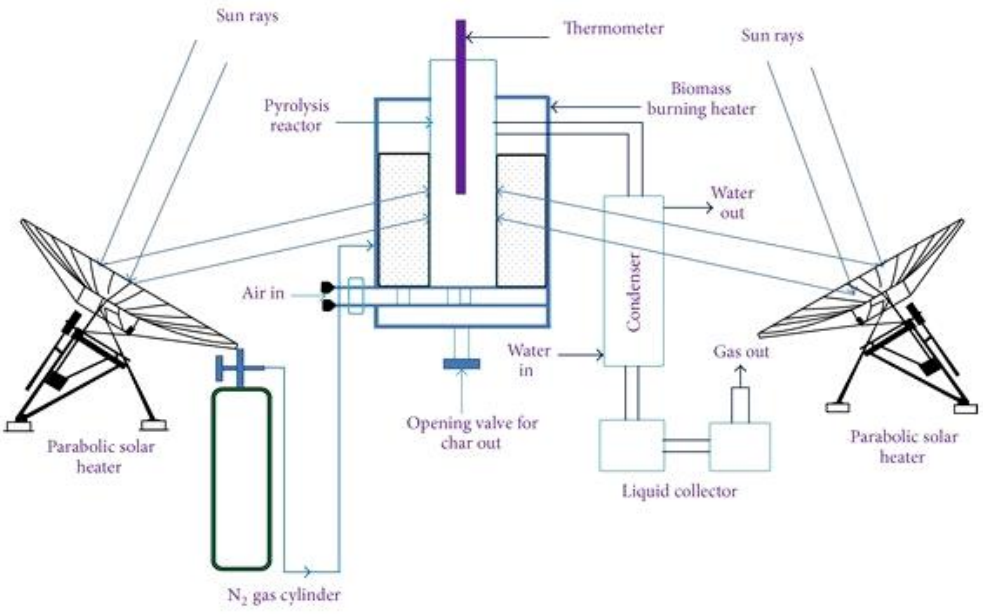


***Fig 6**: Schematic diagram of solar assisted fluid bed pyrolysis system*

From the diagram it has been shown that the sun rays are reflecting upon a reactor after being reflected from the Scheffler Dish. A lab scale view (3D) (Figure 7.1 & 7.2) has also been sketched to understand the overall reaction process.

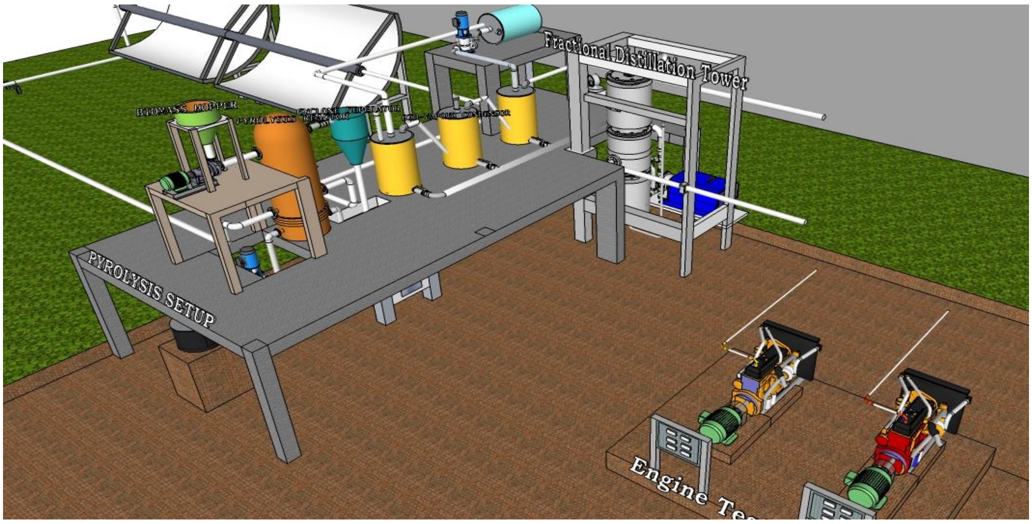


Fig 7.1: *3-D view of a pilot plant*

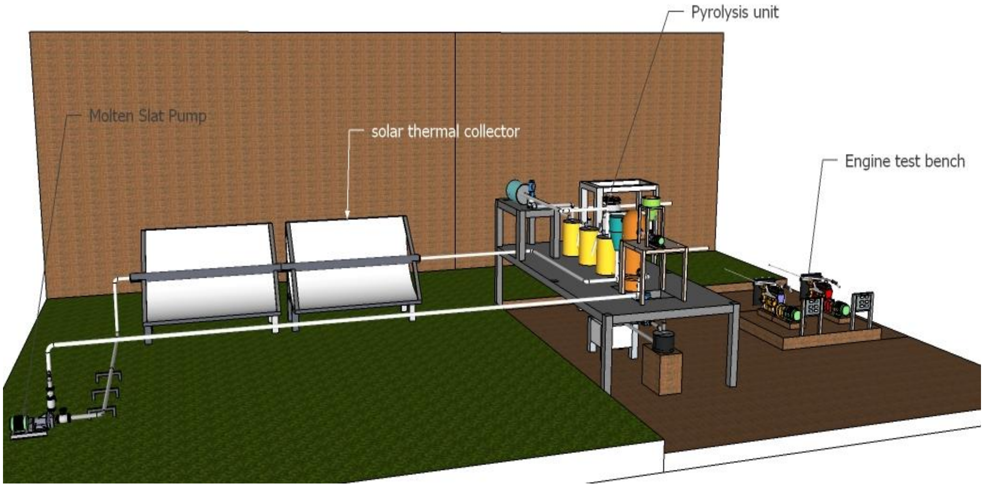


Fig 7.2: *3-D view of a pilot plant*

Bio oil is created due to glimmer pyrolysis procedure utilizing concentrate sun based energy. A Scheffler explanatory dish (sixteen meter square reflecting territory) is utilized to focus solar radiations on the reactor. A consequently followed Scheffler dish incorporated reactor framework (Figure 8) was created in pyrolysis procedure. So as to make up for west-east revolution of the earth Scheffler Dish moves from east to west (Daily following: East to West) (Figure 10). The dish moves by 1° at regular intervals about pivoting pipe. Regular following is stated for changing the situation of Reflector in North-South heading relying upon the situation of the sun (Seasonal Tracking: North – South). The coordinated framework was adaptable so that various types of biomasses raw materials can be nourished in the reactor for oil generation.

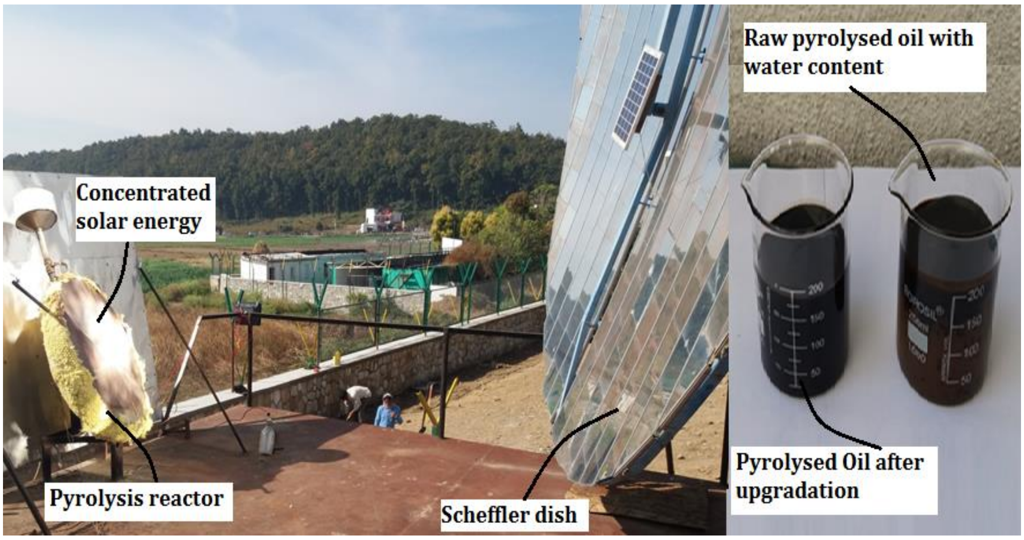


Fig 8: *Photographic representation of integrated installation of Scheffler dish and pyrolysis reactor*

The specifications of the Scheffler dish used in the experimental set-up shown in Table VI.

Table X: *Specification of a 16 m^2 Scheffler Dish*

Sl. No.	**Module Description**	**Rating**
1	Surface Area of Collector	16 m^2
2	Aperture Area of Collector	11.65 m^2 (Average)
3	Dimension & Shape	Parabolic
4	Reflectivity	92%
5	Thermal output Capacity	5.5 KW
6	Thermal Efficiency	42% (approx.)
7	Footprint Ground Area Required for Single Dish Stand and Receiver	35m

The Scheffler disk that has been chosen for the experimental setup has the following minimum criteria:

- Material-Solar category mirror with layer shields of covering.
- Reflectivity- 90 percent least with time cycle of 15 to 20 years. Warranty period of 5 years.
- The mirror is fixing- With positive fastening or inserting superior standard adhesives. Particular protections have to specify keeping in mind for wind of the area.
- Concentration ratio- Over sixty.
- Frame & supporting structure- Manufactured by Aluminum / mild steel with powder covering for resisting any distortion of the dish because of wind force or physical handling.
- 0.4 mm thickness of aluminum sheets
- Withstanding temperature as 500^0C and wind force with respect to area of 250 km/hour.
- Reliable Timer or PLC based automatic tracking system made up of standard components with tracking accuracy of +/- 0.5 degree.

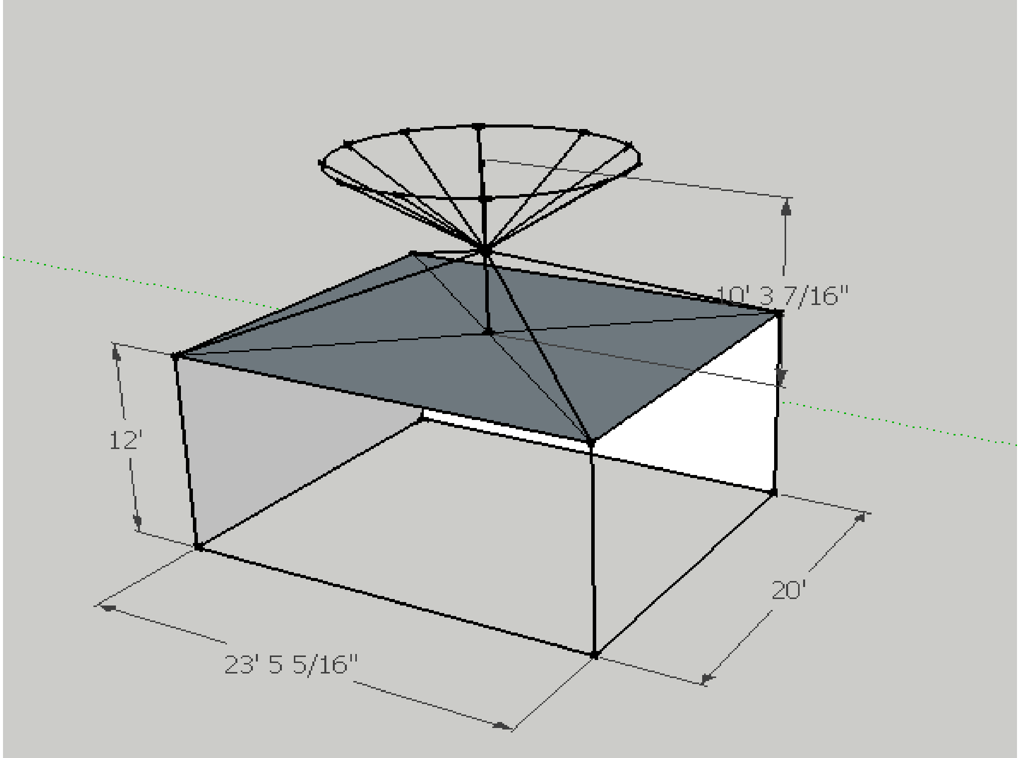


Fig 9*: Geometrical view of the experimental set-up*

Table XI: *Technical specifications of tracking system*

Component	**Description**
Tracking system	PLC based automatic tracking arrangement
Tracking axis	Single axis (East to West)
Seasonal tracking	Manual
Drive mechanism	DC motor; Scheffler dishes are interconnected with wire rope going over gear-box which is driven by DC motor (in a clockwise/ anticlockwise direction)
Mounting Structure	Elliptical Parabolic Dish mounted on a stand rotating parallel to Earth’s Polar Axis

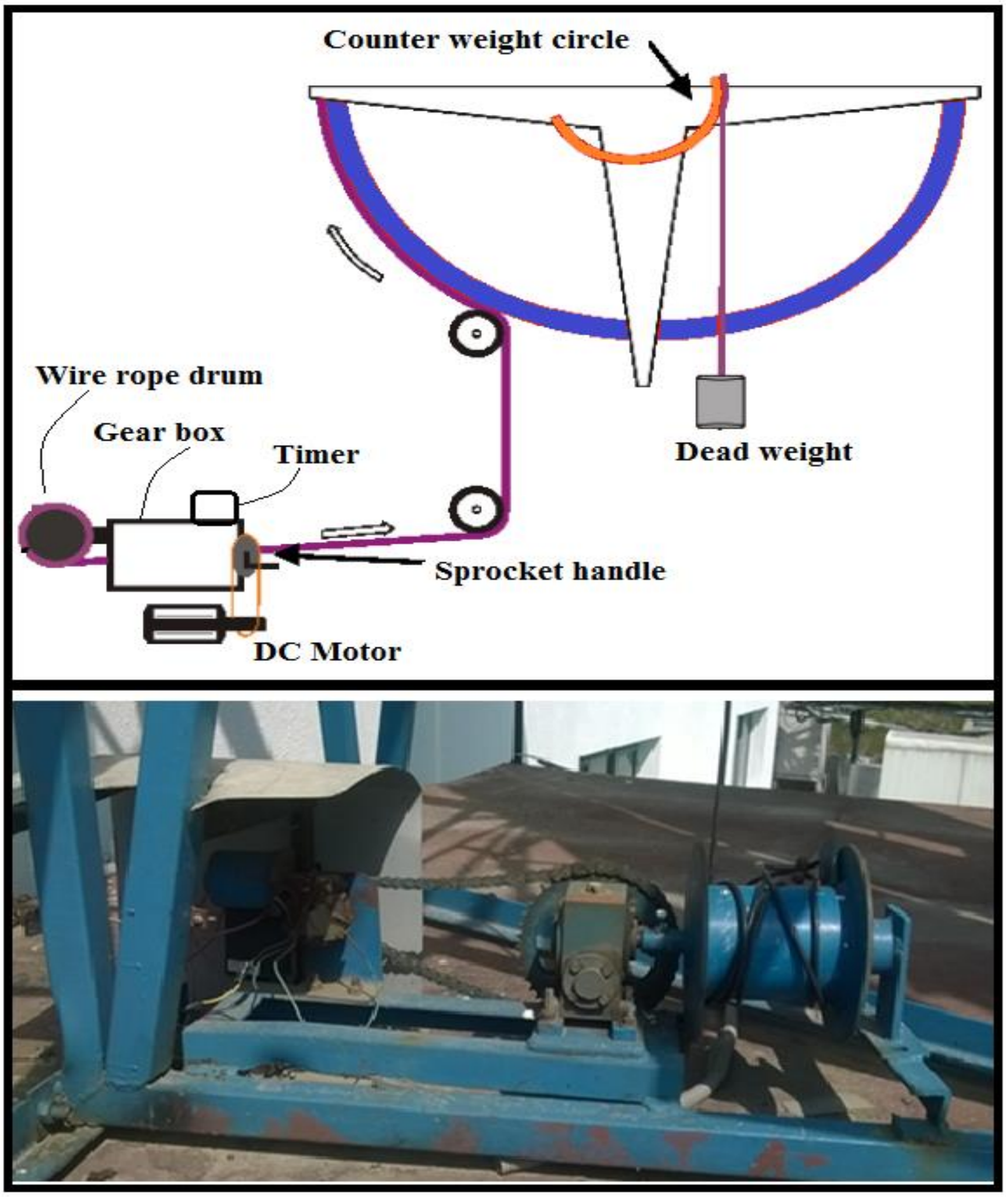


Fig 10: *Automatic solar dish tracking system*

Fig. 11.1: *Overall set-up for Solar Thermal Pyrolysis*

***Fig. 11.2**: Focused reactor place in front of Scheffler dish*

***Fig. 11.3:** Photographic view of Solar thermal pyrolysis reactor*

Technical description for pyrolysis reactor used in the solar thermal pyrolysis set up has been shown in Table VIII.

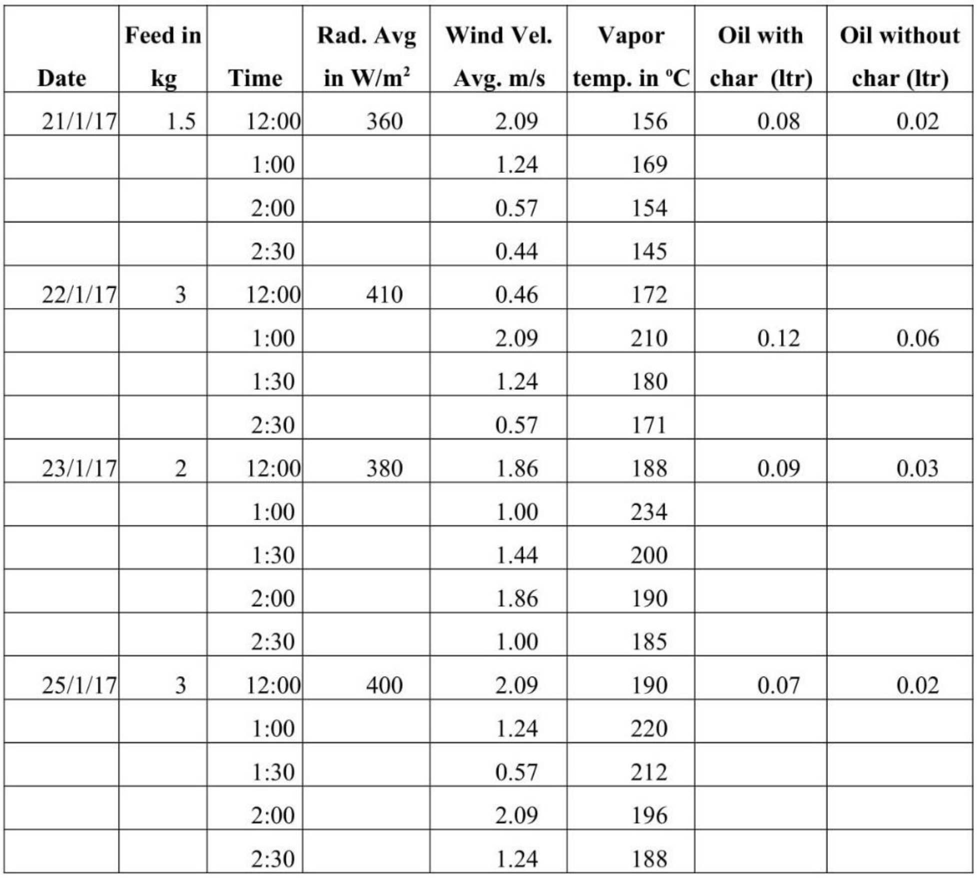
***Table XII**: Technical description for pyrolysis reactor*

Description	Values
Type	Conventional type reactor (no cavity)
Configuration of the reactor	Circular
Reactor material	SS 316
Maximum Temperature (ºC)	600
Peak pressure (bar)	5
Biomass sustainable capacity (kg)	15
Accessories	Having two catalyst port, pressure sensor and temperature sensor

The above mentioned reactor has been used for extracting oil by using solar thermal energy.

Using solar energy and Scheffler dish the pyrolysed oil is being produced inside the chamber. There are 2 portions of the reactor. The upper chamber has been used for feeding the feedstock and the lower portion has been used to keep water for heating. Like when the sun rays directly focused on the reactor then the reactor temperature keeps increasing and the feedstock's that has been kept in the upper chamber of the reactor by using biomass hopper, started melting and forming oil with the absence of oxygen. Mainly in the daytime between 11.30 AM to 2.30 PM maximum sunrays are available. Based on that a small data has been shown in Table IX. Based on the feed, the radiation, wind velocity and other atmospheric condition the output in the form of oil and char can be shown.

Table XIII: *Observations of radiation and pyrolysed oil yield obtained with reactor*



Date	Feed in kg	Time	Rad. Avg in W/m²	Wind Vel. Avg. m/s	Vapor temp. in °C	Oil with char (ltr)	Oil without char (ltr)
21/1/17	1.5	12:00	360	2.09	156	0.08	0.02
		1:00		1.24	169		
		2:00		0.57	154		
		2:30		0.44	145		
22/1/17	3	12:00	410	0.46	172		
		1:00		2.09	210	0.12	0.06
		1:30		1.24	180		
		2:30		0.57	171		
23/1/17	2	12:00	380	1.86	188	0.09	0.03
		1:00		1.00	234		
		1:30		1.44	200		
		2:00		1.86	190		
		2:30		1.00	185		
25/1/17	3	12:00	400	2.09	190	0.07	0.02
		1:00		1.24	220		
		1:30		0.57	212		
		2:00		2.09	196		
		2:30		1.24	188		

From the table it’s observed, the amount of oil and char is little less compared to the theoretical calculation. The main reason for this is reactor design. When the reactor has been designed (Figu.11.3) there was no insulation for keeping the heat for maximum time. So when there was proper sunlight and the Scheffler dish properly placed in front of the reactor, the reactor is getting proper sunlight and being heated. At the best atmospheric condition, the oil extraction is also good. But when the sun rays are not proper then the heat is being dissolved in the atmosphere easily as there is no insulation at the back of the reactor. For this reason reactor dismantles occur (Fig. 12.1).

Fig 12.1: *Reactor dismantles*

***Fig 12.2**: Insulating Material for reactor*

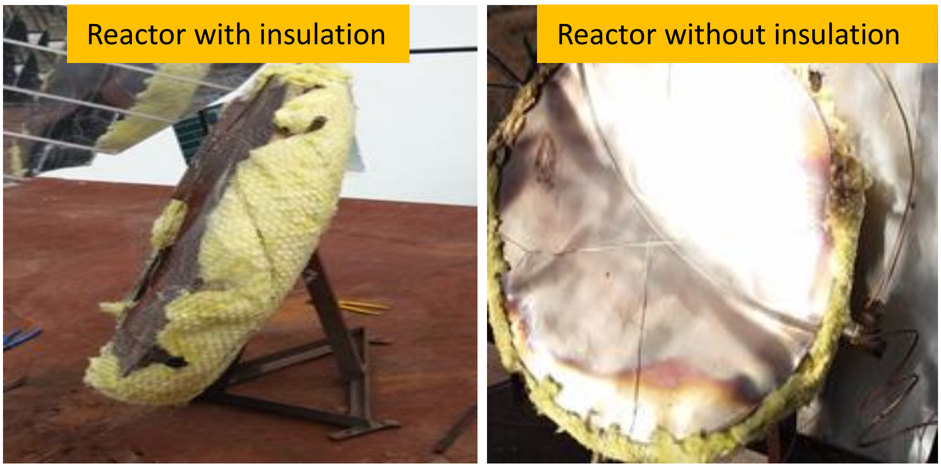


***Fig 12.3:** Reactor with insulation* ***Fig 12.4**: Reactor with proper oil vapor collection system*

By the proper insulation of the reactor, temperature can be stored for more time and the reaction was fast to produce more pyrolysed oil and less amount of char. So the overall efficiency of the system has increased referred to the old reactor. The insulation material Glass Wool used in the modified reactor (12.3 & 12.4). The overall schematic representation after the modified reactor has shown in Fig. 13.

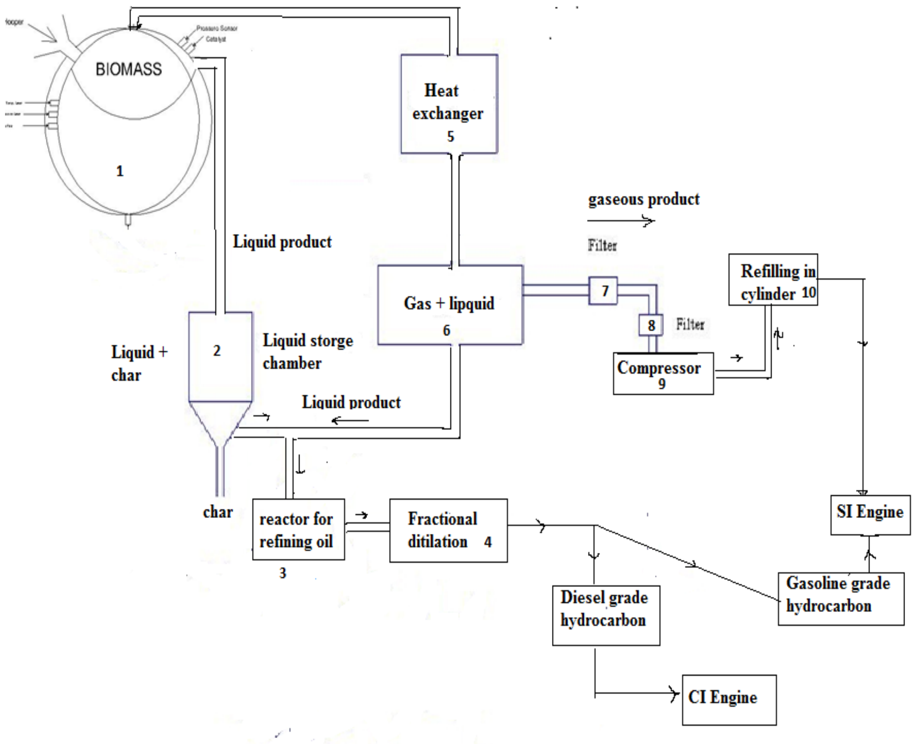


***Fig 13**: Schematic representation of the overall setup after modifications of reactor*

This figure no. 13 gives the exact idea of the experimental work. Starting from the feeding the biomass into the reactor chamber through biomass hopper, to the extraction of oil and used it to CI and SI engine undergoes via these paths. Although the several modifications had done to get more oil and make the system more efficient, still it lagged for the leakage of the reactor. At a very high pressure and continues to focus on the reactor, leakage took place at the junction of temperature sensor and pressure sensor. Also for the curved portion that segregates upper and lower part of the reactor, oil didn’t come out properly and when the reactor became cold the oil also gets thicker and be inside.

Based on the above mentioned issues the reactor has been remedied and based on the expert’s suggestion cavity type reactor (Fig. 14 & Fig. 15) has been built. By that it has been presumed that effectiveness of the overall installation will be raised and the main concern ‘heat loss’ will be minimized.

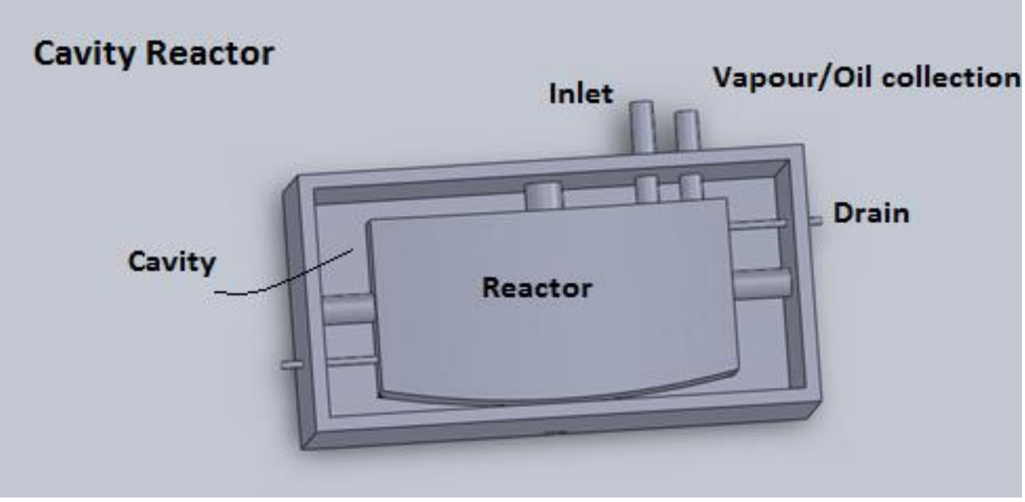


Fig 14: *Cavity type solar reactor for Pyrolysis*

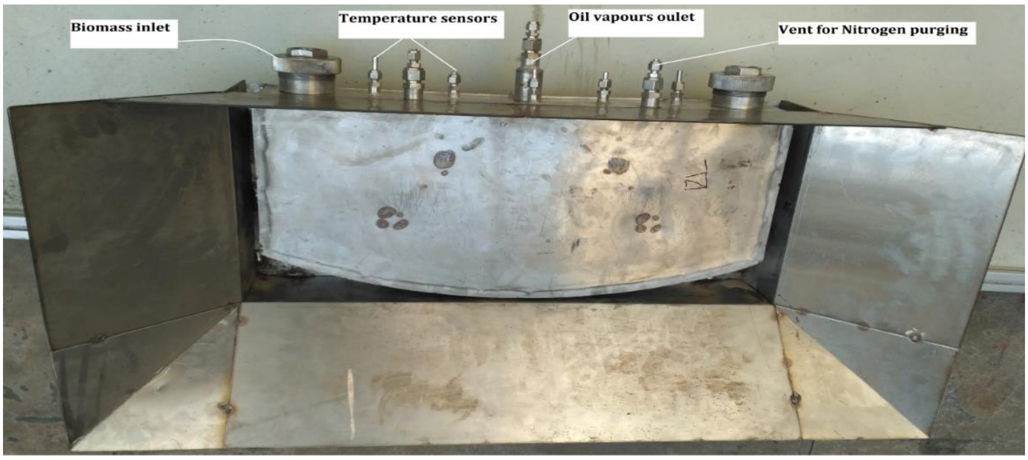


Fig 15: *Photographic view of cavity reactor for flash pyrolysis of biomass*

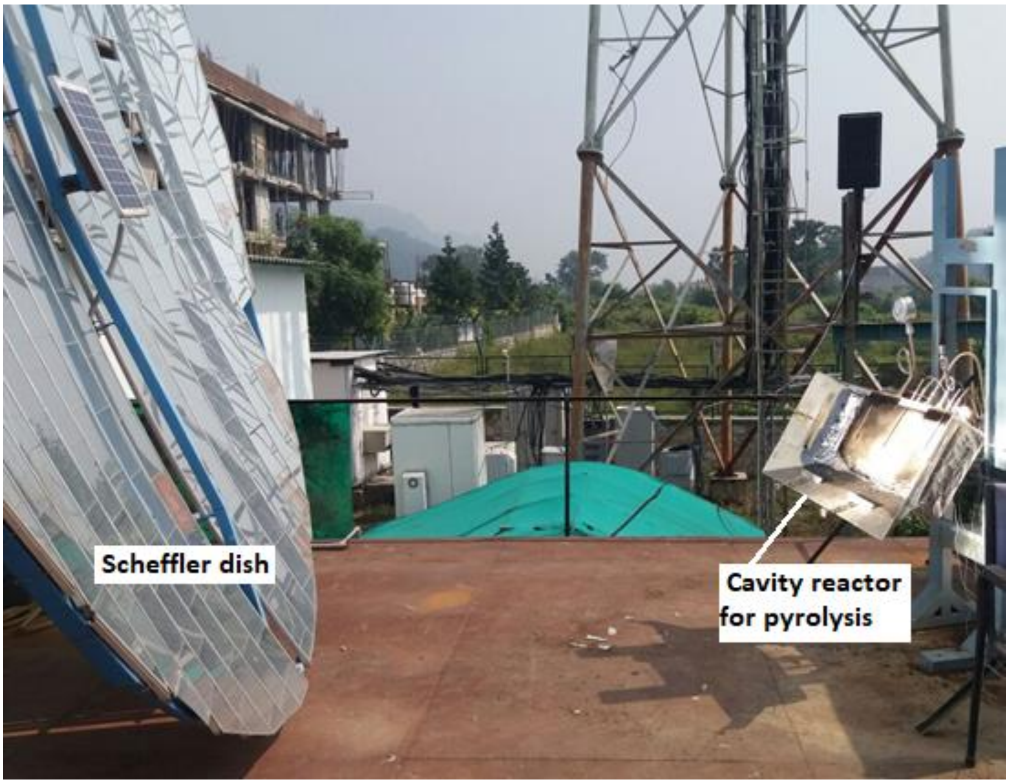
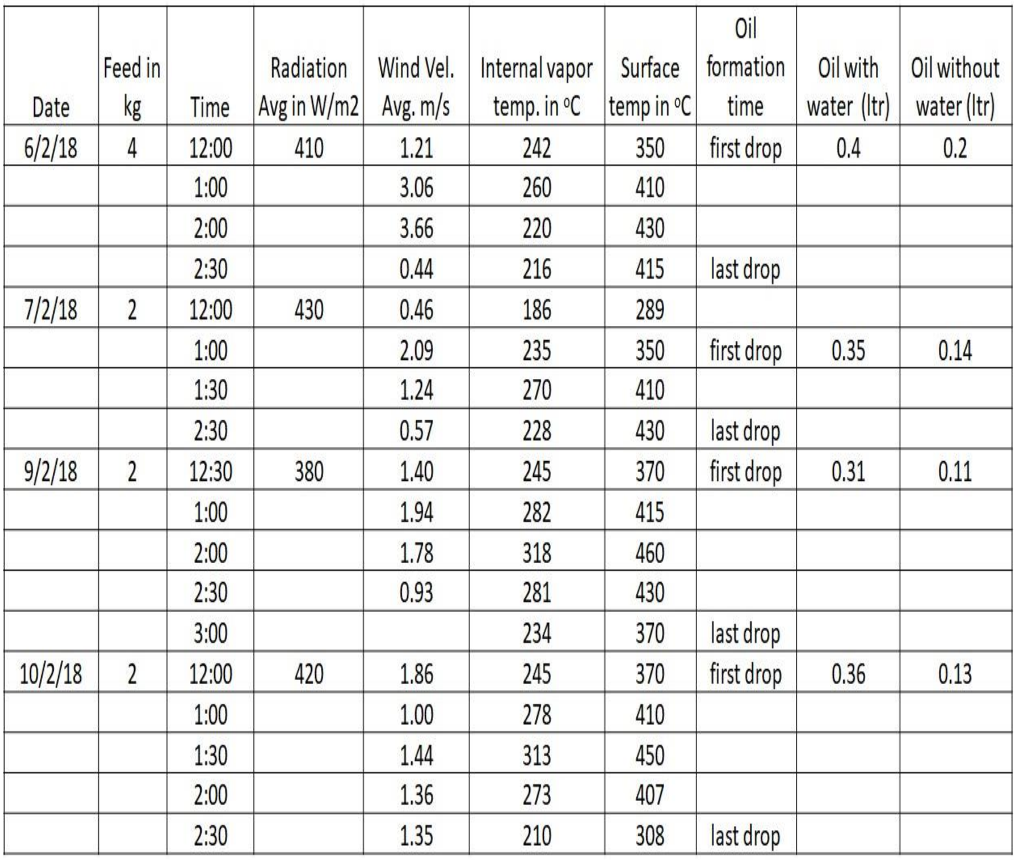


Fig 16: *Site photograph of integral installation of Scheffler dish and cavity reactor.*

Fig 17: *Photographic views of condensable and non-condensable gas collection*

Fig 16 demonstrates the newly made reactor focused and placed in front of the Scheffler dish. If closely follows the figure, it is showing that the focus of sunlight is directly upon the pyrolysis reactor. Based on **Fig 11**, there are so many drawbacks in reactor design. In this case the efficiency is in the higher side and the heat loss is also less.

Table XIV: *Observations of radiation and pyrolysed oil yield obtained with modified reactor*



Date	Feed in kg	Time	Radiation Avg in W/m2	Wind Vel. Avg. m/s	Internal vapor temp. in °C	Surface temp in °C	Oil formation time	Oil with water (ltr)	Oil without water (ltr)
6/2/18	4	12:00	410	1.21	242	350	first drop	0.4	0.2
		1:00		3.06	260	410			
		2:00		3.66	220	430			
		2:30		0.44	216	415	last drop		
7/2/18	2	12:00	430	0.46	186	289			
		1:00		2.09	235	350	first drop	0.35	0.14
		1:30		1.24	270	410			
		2:30		0.57	228	430	last drop		
9/2/18	2	12:30	380	1.40	245	370	first drop	0.31	0.11
		1:00		1.94	282	415			
		2:00		1.78	318	460			
		2:30		0.93	281	430			
		3:00			234	370	last drop		
10/2/18	2	12:00	420	1.86	245	370	first drop	0.36	0.13
		1:00		1.00	278	410			
		1:30		1.44	313	450			
		2:00		1.36	273	407			
		2:30		1.35	210	308	last drop		

Fig 17 demonstrates the photographic view of condensable and non-condensable gas collected from the cavity reactor. The gases coming from the pyrolysis reactor are passing through the 3 stage condensing counter flow heat exchanger and collected in the tube. The oil can be collected from heat exchange 1, 2 and 3 outlets after condensing. Table X shows the data for the pyrolysed oil yield with the modified reactor.

Fig 18: *Various steps of collection and upgradation of pyrolysed oil*

Fig 18 describes the various steps for collection and upgradation of pyrolysed oil. After upgradation of the fuel it will be used for final step i.e. engine testing.

The guideline issues experienced while bio-oil age are; bad fuel standard (assorted in with higher suddenness and bio-burn substance), lower oil yield, and changing thermal source. Attempts has been made to attain the ideally extent of temperature the reactor for the pyrolysis process around 410°C to 500°C for Karanja biomass. The extracted pyrolysed bio-oils are exquisite mixes of water and diverse normal blends. This extracted oil is exceptionally oxygenated, corrosive and destructive to motor parts. Furthermore, consistency and thickness of the PO is more than regular diesel. Critical issues related with utilization of PO in Compression Ignition motors are blocking in fuel channel components, fuels infusion issue (higher thickness, the higher consistency of oil, bad atomization, blend and vaporization in air); and erosion of motor components because of profoundly acidic nature. Thus, the PO must be redesigned so as to utilize it in Compression Ignition motors. In ongoing investigation, the nature of PO was upgraded by esterification procedure and diminished its p-H incentive to value of 6.2. The physiochemical attributes of the fills utilized in the examination are represented in Table I. There are for the most part physical and compound, oil upgradation techniques are delineated below.

3.1. Physical methodology:

3.1.1. Emulsion

The existence of the opposing components, i.e. phenol and aromatic carboxylic acids etc. In bio-oil, it’s not possible to mix with diesel fuel. But having genuine surfactants, similar emulsions could be acquired.

3.1.2. Filtration

- Bio-oil consists of alkali metal, solid compounds and bio-char that minimizes storing ability and resulting problem in implementations.
- Channels, for example, granular channel and glass fleece hot fume channel could be utilized to redesign the nature of the bio-oil.
- Be that as it may, the water substance of the bio-oil higher than the unfiltered bio-oil, the warming worth is still lower contrasted with the petroleum derivative, which is the most significant bottleneck in the application.

3.1.3. Solvent addition

- Adding a natural dissolvable to the bio-oil can lessen its viscosities and improve its strength, in addition, this strategy is straightforward and simple to actualize.
- Ethanol and different alcohols, methanol could be utilized as an added substance.

3.1.4. Distillation

- Distillation is the process of separating components of a mixture based on different boiling points. Examples of uses of distillation include purification of alcohol, desalination, crude oil refining, and making liquefied gases from air.

3.2. Chemical methods:

The chemical methods have been segregated in the following classifications.

3.2.1. Catalytic esterification

- Synergist esterification, an activity where alcohols utilized to respond with the –COOH groups in bio-oil with the assistance of impetuses, and produces esters.
- This technology could evacuate the vast majority of the acids, decreases the cohesiveness of this oil and builds the steadiness. Its response is typically catalyzed by strong corrosive, strong soluble base, and an ionic fluid particle trade tar.

3.2.2. Catalytic hydrogenation

- Catalytic hydrogenation is hydrogenation (adding hydrogen) of a compound with a double or triple bond. The process of catalytic hydrogenation utilizes a metal catalyst such as nickel, palladium or platinum. The mechanism begins by bonding hydrogen atoms to the metal through pressurized hydrogen gas.

- Hydrogenation means to treat with hydrogen. In other words, it means adding hydrogen (or adding more kids) so that the carbon atoms (or parents) have fewer bonds between themselves. A compound that has been fully hydrogenated looks a lot like the parents who are only holding one hand, leaving two feet and one hand each for the kids to hold onto.

- So if hydrogenation means adding hydrogen to a double or triple bond, catalytic hydrogenation means using a catalyst to add hydrogen. In other words, in order to add more kids to the tubing family, you need an aunt or uncle on the shore guiding the kids into the water.

3.2.3. Fluidized catalyzed cracking

- Fluid catalytic cracking is a chemical process that utilizes a catalyst and heat to break long-chain hydrocarbons into smaller-chain hydrocarbons. Typical products include gasoline, distillate, butane, and propane fuels.
- Fluid Catalytic Cracking Units (FCCUs) are a secondary conversion operation within more complex refineries, and is used to produce additional gasoline, primarily, from the gas oils produced in the atmospheric and vacuum distillation units.
- Fluid catalytic cracking is a chemical process that utilizes a catalyst and heat to break long-chain hydrocarbons into smaller-chain hydrocarbons. Typical products include gasoline, distillate, butane, and propane fuels. The catalyst is a sand-like solid material that is fluidized by the hot liquid and vapor fed into the FCCU. The catalyst can flow between the reactor and regenerator vessels in the FCCU due to this fluidity.

3.2.4. Steam reforming

- Steam reforming or steam methane reforming is a method for producing syngas (hydrogen and carbon monoxide) by reaction of hydrocarbons with water. Commonly natural gas is the feedstock. The main purpose of this technology is to hydrogen production. The reaction is represented by this equilibrium: $CH_4 + H_2O \rightleftharpoons CO + 3H$.

- Reforming, in chemistry, processing technique by which the molecular structure of a hydrocarbon is rearranged to alter its properties. The process is frequently applied to low-quality gasoline stocks to improve their combustion characteristics.

3.3. Oil blending with diesel and its use in Diesel engine

The pyrolysed oil has been mixed in 20 percent, 40 percent, and 60 percent on a volume premise, engine with Euro IV facility. Trial tests has been done on a solitary chamber straight infusion Compression Ignition motor (3.7 kilowatt evaluated power at 1500 Rotation per Meter) with the PO-diesel mixes up to 60%. Be that as it may, with past 60% PO share motor operational issues, for example, fuel channel component blockage was seen as appeared in Figure 19. It might be noticed that during sunlight based driven pyrolysis process, for the most part three items were acquired mainly (1) bio-oil fumes, (2) bio-burn and (3) vaporous items. Oil fumes were consolidated and utilized as fluid fuel in the testing motor. As these fluid fuel likewise contains bio-roast, it has been expelled by a tri phase filtration process. Be that as it may, total expulsion of inborn biochar content was impractical, because of which motor activity issues have been raised with higher level of PO mixes.

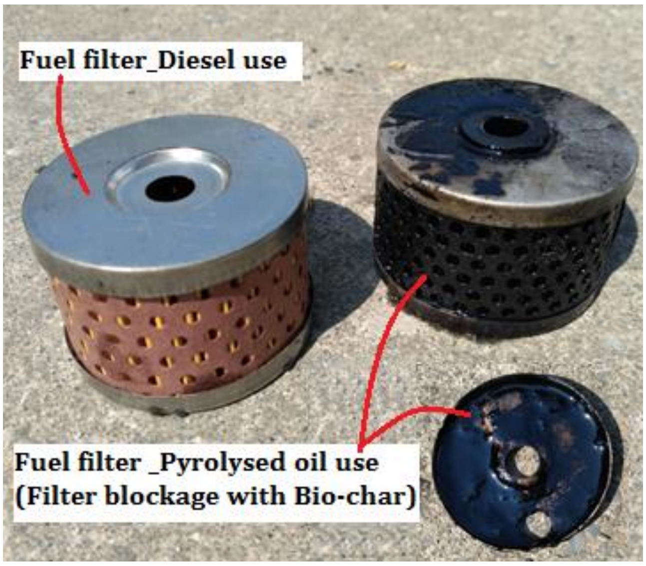
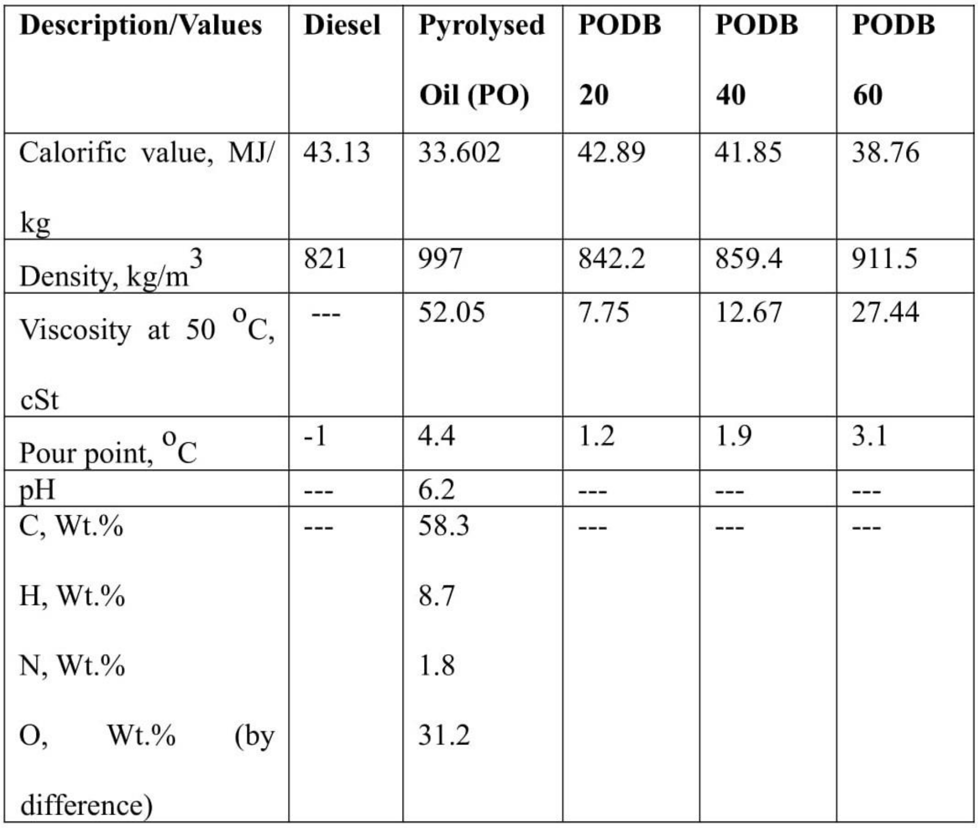


Fig 19: *Fuel filter elemental blocking because of Bio-char characteristics in pyrolysis of oil.*

***Table XV**: Physiochemical properties of fuels used*



Description/Values	Diesel	Pyrolysed Oil (PO)	PODB 20	PODB 40	PODB 60
Calorific value, MJ/kg	43.13	33.602	42.89	41.85	38.76
Density, kg/m^3	821	997	842.2	859.4	911.5
Viscosity at 50 ^oC, cSt	---	52.05	7.75	12.67	27.44
Pour point, ^oC	-1	4.4	1.2	1.9	3.1
pH	---	6.2	---	---	---
C, Wt.% H, Wt.% N, Wt.% O, Wt.% (by difference)	---	58.3 8.7 1.8 31.2	---	---	---

Raw materials:

Karanja seeds were procured from the local market and directly used for pyrolysis. The procured seeds were washed several times to remove the dust and then kept in open for drying and then kept into the oven at 110°C for removing moisture. The seeds were then crushed by the seed crusher and placed into the pyrolysis reactor through the hopper. To evaluate the unstable and non-unpredictable issue in the material, dampness substance and debris content, proximate examination was done by following ASTM D3172-07a rules. Carbon, hydrogen, nitrogen, sulfur and oxygen basic analyzer (Thermo, Flash 2000 CHNS/O analyzer) was utilized to survey the substance of carbon, hydrogen, nitrogen, sulfur and oxygen. A hairlike segment covered with a 0.25 mm film with DB-5 was utilized. The slim cylinder's length and distance across were 30 m and 0.25 mm individually. Helium gas of 99.999% immaculateness was utilized as a bearer gas. The stove starting temperature was set 60°C for 2 min and afterward 300°C at a pace of 10°C/min and kept up for 10 minutes. The mixes were distinguished by the NIST library.

3.4. Experimental testing on a Compression Ignition engines

An exploratory testing seat was created via coupling an immediate infusion Compression Ignition motor to a swirl momentum dynamometer (20 kilowatt) as appeared in Fig 20. Specialized particulars of the test motor are represented in Table II. Motor fumes gas has been tapped at the tailpipe to gauge Carbon monoxide, Hydrocarbon (Hexane equal outflow), Nitrogen oxides (NOx) discharges utilizing DI gas emanation analyzer. Tapped motor out fumes gas has been additionally associated with the meter for smoke estimation in % obscurity. A completely electronic framework with ignition analyzer has been utilized for admission air and fuel stream estimations alongside burning information (Fig 20). The start analyzer for the most part includes consuming data acquiring system with post getting ready programming. In-chamber pressure was assessed concerning degrees wrench edge (^{o}CA) using a weight transducer and wrench point encoder. All other ignition qualities were resolved dependent on the information of in-chamber pressure against degree CA for the whole cycle of motor activity.

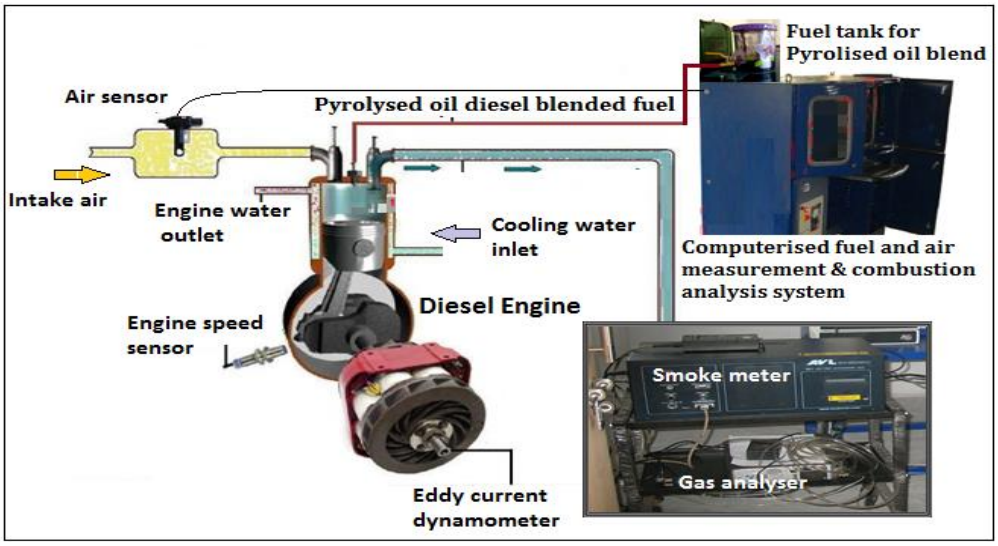
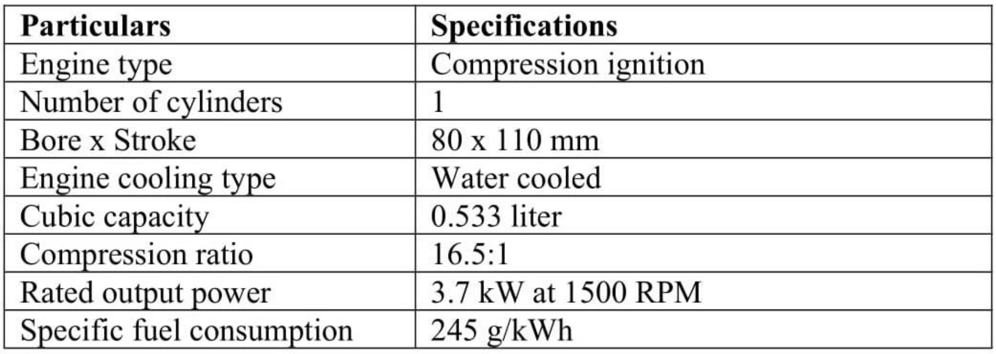


***Fig 20**: Pictorial image of engine experiment testing installation with emission analyzing*

Table XVI: *Technical characteristics of the testing engine*



Particulars	**Specifications**
Engine type	Compression ignition
Number of cylinders	1
Bore x Stroke	80 x 110 mm
Engine cooling type	Water cooled
Cubic capacity	0.533 liter
Compression ratio	16.5:1
Rated output power	3.7 kW at 1500 RPM
Specific fuel consumption	245 g/kWh

3.5. Engine experiment testing procedure

Wide scopes of exploratory tests were led on the test motor at various burdens and consistent velocity of 1500 Rotation per Meter. The point by point test lattice is represented in Table XII. Motor out fumes gas emanations were estimated on a volumetric premise and these discharges were changed over into mass premise utilizing in Equation 1. By Table XIII the estimated range and goals for various constraints can be understood. It might be noticed as the tests estimations have some mistake/vulnerability that are resolved utilizing Equation (2).

$$\text{Mass emission of species} = \mathrm{F_{species}} \times \frac{\mathrm{MW_{species}}}{\mathrm{MW_{exhaust\ gas}}} \times \frac{\dot{\mathrm{m}}_{\mathrm{Exhaust\ gas}}}{\text{Brake power}} \times 360 \qquad (1)$$

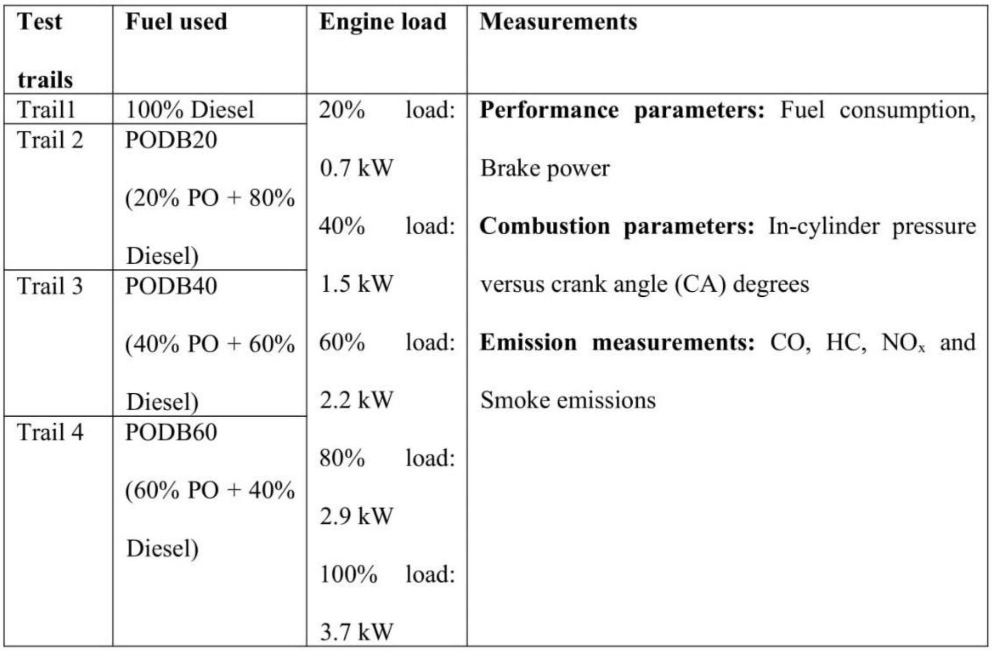
Here

$\mathrm{F_{species}}$ = Mole fraction of exhaust gases (CO, HC and NO_x)

MW = Molecular weight; m= Mass flow rate, kg/s

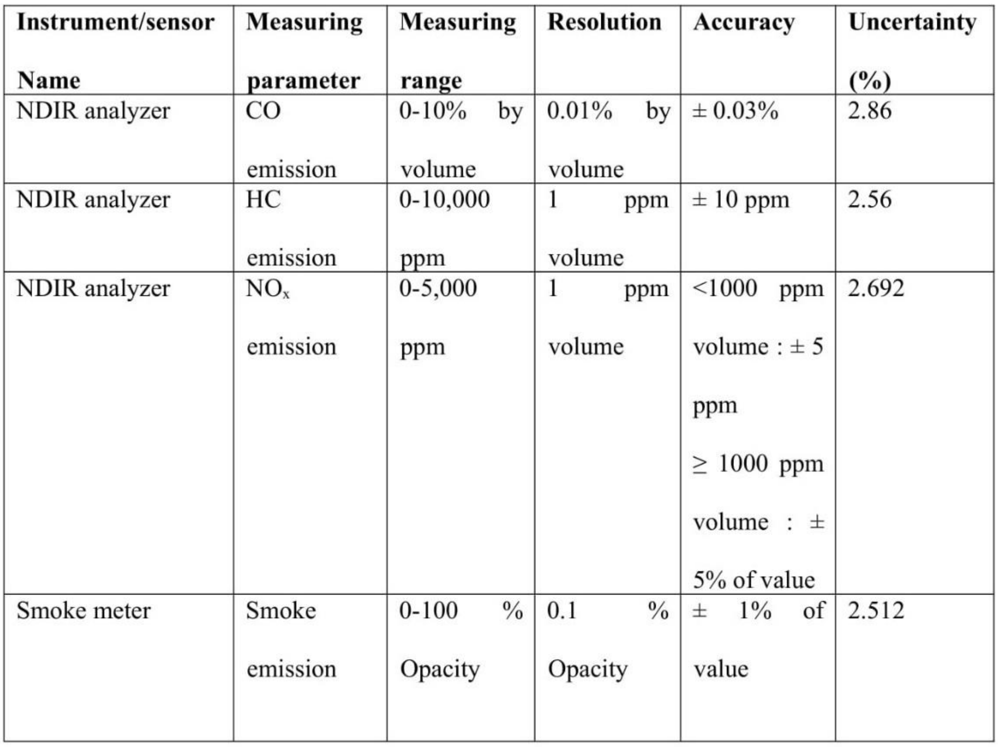
$$\mathrm{Q} = \left[\left(\frac{\partial \mathrm{q}}{\partial \mathrm{x_1}}\Delta \mathrm{x_1}\right)^2 + \left(\frac{\partial \mathrm{q}}{\partial \mathrm{x_2}}\Delta \mathrm{x_2}\right)^2 + \cdots \dots \dots + \left(\frac{\partial \mathrm{q}}{\partial \mathrm{x_n}}\Delta \mathrm{x_n}\right)^2\right]^{\frac{1}{2}} \qquad (2)$$

***Table XVII**: Detailed experimental test matrix*



Test trails	**Fuel used**	**Engine load**	**Measurements**
Trail1	100% Diesel	20% load: 0.7 kW 40% load: 1.5 kW 60% load: 2.2 kW 80% load: 2.9 kW 100% load: 3.7 kW	**Performance parameters:** Fuel consumption, Brake power **Combustion parameters:** In-cylinder pressure versus crank angle (CA) degrees **Emission measurements:** CO, HC, NO_x and Smoke emissions
Trail 2	PODB20 (20% PO + 80% Diesel)		
Trail 3	PODB40 (40% PO + 60% Diesel)		
Trail 4	PODB60 (60% PO + 40% Diesel)		

Table XVIII: *Representation of measurement ranging and instrumental resolutions*



Instrument/sensor Name	Measuring parameter	Measuring range	Resolution	Accuracy	Uncertainty (%)
NDIR analyzer	CO emission	0-10% by volume	0.01% by volume	± 0.03%	2.86
NDIR analyzer	HC emission	0-10,000 ppm	1 ppm volume	± 10 ppm	2.56
NDIR analyzer	NO_x emission	0-5,000 ppm	1 ppm volume	<1000 ppm volume : ± 5 ppm ≥ 1000 ppm volume : ± 5% of value	2.692
Smoke meter	Smoke emission	0-100 % Opacity	0.1 % Opacity	± 1% of value	2.512

Detailed reporting of outcomes representing contributions stated towards raising the state of knowledge in the domain.

***Table XIX**: Different solar reflector set-up built for different solar thermal experiments*

Sl. No.	Design Implemented	System Performance	Authors
1	Dual axis tracking system with linear Fresnel lens collector.	• Global efficiency is less than 20% due to optical losses. • Global efficiency increased to 55% after insulating with evacuated receiver.	Perini Simoni et al [126]
2	Dual axis tracking system with declination clock mounting system.	Average energy efficiency of normal tracking with respect to that of fixed PV is more than 23.6%.	Yao et al. [127]
3	Dual axis solar tracker with sensor & sensor less feature.	The average captured solar energy with sensor feature is 35.22% in one year & that for sensor less is 24.59% in one year.	Fathabadi [128]

4	Dual axis sun tracker using mechatronic design & PV system driven by robotic sensor.	It achieves a better performance than fixed as well as single axis mechanism.	Hernandez et al. [129]
5	Dual axis solar tracker with three identical LDRs in tetrahedron shape.	It has wide field of view, accuracy & effectiveness as compared with previous types of model.	Away & Ikhsan [130]
6	Dual axis solar tracker with PLC to control the motion of solar tracking system.	Increment in total daily collection of about 41.34% as compared with that of 32° tilted fixed surface.	Abdallah & Nijmeh [131]
7	Study of thermal performance of two axis solar tracker with compound parabolic concentrator.	CPC collector showed an increase in the collector energy of 75% when compared with identical fixed collector	Khalifa & Mutawalli [132]
8	Field programmable gate array [FPGA] based intelligent sun tracking system with the usage of NI9642 controller to	This system is assist with MATLAB so that the system can be switched to dual	Chen et al. [133]

	integrate dual axis solar tracker with Maximum Power Point Tracker.	axis solar tracker, one axis solar tracker & fixed solar panel according to the need of the user.	
9	A day lightning system which consists of optical fibers & solar tracking model. The device contains two feedback circles, coarse & fine adjustments due to which system exhibits good tracking performance.	Optical transmission efficiency lies between 37% & 40% which is close to theoretical value of 42%.	Song et al. [134]
10	Closed loop dual axis solar tracking system with 4 quadrant photo detectors & 2 small D.C. servo motors & a pyrheliometer for direct solar radiation measurement a z-80 processor.	At solar irradiance below 140 W/m2, the radiation falls nearly to zero but above this the system works fine.	Roth et al. [135]
11	Single spherical motor with the ability to Move the panel in both the directions is used.	Panel output of spherical motor based PV panel	Oner et al. [136]

		was better than the fixed PV panel.	
12	Altitude-azimuth dual axis solar tracking mode is used as main tracking mode & time-based tracking system is used as the auxiliary support with battery, MCV, photosensitive sensors & temperature sensors for a solar streetlight active sun tracker.	Tracking was done after a regular interval of 20 min saving energy & producing an average energy efficiency of about 36% in a year proving superiority of tracking mode.	Zhang et al. [137]
13	Dual axis solar tracking system using a PLC with a program based on the mathematical calculations of azimuth & altitude solar angles.	This system yielded 42.6% more energy in comparison with a similar fixed solar module.	Sungur [138]
14	A low profile 2 axis solar tracker with unique linkage geometry (2 coplanar & perpendicular linear actuators coupled with a single linkage arm & pivots) was used to	On comparison with existing mast style trackers, no significant change in shadow footprint was observed.	Barker et al. [139]

	minimize the shading by adjacent trackers.		
15	Low prototype for dual axis system & fixed system was created for comparison & azimuth angles were calculated using MATLAB m-file.	Dual axis system produced 34.02% more energy than the fixed one. Whole day production of panel involving tracking system was 55.91 Wh whereas fixed system produced a total of 41.71 Wh.	Yilmaz et al. [140]
16	6 different types of tracking system namely HAMA, HAWA, HADA, HACA, VACA & TA were compared with a fixed tilt system.	The 2 axis tracking (TA) system was found to be more advantageous than others.	Sinha & Chandel [141]
17	3 pilot dual axis sun tracking system (LDR based, date & time based using screw nut actuators, date & time based using reduction gear units) were compared.	Date & time based sun tracker using reduction gear units was more stable & accurate.	Skouri et al. [142]
18	A hybrid sun–wind tracking system using 2	In comparison with the fixed panel,	Rahimi et al. [143]

	actuators motors for solar tracking & 1 for wind tracking is built with a wind vane & wind tunnel for cooling purposes.	solar tracking panel produces 39.43% more energy whereas a hybrid tracking system produces 49.83% more on a daily basis.	
19	A parabolic solar cooker with automatic 2-axes tracking system using PLC whose program is based on pre calculated solar angles is built.	It can heat up the water to 90°C when the maximum ambient temperature reaches 36°C & allows food to be left in all day without burning.	Al-Soud et al. [144]
20	They studied that an inexpensive dual-axis solar tracker with high accuracy for PV applications. Processing of images from a bar shadow was used to track sun. The system required no astronomical equipment to position sun and was independent of the geographical	Tracking system was successful in tracking the sun with an accuracy of about 2%.	Abdollahpour et al. [145]

	location and initial settings.		
21	Two axis solar tracker with open loop control system.	It produces more than 27% electric energy than the fixed system.	Seme et al. [146]

Chapter 4: Characterization of Biomass and the Bi-products

To evaluate the various components of Biomass and biomass bi-products, various characterization methods had used. Before the pyrolysis process, SEM-EDX method were used to evaluate the oil content of the seeds. Getting an adequate amount of knowledge of the oil content of the seeds, further experimental studies have performed. Here is the glimpse of the few methods that has been used in the doctoral research.

SEM:

SEM (Quanta FEG200) was utilized to assess the actuated carbon surface. For SEM, the electron shaft is made to be occurrence on the example at a point of 45°. The finder distinguishes the electrons which go through the terminal (permeable) and afterward redirected towards the second electron indicator for additional identification. The perceptions were performed at a quickening voltage of 5.0 KV. The amplification was going from 30 to 60,000. The examination of the structures of biomass and the framed enacted carbon was broke down, as far as compound actuating the pores on the carbon covering using phosphoric corrosive as an initiating specialist.

FTIR:

For location of useful gatherings in the readied AC, FTIR (PerkinElmer, L12) investigation was finished utilizing standard techniques (KBr pellet with AC powder). The yield was as vibrational energy top, using the NIST-FTIR library, the working gathering were broke down. Separate checks of FTIR have been performed. The consequences of which from the point of view of compound strength were indistinguishable.

TGA:

Heating gravimetric investigation or thermogravimetric examination (TGA) is a strategy for heating investigation wherein change in physical and substance properties of materials are estimated as a component of expanding temperature (with consistent warming rate), or as an element of time (with steady temperature and additionally steady mass. It decides temperature and weight change of deterioration responses, which frequently permits quantitative creation examination. The peaks in the DTG-TGA gives us the exact idea of the temperature zone of collecting oil. By that analysis, we used to go for experimental study.

GC-MS:

This is a scientific technique that joins the highlights of gas-chromatography and mass spectrometry to recognize various substances inside a test. Right now the removed pyrolysis oil has been considered through the pinnacles acquired in GC-MS. After every single example run, hardly any pinnacles have been chosen to break down the segments through the NIST library.

4.1. Characterization of pyrolysed products

Solar thermal pyrolysis is basically a way to generate energy from the sun for the pyrolysis of biomass production. A process which involves burning of substances at high temperature in the absence of oxygen or oxidation environment. In short, it is thermochemical processing of biomass under inert atmosphere. Pyrolysis reactions are endothermic. Heating rate and residence time divide pyrolysis into three types: flash, fast and slow. The main challenges in biomass are its composition and related decomposition mechanisms. Different types of reactors, heating rate, residence time and present environment also have significant effects on the pyrolysis process. Mechanism of conversion of biomass constituents by pyrolysis involves breakage of bonds between the polymers and leads to release of volatile compounds and the rearrangement reactions. This product is known as primary conversion and some unstable compounds can undergo further conversion called secondary conversion. Primary conversion includes char formation, depolymerization and fragmentation. Compounds formed in primary mechanism, unstable under reactor temperature can undergo further cracking or recombination. Volatile compounds break into lower molecular weight stable molecules by cracking.

4.2. Ultimate and proximate analysis:

The Karanja seeds have a very high volatile content of 72.25%, which was reduced to 31.5% drastically after the solar thermal pyrolysis. These parameters are based on Table XX. As the volatile content decreased after the pyrolysis, the fixed carbon increased significantly. Table 6 also shows the other elemental composition after the ultimate analysis and proximate analysis of bio char from different feedstocks.

4.3. Thermo-gravimetric (TG) analysis:

Getting the knowledge about the pyrolytic zone of producing oil of Karanja seeds, Karanja biomass thermo-gravimetric analysis has been performed by using (TG) analyzer '(EXSTAR TG/DTA 6300)'. To perform TG analysis the air flow rate of 200 ml/min was maintained. From the Fig. 21, the TGA and DTG values can be understood in a graphical representation. For this experiment, 10 mg alumina (Al_2O_3) and seeds powder was taken with the heating rate of 10°C/min from room temperature to 980°C.

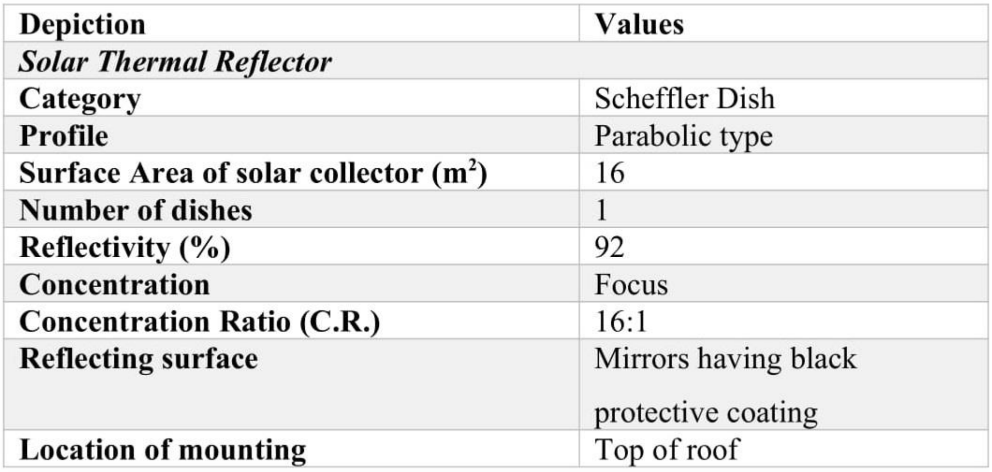
4.4. Fourier transform infrared (FTIR) analysis:

For the best possible outcomes and to monitor the key reaction type formations during the Karanja seed pyrolysis method, Fourier transform infrared (FTIR) spectroscopy was used. FTIR used to be on the make of Perkin Elmer (Frontier FT-IR/ FIR) with KBR as reference (Mawhinney & Yates Jr. 2001). From Fig. 22, it can be observed that the peak range is between400 cm^{-1} and 4000 cm^{-1} with the resolution of 8 cm^{-1}.

4.5. GC-MS analysis:

Gas chromatography-mass spectrometry (GC-MS) is utilized to arrange the variable parts in the substance. The substance mixes present in the pyrolysed oil can be controlled by the GC-MS examination as it were. From the Table XIX, the compound names, their formula and molecular weight can be seen. The GC-MS instrument is of the Perkin Elmer make.

Table XX: *Technical Specifications of the solar reflector*



Depiction	**Values**
Solar Thermal Reflector	
Category	Scheffler Dish
Profile	Parabolic type
Surface Area of solar collector (m^2)	16
Number of dishes	1
Reflectivity (%)	92
Concentration	Focus
Concentration Ratio (C.R.)	16:1
Reflecting surface	Mirrors having black protective coating
Location of mounting	Top of roof

This table XX is providing the technical specifications of the solar reflector has been used in this experimental set-up. Based on the surface area and the concentration ratio of the reactor, the reactor has been placed in front of the scheffler dish, so that the rays will be directly focusing on the reactor and maximum temperature will be achieved.

4.6. DTG and TGA of Karanja seeds biomass:

Rate weight reduction of Karanja oil seed biomass as for temperature is outlined in Fig 21. The thermal debasement of the material initiated at 203^{o}C and caused 7.9 % reduction in presence of air. When the temperature reached at 508^{o}C within the sight of air, 93% of debasement was and further thermal degradation got steady. Be that as it may, the maximum thermal debasement was seen as around 94% at 1000^{o}C. It could be observed that the TGA method has three basic level preset in the chart (1) ranging surrounding temperature to 203^{o}C, (2) from 203^{o}C to 508^{o}C and (3) from 508^{o}C onwards. First stage partner with disappearing of suddenness and unsteady composites; second stage shows the disintegration of cellulose and hemicellulose of biomass during pyrolysis. After the subsequent stage, mass misfortune saw as extremely moderate which demonstrates the decay of lignin. At 507ºC high rate of mass loss was undergoing in barometrical condition in air. TGA of karanja seed biomass was steady in comparison to the other seed biomass. Mangaba seeds detoriates to 82% at 500ºC.

DTG analysis of Karanja seed biomass under air atmospheric condition is given in Figure 21. Pyrolysis of biomass takes place typically in three main stages: (i) drying of biomass, (ii) degradation of the organic matter and (iii) continuous de-volatilization. In the first step moisture content in biomass is removed. In the second step, intermolecular associations and weaker chemical bonds are demolished. Then breakage of side aliphatic chains occurs which further leads to production of small gaseous molecules. During the third stage, parent molecular skeletons are demolished due to breakage of chemical bonds. In this stage, the larger the molecule decomposes into smaller molecules in the form of gas phase. Among the three stages, second one is the most crucial step and responsible for bio-oil and pyrolytic gas production. It is recognized from the TGA and DTG studies that the pyrolytic thermal zone for karanja seed biomass is in-between the temperature scope of 203ºC and 508ºC. It is additionally affirmed from publications that pyrolytic thermal zone for a large portion of biomass seeds lies in the scope of 200-600ºC (for Mahua seeds) [4], 200 to 550ºC for Jatropha seeds [8], 200 to 500ºC for Castor seeds [6].

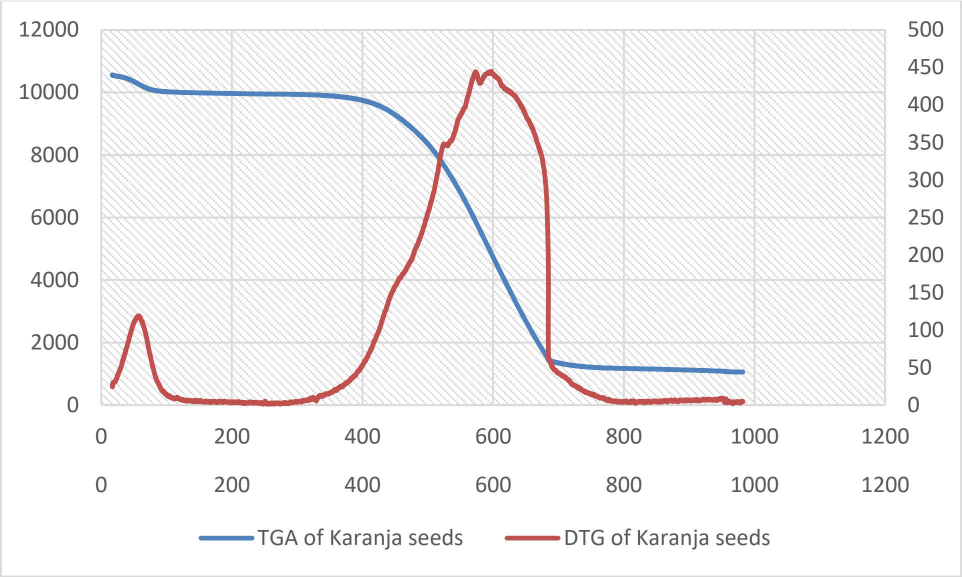


***Fig. 21**: DTG and TGA of Karanja Seeds*

4.7. FTIR analysis of Karanja seeds biomass:

FTIR examination of Karanja seed biomass appeared in figure 22. The fallouts obviously address that alkyl, ester and essential portions of the fuel is present inside biomass. Ranges between 2850-3000 cm^{-1} speaks to a stronger C-H stretches for gathering. The C=O (strong bond) reaching out at 1750-1735 cm^{-1} exhibits the proximity of the ester gathering. Presence of skin break out and sweet-smelling impacts C=C extending to vibrate at 1650-1580 cm^{-1}. The range gained in scope of 1470 cm^{-1} and 1350 cm^{-1} choose vibration and miss happening in view of existing skin inflammation gatherings. Also, the C=O is deforming, ranges 1300-950 cm^{-1} certifies the occurrence of ether & ester and range at 900-640 cm^{-1} having O-H twist uncovers the existence of a group ‘mono and polycyclic’ substitute's (fragrant gatherings). Nearness of aliphatic particles close by fragrant notification the proximity of cellulose and hemicellulose nearby lignin in the structure. In this manner the tops in the diagram prescribed that the karanja seed biomass contains fuel segments for example alkyl, ether, ester, mono and polycyclic from fragrant gathering.

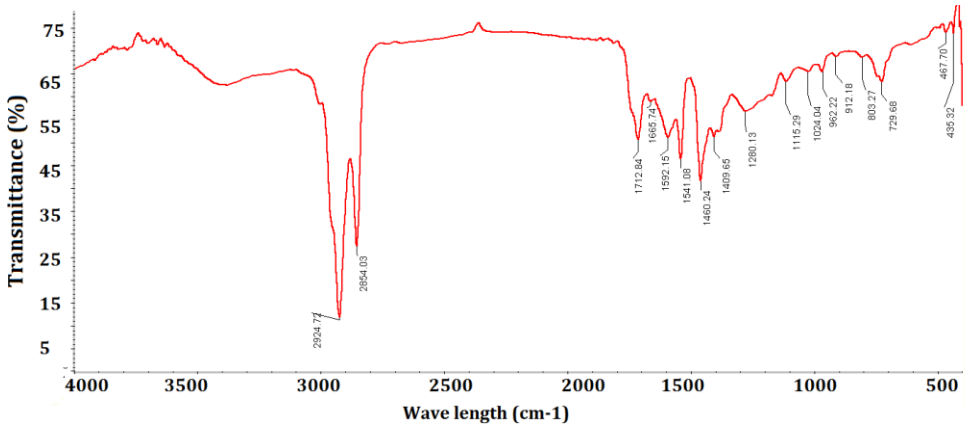


Fig. 22*: FTIR analysis of Karanja seeds*

Various FTIR spectra are shown in Table 20, this confirms the presence of alcohol, alkane, aldehyde, ketones and alkyne utility group (i.e. pivotal elements of fuel to ignite the combustion engines) in the bio-components (i.e. biomass and bio-oil).

Table XXI: *FTIR spectra peaks analysis of Karanja seeds*

Peak range (Cm^{-1})	**Wavelength (cm^{-1})**	**Functional group**	**Vibration type**
2850-3000	2924.12	Alkane	C-H stretching
1750-1735	1712.84	Ester	C=O stretching
1650-1580	1592.15, 1541.08	Alkene and aromatics	C=C stretching
1470-1350	1460.24, 1409.65	Alkyne	$C \equiv C$ deformation
1300-950	1280.13, 1115.29, 1024.04	C=O stretching and deformation	ether and esters
900-650	803.27, 729.68,	Mono and polycyclic substituted aromatics groups	O-H bending

By the FTIR spectra and table mentioned above, peaks have identified for various wavelength range and peak range. By the peak range, the functional group has been identified.

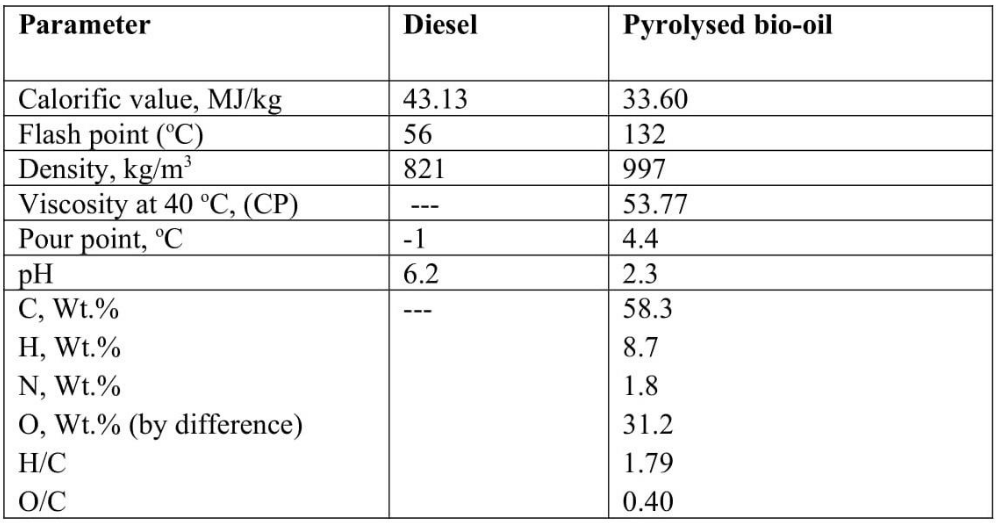
4.8. Bio-oil classification:

Bio oil can be classified by the ultimate and proximate analysis. This analysis was performed under some condition and then compared with Diesel.

Physico-chemical properties of pyrolysed bio-oil

The below mentioned table is providing an abrupt idea of various physio-chemical properties of the pyrolysed oil after blended with diesel.

Table XXII: *Properties of blended pyrolysed oil with diesel*



Parameter	Diesel	Pyrolysed bio-oil
Calorific value, MJ/kg	43.13	33.60
Flash point (ºC)	56	132
Density, kg/m^3	821	997
Viscosity at 40 ºC, (CP)	---	53.77
Pour point, ºC	-1	4.4
pH	6.2	2.3
C, Wt.%	---	58.3
H, Wt.%		8.7
N, Wt.%		1.8
O, Wt.% (by difference)		31.2
H/C		1.79
O/C		0.40

A graphical representation of bio-oil yield, bio-char yield and pyrolysed gas has been shown in fig 23.

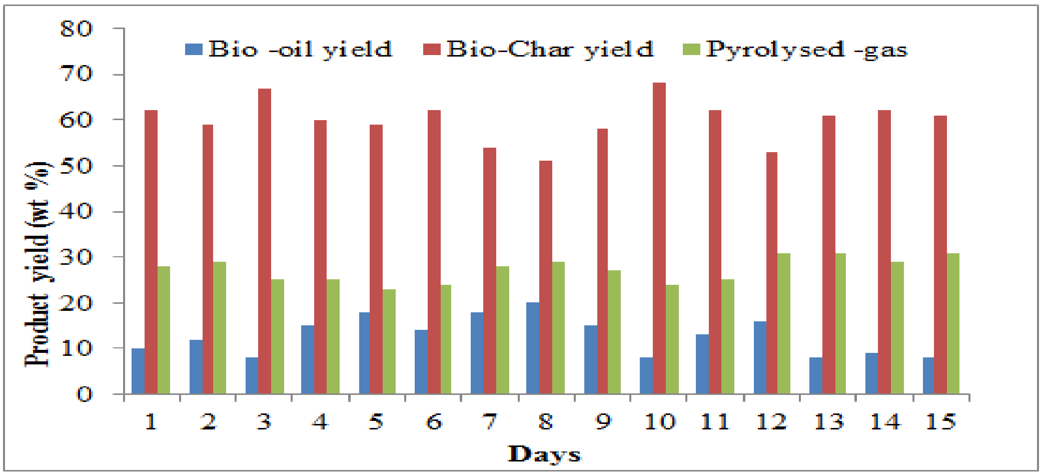


Fig. 23: *Schematic observations of the variation of production of bio-char yield, bio-oil yield and pyrolysed gas* [101]

4.9. FTIR analysis of pyrolysed bio-oil:

Extracted bio-oil from karanja Seeds has assessed FTIR by solar thermal pyrolysis, portrayed in Figure 13. Ranges 3200-2900 cm^{-1} addresses the closeness of alkane as a result of C-H broadening vibration. Apex scope of 1725-1760 cm^{-1} exhibits the existence of the ‘strong ester’ gathering. The existence of ‘aromatics and alkane’ were certified by entrance of apex go recognized in the extent of 1660-1590 cm^{-1}. Moreover, tops got in the scope of 1550-1500 cm^{-1} were because of the solid N–O extending vibration. Pinnacles saw between the scopes of 1470-1350 cm^{-1} affirm the nearness of skin inflammation bunch because of C-C distortion vibration. Tops somewhere in the range of ‘1300 and 950 cm^{-1}’ speak to ‘esters and ethers’ because of the C-O extending & miss-happening vibration. The existence of ‘mono and the polycyclic’ subbed aromatic bunch is assigned by top range of ‘900-650cm^{-1}’**.** Along these lines FTIR effects uncovered about utilitarian grouping existing in the bio-oil are similar to various literature surveys.

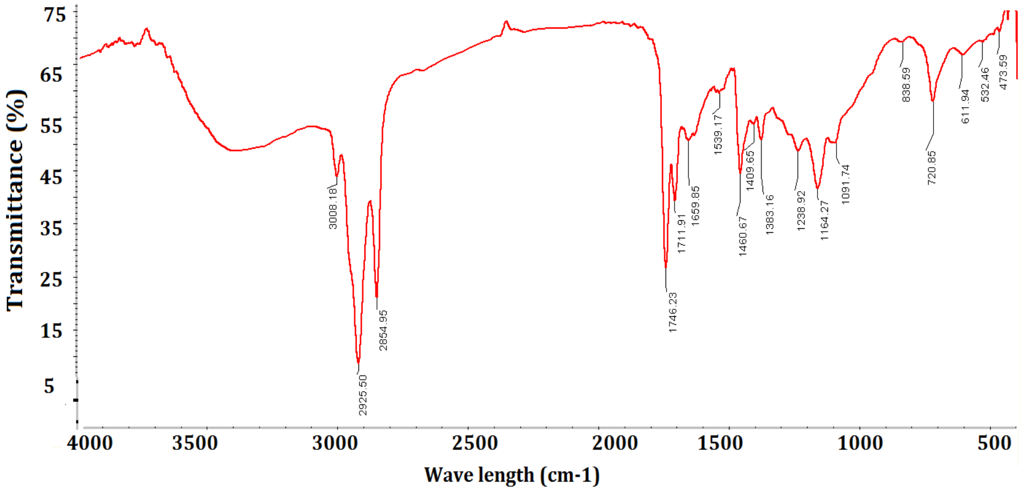


***Fig. 24**: FTIR of solar thermal pyrolysed bio-oil*

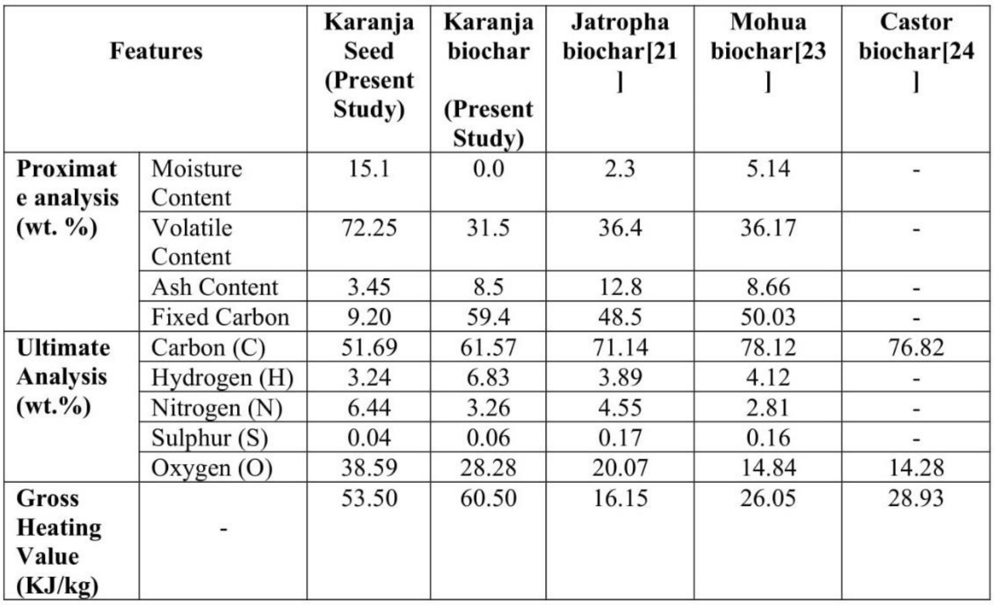
4.10. Gas Chromatography-Mass Spectrometer study of pyrolysed oil:

GC-MS analysis is one of the important instrument that analyses the various compounds present in any product. After the injection of the pyrolysed oil into the GC-MS chamber with proper program, a graph was obtained. Based on the peaks of the graph, the NIST library was used to evaluate the exact compounds name and details present in the product. Through the below mentioned table it has been observed the compounds name, molecular weight and formula present in the pyrolysed oil.

***Table XXIII:** Chemical compounds in Karanja seed pyrolytic oil as determined by GC-MS*

Compound Name	Molecular Weight	Molecular Formula
4H-1,3-BENZODIOXIN	136	$C_8H_8O_2$
3-(3-METHYL-3-OXAZIRIDINYL)PYRIDINE	136	$C_7H_8ON_2$
1H-PYRIMIDO[5,4-E] [1,2,4]TRIAZINE-5,7-DI	270	$C_{12}H_{10}O_2N_6$
CYCLOOCTYLIDENE-(2-PHENYLAZIRIDIN-1-YL)	242	$C_{16}H_{22}N_2$
2-[3-[2-OXO-3-OXAZOLIDINYL]PROPYL]-1,2-B	310	$C_{13}H_{14}O_5N_2S$
SPIRO[ISOBENZOFURAN-1(3H)-ONE-3,2'-TETRA	204	$C_{11}H_8O_4$
3-CYANO-1,4,5-TRIMETHYL-2-PHTHALIMIDO-PY	279	$C_{16}H_{13}O_2N_3$
SYDNONE, 3-PHENYL	162	$C_8H_6O_2N_2$
4H-THIOPYRAN-4-ONE, TETRAHYDRO-, 1-OXIDE	132	$C_5H_8O_2S$
TETRAHYDRO-2H-THIOPYRAN-4-YLIDENEMALONON	196	$C_8H_8O_2N_2S$
CYCLOHEXANAMINE, N-(BENZOYLOXY)	219	$C_{13}H_{17}O_2N$
(2E,4Z)-3-METHOXY-2,4-HEXADIENEDINITRILE	134	$C_7H_6ON_2$
CYCLOOCTYLIDENE-(2-PHENYLAZIRIDIN-1-YL)A	242	$C_{16}H_{22}N_2$
4H-THIOPYRAN-4-ONE, TETRAHYDRO-, 1-OXIDE	132	$C_5H_8O_2S$
10-CHLORO-1-DECANOL	192	$C_{10}H_{21}Ocl$
CYCLODECANE	140	$C_{10}H_{20}$
1H-IMIDAZOLE, 2-ETHYL-4,5-DIHYDRO-4-METH	112	$C_6H_{12}N_2$
E-11-TETRADECEN-1-OL TRIFLUOROACETATE	308	$C_{16}H_{27}O_2F_3$
CYCLOPENTANE, BUTYL	126	C_9H_{18}

Table XXIV: *Ultimate and Proximate analysis of various biochar from various feedstocks:*



Features		**Karanja Seed (Present Study)**	**Karanja biochar (Present Study)**	**Jatropha biochar[21]**	**Mohua biochar[23]**	**Castor biochar[24]**
Proximate analysis (wt. %)	Moisture Content	15.1	0.0	2.3	5.14	-
	Volatile Content	72.25	31.5	36.4	36.17	-
	Ash Content	3.45	8.5	12.8	8.66	-
	Fixed Carbon	9.20	59.4	48.5	50.03	-
Ultimate Analysis (wt.%)	Carbon (C)	51.69	61.57	71.14	78.12	76.82
	Hydrogen (H)	3.24	6.83	3.89	4.12	-
	Nitrogen (N)	6.44	3.26	4.55	2.81	-
	Sulphur (S)	0.04	0.06	0.17	0.16	-
	Oxygen (O)	38.59	28.28	20.07	14.84	14.28
Gross Heating Value (KJ/kg)	-	53.50	60.50	16.15	26.05	28.93

4.11.Configuration of pyrolytic gas:

Pyrolysed gas components were evaluated utilizing gaseous chromatographic stickled with TCD (as shown in fig 14). Results are also represented in respective figure. We can reveal it from figure that composition of carbon dioxide is higher than others (i.e. 26%). This attribution is due to thermal decomposition. Methane and Hydrogen gases composition are 4.37% and 3.56% approx. Presence of these gases indicate the suitability of pyrolytic gas as proxy fuel for spark ignition devices.

4.12. Bio-char characterization

4.12.1. Proximate and ultimate analysis of pyrolysed biochar

Promixation processing of biochar sustained as a by-product of sun based thermodynamics pyrolysis of karanja seed biomasses represented in table XI. Growth in carbon is because of thermodynamics decomposition of biomasses, ‘stating to dehydration and decarboxylation’ reaction that outcome in low oxygen and volatile solidification.

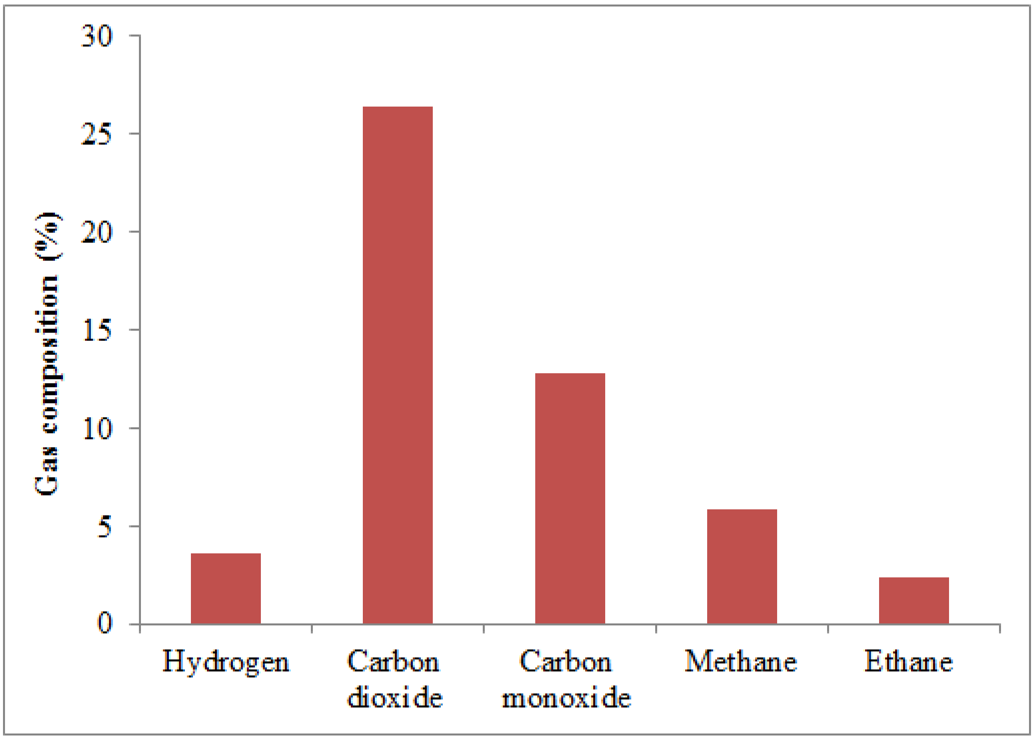


***Fig. 25**: Various composition of pyrolytic gas through Solar Thermal Technology karanja seed biomass*

4.12.2. FTIR investigation of pyrolysed biochar

2800-3200 cm-1 stated ‘C-H stretching of alkane groups’.

Fig 26 represents the FTIR analyze of bio-char sustained via sun based pyrolysis of Karanja seed biomasses. It’s resulted the vibrations declined in the scale of

2800-3200 cm^{-1} stated ‘C-H stretching of alkane groups’.

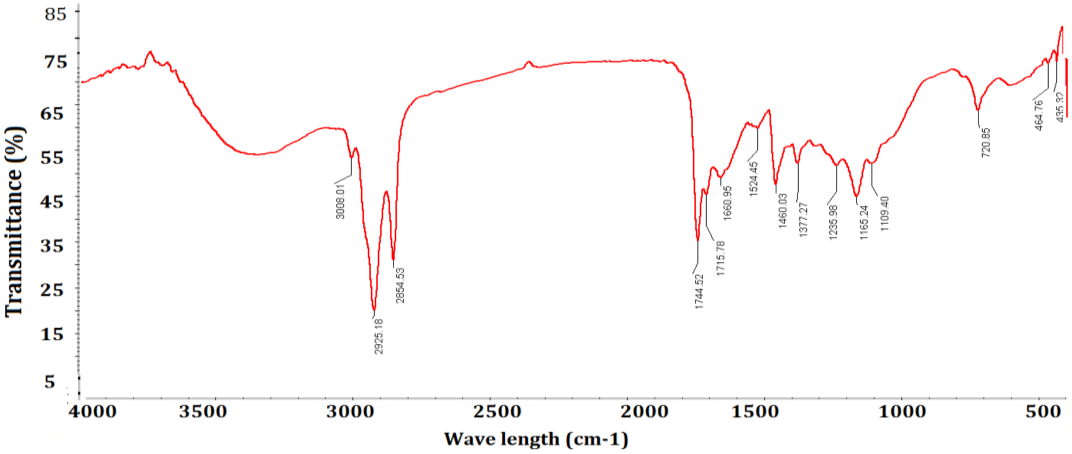


Fig. 26*: FTIR of karanja seeds biomass obtained through Solar Thermal pyrolysis*

Comparative analysis of all the FTIR spectra:

Fig. 22 describes the FTIR spectra of Karnaja Seeds, where fig. 25 describes about the FTIR spectra ranges for the pyrolysed oil. The fig. 27 shows the spectra for the karanja seeds biomass after the pyrolysis. That means when the pyrolysis process was completed, the biochar collected for the characterization. This figure describes about the spectra range of the biomass (after pyrolysis).

4.13. **Effect on thermal efficiency of a CI engine tested on pyrolysed blended oil:**

A comparison of in-cylinder pressure variation with different fuel blends at a particular load (80% load) is represented in Fig. 27. It could be clearly understood from the figure that the in-cylinder pressure during combustion is higher with PODB20 and PODB40 fuels and lower with PODB60 fuel as compared to base diesel fuel. For example, the in-cylinder peak pressure increased drastically from 66.5 bar with base diesel to 71.4 bar with addition of 20% PO and then declined gradually to 69.7 bar and 65.9 bar with addition of 40% and 60% PO with the diesel. It could be attributed for the initial increase in the peak pressure with 20% PO is due to inherent oxygen compounds which promoted the combustion efficiency, whereas further addition of PO might be caused poor atomization, vaporization, and fuel-air mixing problems due to high viscosity (52.05 cSt) and density (997 kg/m3) of the PO. In addition to this, calorific value of higher PO share (38.76 MJ/kg for PODB60) blended fuels also significantly lower than the base diesel fuel (43.13 MJ/kg) which resulted in poor combustion characteristics. However, it is clearly seen from Figure 27 that the in-cylinder peak pressure levels with PODB20 and PODB40 are higher than the base diesel fuel operation which resulted in higher thermal efficiency with PODB20 and PODB40 as compared to base diesel fuel.

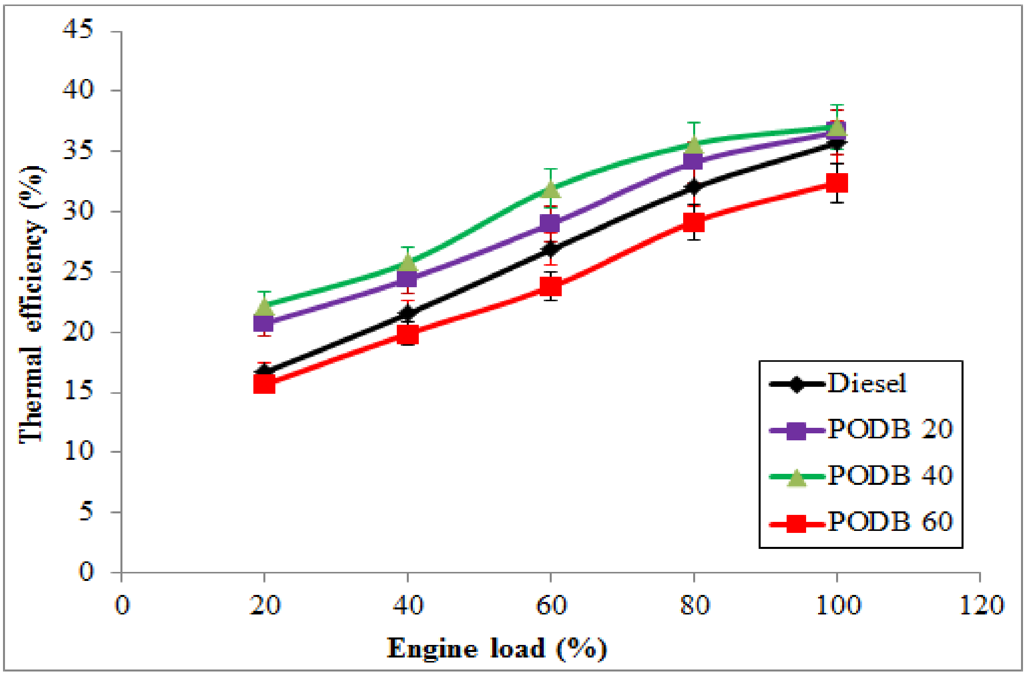


***Fig. 27:** Brake thermal efficiency variation with respect to engine loads for different fuels*[100]

4.14. Effect of pyrolysed oil blending on combustion parameters of the engine

Fig 28 describes the comparison of heat release rate (HRR) profiles of the test engine at a specific load and speed for different fuels. The HRR for different engine operating conditions were determined using first law of thermodynamics (Eq. (3)) with the input data of measured in-cylinder pressure.

Fig. 29 represents comparison of combustion duration with different fuels while the test engine operated at different loads and constant speed of 1500 rpm. Combustion duration was prolonged with increasing PO share due to high density and viscosity of PO. Combustion of high denser fuels takes longer time due to slower combustion. Diffusion combustion phase might be increased with high percentage of PO diesel blends due to slower evaporation of fuel droplets and air-fuel charge preparation. It is widely accepted that the degree CA at which 90% of the total mass burned is considered as end of combustion

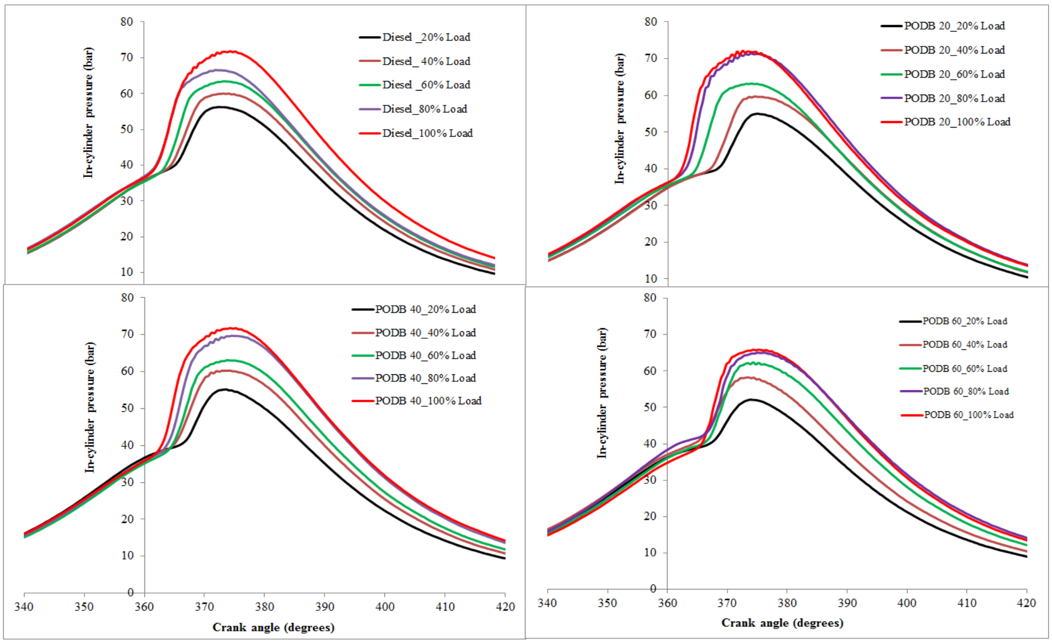


Fig. 28: *Comparison of in-cylinder pressure profiles with different PO blended fuels at all loads* [100]

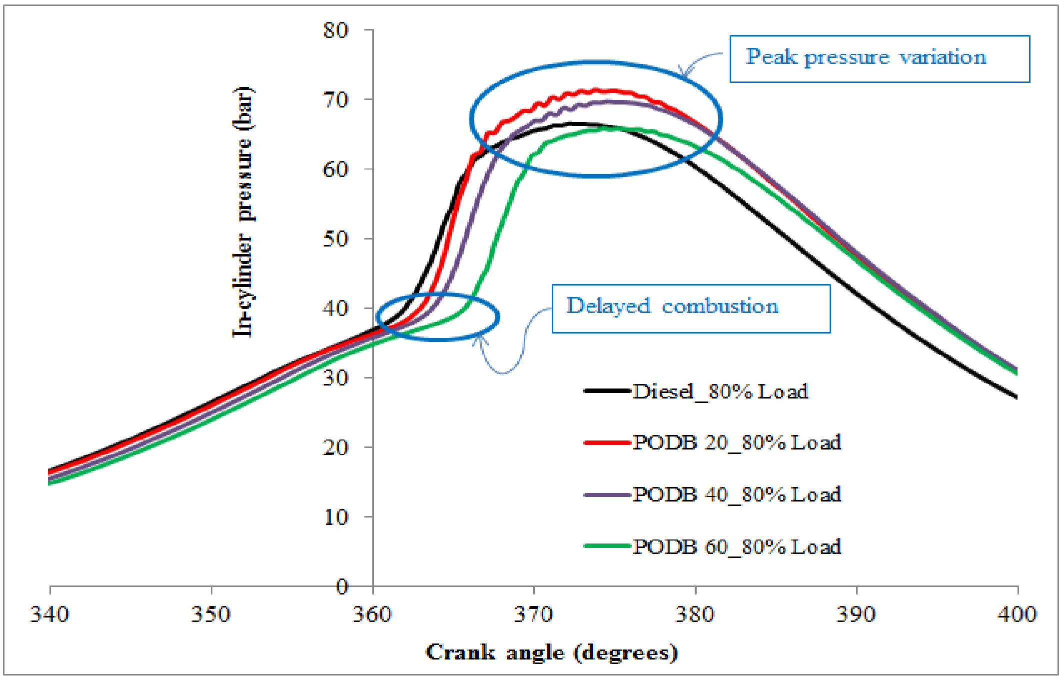


Fig. 29: *In-cylinder pressure profiles with different PO blended fuels at 80% load* [101]

This figure explains the testing of heat releasing rate profiles of the testing device at a particular burden and velocity for various powers. The HRR for diverse device working conditions were restored using the primary ‘law of thermodynamics (Eq. (3)) with the knowledge of estimated in-chamber pressure.'

$$\frac{dQ}{d\theta} = \frac{\gamma}{\gamma-1} p \frac{dV}{d\theta} + \frac{1}{\gamma-1} V \frac{dp}{d\theta} + h_c \frac{dA_{cylinder}}{d\theta} \frac{d(T_{gas} - T_{wall})}{d\theta} \quad (3)$$

Woshchni correlation can be used for calculating heat transfer coefficient as given in Eq. (4).

$$\text{Convective heat transfer coefficient } (h_c) = 0.82 \times B^{-0.2} \times P^{0.8} \times v_g^{0.8} \times T^{-0.53} \quad (4)$$

It's all around acknowledged that the fuel shower qualities breaks as the thickness of the fuel increments. Other exploratory examinations likewise all around affirmed the expansion in start delay with expanding portion of PO in fuel mixes.

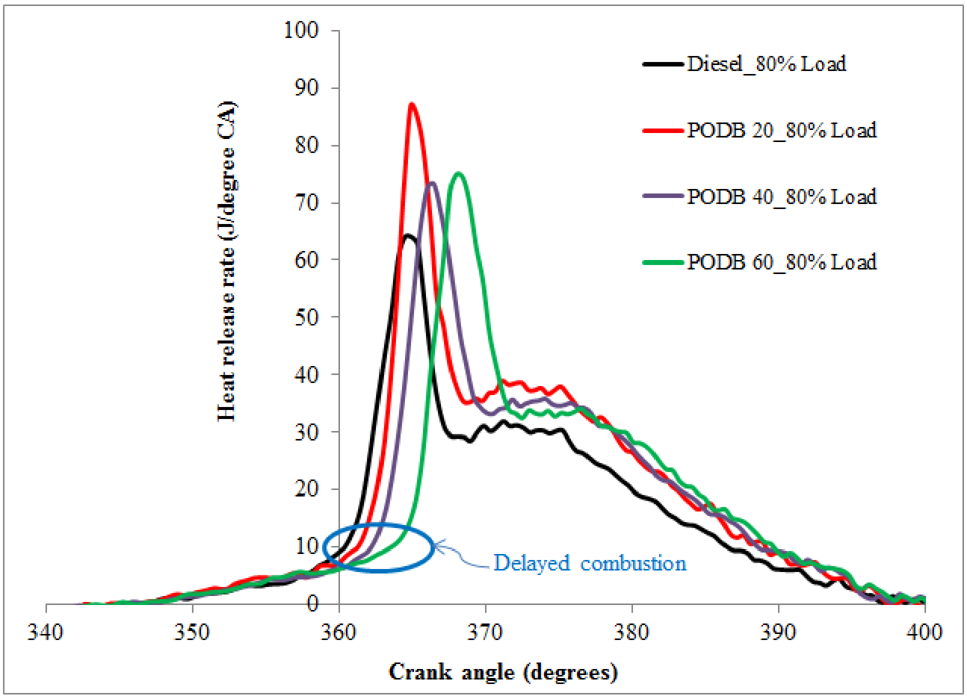


***Fig. 30**: Heat release rate profiles with different PO blended fuels at 80% load [101]*

As per Figure 30, it is quite evident that the end of combustion increased with increasing PO share at all loads. Delayed end of combustion indicates a significant loss of heat energy release as combustion process is taking place during late expansion stroke.

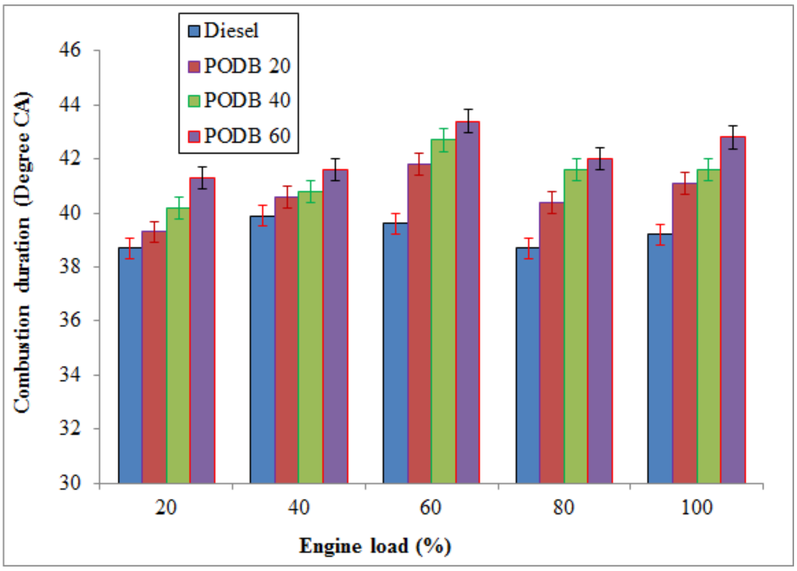


***Fig. 31**: Combustion duration with respect to engine loads for different PO blended fuels [101]*

Fig. 31 refers the engine tailpipe carbon monoxide (CO) emission for different fuels. The CO emission levels with PODB20 and PODB40 were lower than base diesel fuel at all loads due to increasing oxidation rates with high oxygen compounds in pyrolysed oil blends. With the available additional inherent oxygen content, the partially oxidized species (CO) in combustion chamber could further reacted with oxygen and converted to carbon dioxide (CO_2), leading to reduced CO emission level. However, the emission was higher with PODB60 than base diesel due to dominant effect of lower calorific value and poor combustion characteristics with high percentage of PO share. In the current study, the CO emission initially decreased and then increased with high percentage of PO blends at all loads. For example, at 80% load, the emission decreased from 2.44 g/kWh with base diesel to 1.95 g/kWh and 1.27 g/kWh with PODB20 and PODB40, later increased to 2.71 g/kWh with PODB60 as shown in Fig. 31.

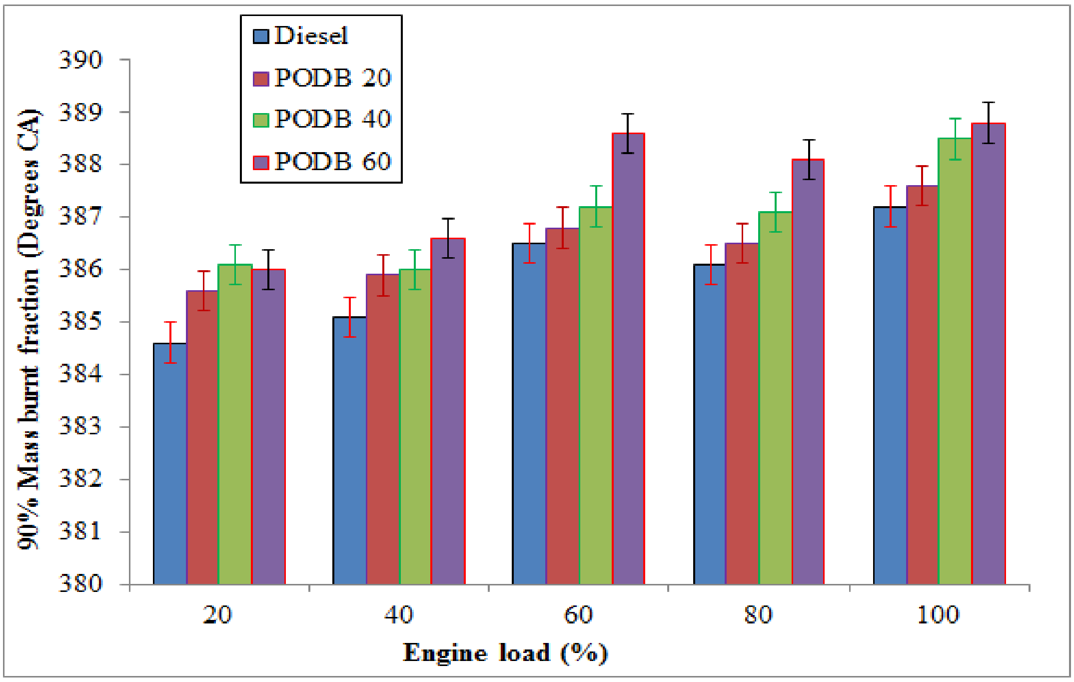


***Fig. 32**: 90% mass burnt fraction with respect to engine loads for different PO blended fuels [102]*

Fig. 32 represents hydrocarbon (HC) emission level for different fuels at all loads. The HC emission also followed the same trend as CO emission with increasing PO share. However, the HC emission levels are lower than CO emission levels at all loads. It could be seen from Fig. 32 that at 80% load, the engine out HC emission decreased from 0.66 g/kWh with diesel to 0.58 g/kWh and 0.41 g/kWh with PODB20 and PODB40 fuels, later increased to 0.83 g/kWh with PODB60 fuel. These results are in line with the earlier studies carried out on diesel engines with different biomass derived pyrolysed oils.

4.15. ‘Effect of pyrolysed oil blending on emission parameters of the engine’:

‘Fig represents the motor tailpipe carbon monoxide (CO) release for diverse energizes. The CO emanation scales with PODB20 and PODB40 were lower than base diesel fuel at all heaps because of expansion in oxidation rates with higher oxygen mixes in pyrolysed oil mixes’.

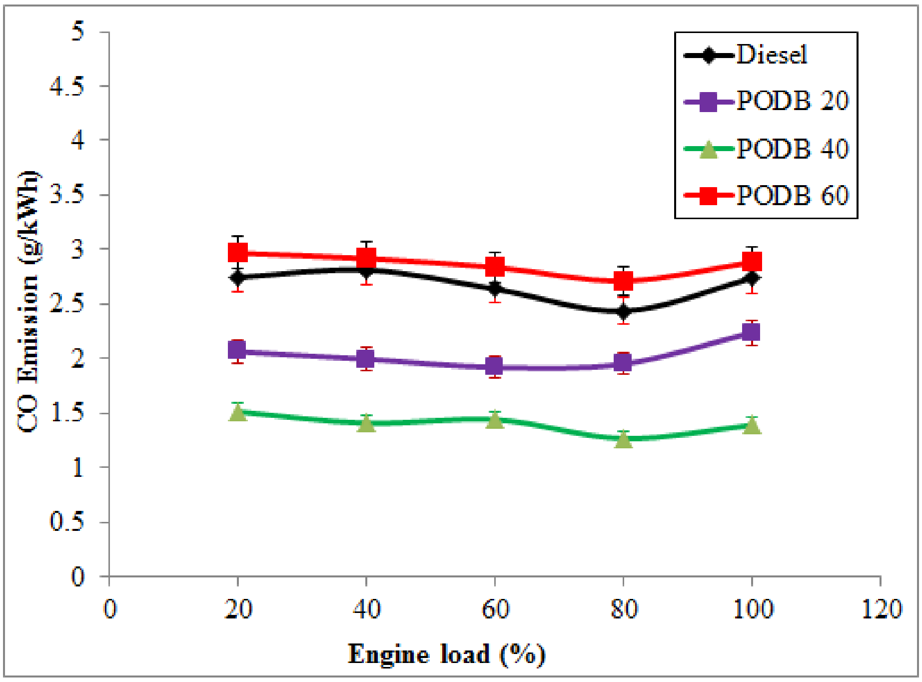


Fig. 33*: Carbon monoxide emission variation with respect to load for different fuels [101]*

It is evident from Fig. 33 that oxides of nitrogen (NOx) emission increased with increasing load on the engine for all the test fuels (diesel, PODB20, PODB40, and PODB60). For example for PODB40 fuel, the NOx emission increased from 4.26 g/kWh at 20% load to 8.1 g/kWh, 12.4 g/kWh, 21.9 g/kWh and 28.5 g/kWh at 40%, 60%, 80% and 100% loads as shown in the figure. This could be interpreted as mainly due to increase in the combustion temperature with increase in the engine load. It is widely accepted that the NOx formation is mainly dependent on three parameters; (i) temperature raised during combustion, (ii) presence of oxygen in combustion chamber and (iii) time available for nitrogen and oxygen species reaction.

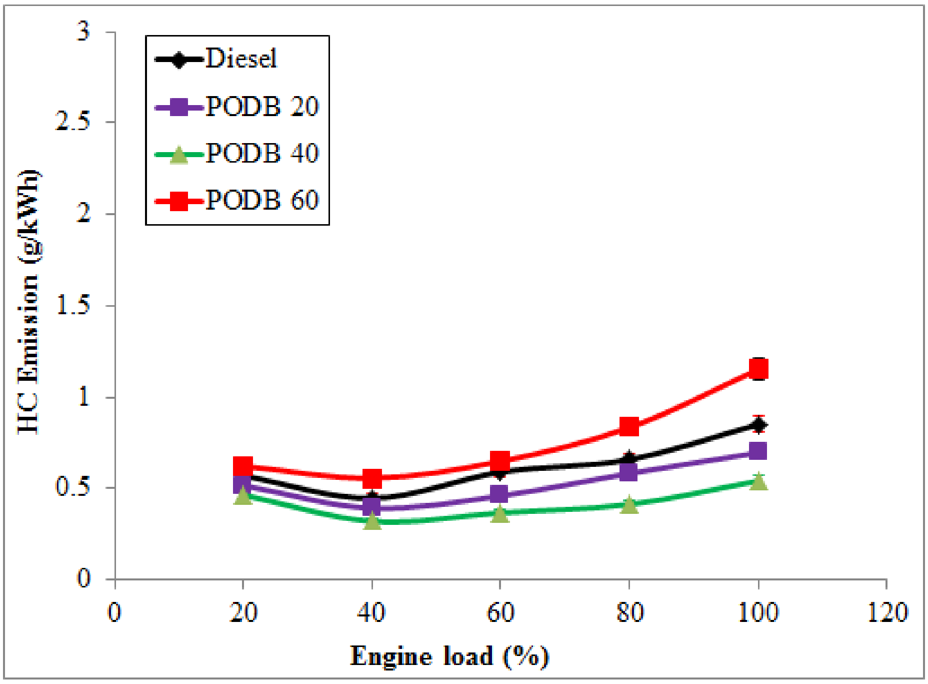


Fig. 34: *Hydrocarbon emission variation with respect to load for different fuels [101]*

Fig 34 speaks to hydrocarbon (HC) release scaling for diverse energizes at all heaps. It is clear from Fig 35 that (NOx) release expanded 'with expanding load on the motor for all the test fills (diesel, PODB20, PODB40, and PODB60)'.

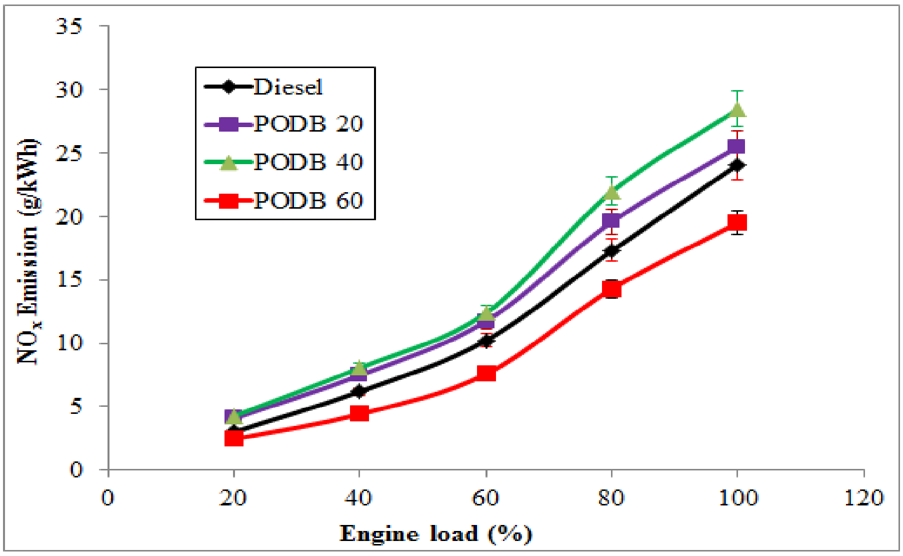


Fig. 35: *Oxides of nitrogen emission variation with respect to load for different fuels* [101]

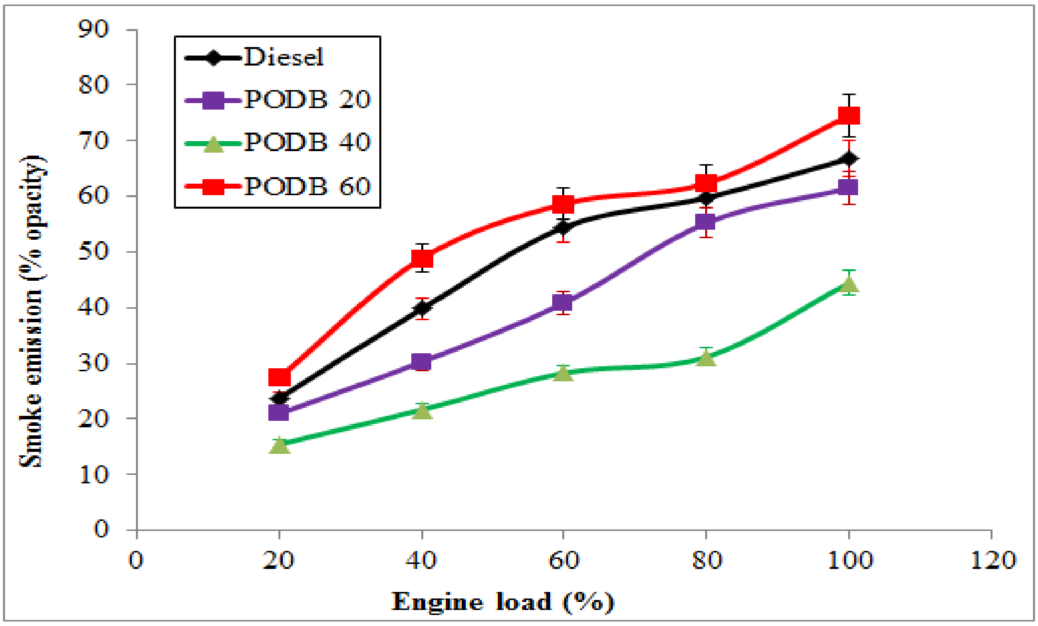


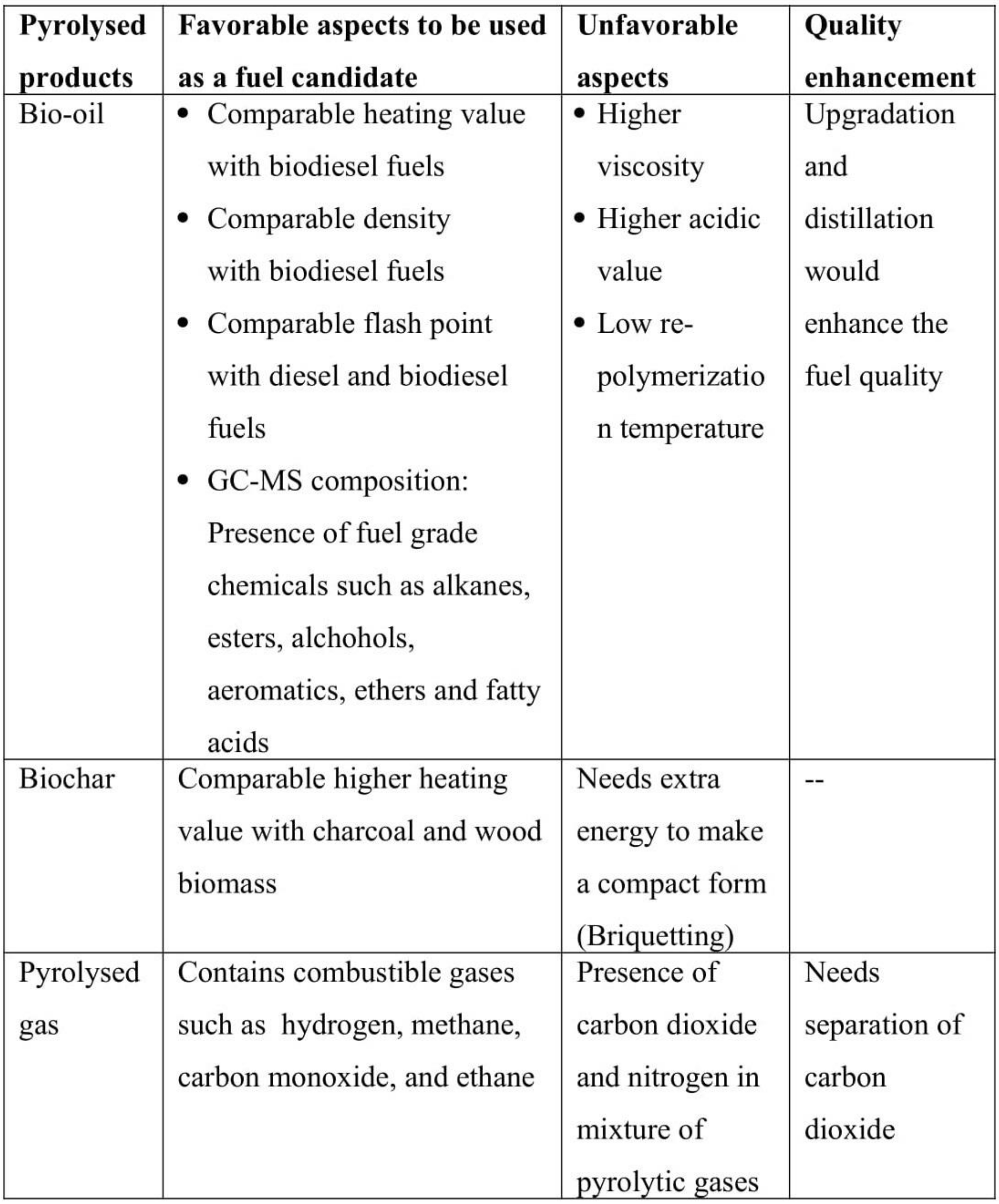
***Fig. 36**: Smoke emission variation with respect to load for different fuels* [101]

This figure illustrates fuel, RPM release scales with various fuel RPMM all heaps and continue velocity of 1500 rotation per meter. The outflow expanded radically with expanding load for all fuel mix.

4.16. Feasibility study of the pyrolysed fuel as a summarized way:

The thermodynamics ‘pyrolysis of karanja seeds’ yeilds triple important products that consist of bio- oil, biochar and pyrolytic gas. As detailed in the figure these represented products represents favourable attributes that can be adopted as an substitute feul in diverse industrial and transport sector applications. ‘On the other hand, the second product i.e., pyrolytic gasoline is a combination of combustible gases together with hydrogen, carbon monoxide, methane and ethane, which may additionally have top ability to replace herbal gas or manufacturer gasoline for spark ignition engine applications'.

Table XXV: *Various aspects of pyrolysed oil to be used as a fuel*



Pyrolysed products	**Favorable aspects to be used as a fuel candidate**	**Unfavorable aspects**	**Quality enhancement**
Bio-oil	• Comparable heating value with biodiesel fuels • Comparable density with biodiesel fuels • Comparable flash point with diesel and biodiesel fuels • GC-MS composition: Presence of fuel grade chemicals such as alkanes, esters, alchohols, aeromatics, ethers and fatty acids	• Higher viscosity • Higher acidic value • Low re-polymerization temperature	Upgradation and distillation would enhance the fuel quality
Biochar	Comparable higher heating value with charcoal and wood biomass	Needs extra energy to make a compact form (Briquetting)	--
Pyrolysed gas	Contains combustible gases such as hydrogen, methane, carbon monoxide, and ethane	Presence of carbon dioxide and nitrogen in mixture of pyrolytic gases	Needs separation of carbon dioxide

This table shows various aspects of pyrolysed oil to be used as a fuel in a diesel engine/petrol engine based on the bi-products. Based on the bi-products characteristics, it will be upgraded before using in any engine.

Chapter 5: Conclusions

- ‘Solar oriented thermo-chemical pyrolysis of Karanja seed biomass was completed in a tempered metallic pyrolysis reactor and in a void reactor (later level) and brought three pyrolysed items; (I) bio-oil, (ii) bio-char, and (iii) pyrolytic fuel. The maximum excessive bio-oil yield received about 20% alongside 51% bio-char and 29% gases. Be that as it may, the yield of bio-oil became approximately 12% because of huge warmness switch misfortunes from the reactor. In the improvement stage of the experimental paintings, the efficiency has been accelerated to 18% after the reactor has been modified. Characterization of products were completed as per the norms. Exploratory tests had been led on a solitary chamber direct infusion diesel motor with 4 precise energizes ‘i.e., diesel, PODB20 (20% pyrolysed oil+80% diesel), PODB40 (forty% pyrolysed oil + 60% diesel), and PODB60 (60% pyrolysed oil+40% diesel) at various burdens (20%, 40%, 60%, 80% and a 100%).’ In light of the test consequences, the subsequent conclusions were drawn.
- Pyrolytic temperature region for Karanja seed biomass became distinguished as 203^0C to 508^0C depending on TGA and DTG effects. About 93 % mass debasement became visible inside the sight of air at 508^0C past which temperature degradation got consistent.
- FTIR variety pinnacle stages, as an example, 2850-3000, 1750-1735, 1650-1580, 1470-1350 cm^{-1} affirmed about the existence of ‘ester,

alkene, and alkyne purposeful corporations (fundamental segments of gasoline) inside the biomass and bio-oil.

- It was determined from the proximate examination that the lifestyles of higher energy difficulty content in Karanja seed biomass advances its reasonableness for pyrolysis process. A definitive analysis indicated that jatropha seed biomass incorporates of fifty 58% C, 4.78% H, 7.36% N, 0.93% S, and 31.13% O.
- GC- MS & Fourier Transform Infrared evaluates the affirmed total life of alkanes, esters and unsaturated fat inside the pyrolysis bio fuel. Moreover, gasoline residences of bio-oil were discovered beneath the farthest factor of ASTM norms. With the mixture evaluation of FTIR investigation, though with the physiochemical properties and GC MS techniques the potential of bio oil can be determined as gas contender for CI appliances.
- ‘Furthermore, GC evaluation of the pyrolytic gasoline affirmed the life of burnable gases, for instance, H_2, CO_2, CO, CH_4, and C_2H_4 which empowers for its utilization as a gas contender for S.I engines. Essentially, subjective investigation and higher heating estimation of biochar suggests that it could be applied to make carbon briquetting which might be used as a sturdy gas for Industrial and mechanical boilers’.
- The brake heat effectiveness of the motor turned into stepped forward by using 2.5% and 3.8% ‘with lower PO stocks (PODB20 and PODB40) even though it faded through nine.2% with higher PO proportion (PODB60) while contrasted with base diesel hobby at evaluated load’.

- ‘In-cylinder stress was better with PODB20 and PODB40 fuels and lower with PODB60 gasoline as compared to base diesel gas. Combustion length multiplied usually with increasing proportion of PO in any respect hundreds on the take a look at engine’.
- ‘Carbon based totally emissions together with hydrocarbon, carbon monoxide, and smoke emissions were decreased notably with decrease percentage of PO stocks while these emissions extended barely with a better percent of PO proportion’.
- ‘Oxides of nitrogen emission showed increasing-lowering trend with increasing proportion of PO in the gas combo in any respect engine hundreds’.

The basic adversity in solar thermal pyrolysis is, it transformed into a low yield of bio-oil in light of change in solar radiation & reactor operating temp. The oil yield can be more prominent considerably with the utilization of empty space based absolutely reactor and limiting thermal misfortunes. Generally, this analysis underpins the sun powered thermal bio-treatment facility idea for the creation of solid, fluid and vaporous fuel. The tremendous drawback in daylight based warm pyrolysis was a low yield of bio-oil because of instability in sun oriented ‘radiation and reactor working temperatures’. ‘The oil yield is most likely ventured forward inside and out with the use of cavity principally based reactor and restricting loses of heat .It could also be concluded that Karanja biomass derived pyrolysis oil could be blended with diesel for its effective utilization in compression ignition engines. Blending of pyrolysed oil with diesel at lower percentages would achieve the dual benefit of engine performance enhancement and emissions reduction (HC, CO and smoke). However, the quality of the pyrolysed oil needs to be improved for its use in diesel engine at higher percentages. In addition to this, engine endurance tests need to be carried out for assessing the pH effect and fuel line blockage with bio-char, etc'.

- **Future Scope and Perspectives:**

  'A comprehensive evaluation of diverse types of biomasses to be had to provide biofuels thru thermochemical process was executed, and the subsequent conclusions emerged:

  - Distinctive thermochemical transformation strategies comprehensive of burning, hydrogenation, liquefaction, gasification, and pyrolysis are utilized for biofuels creation.
  - Pyrolysis is the most extreme attainable decision to utilize inexhaustible sunlight based energy for biofuel creation from unique biomass feedstocks.
  - Pyrolysis bio-oil yield differs from 21.9% to 75%, depending at the kind of biomass utilized, sort of reactor and reactor temperature.
  - Three essential items – for example Non-condensable gases, roast and bio-oil – might be gotten from pyrolysis of any kind of biomass.
  - Pyrolysis bio-oil can be used as an exchange gas for internal combustion engines which caters to the strength call for in the transportation area.
  - Three essential items – for example Non-condensable gases, burn and bio-oil – might be gotten from pyrolysis of any kind of biomass.'

References:

[1] Hossain AK, Davies PA. Pyrolysis liquids and gases as alternative fuels in internal combustion engines–a review. Renew Sust Energ Rev. 2013; 21:165–189.

[2] Sayigh A. Withdrawn: Worldwide progress in renewable energy. Renew Energ. 2009.

[3] Patton MQ, Utilization-focused evaluation. USA: Sage publications; 2008.

[4] Mata TM, Martins AA, Caetano NS. Microalgae for biodiesel production and other applications: a review. Renew Sust Energ Rev. 2010;14(1):217–232.

[5] Abdullah H, Wu H. Biochar as a fuel: 1. Properties and grindability of biochars produced from the pyrolysis of mallee wood under slow-heating conditions. Energy Fuels. 2009;23(8):4174–4181.

[6] Montes MJ, Abanades A, Martınez-Val JM. Performance of a direct steam generation solar thermal power plant for electricity production as a function of the solar multiple. Sol Energy. 2009;83 (5):679–689.

[7] Beattie WH, Berjoan R, Coutures J-P. High-temperature solar pyrolysis of coal. Sol Energy. 1983;31 (2):137–143.

[8] Naik SN, Goud VV, Rout PK, et al. Production of first and second generation biofuels: a comprehensive review. Renew Sust Energ Rev. 2010;14 (2):578–597.

[9] Bose B. Global warming: energy, environmental pollution, and the impact of power electronics. IEEE Ind Electron Mag. 2010;4(1):6–17.

[10] Fukuda H, Kondo A, Noda H. Biodiesel fuel production by transesterification of oils. J Biosci Bioeng. 2001;92 (5):405–416.

[11] Meng X, Yang J, Xu X, et al. Biodiesel production from oleaginous microorganisms. Renew Energ. 2009;34 (1):1–5.

[12] Nabi MN, Akhter MS, Zaglul Shahadat MM. Improvement of engine emissions with conventional diesel fuel and diesel–biodiesel blends. Bioresour Technol. 2006;97(3):372–378.

[13] Knothe G. Dependence of biodiesel fuel properties on the structure of fatty acid alkyl esters. Fuel Process Technol. 2005;86(10):1059–1070.

[14] Singh SP, Singh D. Biodiesel production through the use of different sources and characterization of oils and their esters as the substitute of diesel: a review. Renew Sust Energ Rev. 2010;14(1):200–216.

[15] Chisti Y. Biodiesel from microalgae. Biotechnol Adv. 2007;25(3):294–306.

[16] Carraretto C, Macor A, Mirandola A, et al. Biodiesel as alternative fuel: experimental analysis and energetic evaluations. Energy. 2004;29(12–15):2195–2211.

[17] Ramadhas AS, Muraleedharan C, Jayaraj S. Performance and emission evaluation of a diesel engine fueled with methyl esters of rubber seed oil. Renew Energ. 2005;30(12):1789–1800.

[18] Pienkos PT, Darzins A. The promise and challenges of microalgal derived biofuels. Biofuels Bioprod Biorefin. 2009;3(4):431–440.

[19] Murugan S, Gu S. Research and development activities in pyrolysis–contributions from Indian scientific community– a review. Renew Sust Energ Rev. 2015;46:282–295.

[20] Saha S, Biswas S, Pal S. Survey analysis, scope and application of biomass energy in India. In: Non Conventional Energy (ICONCE), 2014 1st International Conference on; IEEE; 2014.

[21] Nigam PS, Singh A. Production of liquid biofuels from renewable resources. Prog Energy Combust Sci. 2011;37(1):52–68.

[22] Garcıa-Perez M, Chaala A, Roy C. Vacuum pyrolysis of sugarcane bagasse. J Anal Appl Pyrolysis. 2002;65 (2):111–136.

[23] Demirba¸s A. Biomass resource facilities and biomass conversion processing for fuels and chemicals. Energy Convers Manag. 2001;42(11):1357–1378.

[24] Mckendry P. Energy production from biomass (part 1): overview of biomass. Bioresour Technol. 2002;83 (1):37–46.

[25] Demirba¸s A. Mechanisms of liquefaction and pyrolysis reactions of biomass. Energy Convers Manag. 2000;41 (6):633–646.

[26] White LP, Plaskett LG. Biomass as fuel. London: Academic Press Ltd; 1981.

[27] Demiral _I, Ayan EA. Pyrolysis of grape bagasse: effect of pyrolysis conditions on the product yields and characterization of the liquid product. Bioresour Technol. 2011;102(4):3946–3951.

[28] Ortega JV, Renehan AM, Liberatore MW, et al. Physical and chemical characteristics of aging pyrolysis oils produced from hardwood and softwood feedstocks. J Anal Appl Pyrolysis. 2011;91(1):190–198.

[29] Cao J-P, Xiao X-B, Zhang S-Y, et al. Preparation and characterization of bio-oils from internally circulating fluidized-bed pyrolyses of municipal, livestock, and wood waste. Bioresour Technol. 2011;102(2):2009– 2015.

[30] Ger¸cel HF. Bio-oil production from Onopordum acanthium L. by slow pyrolysis. J Anal Appl Pyrolysis. 2011;92(1):233–238.

[31] Onal EP, Uzun BB, P€ut€un AE. Steam pyrolysis of an industrial waste for bio-oil production. Fuel Process Technol. 2011;92(5):879–885.

[32] Amutio M, Lopez G, Artetxe M, et al. Influence of temperature on biomass pyrolysis in a conical spouted bed reactor. Resour Conserv Recycl. 2012;59:23–31.

[33] Thangalazhy-Gopakumar S, Adhikari S, Ravindran H, et al. Physiochemical properties of bio-oil produced at various temperatures from pine wood using an auger reactor. Bioresour Technol. 2010;101(21):8389–8395.

[34] Heo HS, Park HJ, Park Y-K, et al. Bio-oil production from fast pyrolysis of waste furniture sawdust in a fluidized bed. Bioresour Technol. 2010;101(1):S91–S96.

[35] Heo HS, Park HJ, Dong J-I, et al. Fast pyrolysis of rice husk under different reaction conditions. J Ind Eng Chem. 2010;16(1):27–31.

[36] Islam MR, Parveen M, Haniu H. Properties of sugarcane waste-derived bio-oils obtained by fixed-bed fire-tube heating pyrolysis. Bioresour Technol. 2010;101 (11):4162–4168.

[37] Mullen CA, Boateng AA, Goldberg NM, et al. Bio-oil and bio-char production from corn cobs and stover by fast pyrolysis. Biomass Bioenergy. 2010;34(1):67–74.

[38] Erta¸s M, Alma MH. Pyrolysis of laurel (Laurus nobilis L.) extraction residues in a fixed-bed eactor: Characterization of bio-oil and bio-char. J Anal Appl Pyrolysis. 2010;88(1):22–29.

[39] Zhang H, Xiao R, Huang H, et al. Comparison of noncatalytic and catalytic fast pyrolysis of corncob in a fluidized bed reactor. Bioresour Technol. 2009;100 (3):1428–1434.

[40] Asadullah M, Anisur Rahman M, Mohsin Ali M, et al. Jute stick pyrolysis for bio-oil production in fluidized bed reactor. Bioresour Technol. 2008;99 (1):44–50.

[41] Ozbay N, Apaydın-Varol E, Burcu Uzun B, et al. Characterization of bio-oil obtained from fruit pulp pyrolysis. Energy. 2008;33(8):1233–1240.

[42] Bridgwater AV. Review of fast pyrolysis of biomass and product upgrading. Biomass Bioenergy. 2012;38:68–94.

[43] Oyeniyi Y, Itiola O. The physicochemical characteristicmof microcrystalline cellulose, derived from sawdust, agricultural waste products. Int J Pharm Pharm Sci. 2012;4(1):197–200.

[44] Updegraff DM. Semi micro determination of cellulose in biological materials. Anal Biochem. 1969;32(3):420–424.

[45] Raveendran K. Pyrolysis characteristics of biomass and biomass components. Fuel. 1996;75 (8):987–998.

[46] Simashkevich A, Serban D, Bruc L, et al. Indium tin oxide thin-films prepared by vapor phase pyrolysis for efficient silicon based solar cells. Thin Solid Films.2016;610:35–41.

[47] Thunman H, Niklasson F, Johnsson F, et al. Composition of volatile gases and thermochemical properties of wood for modeling of fixed or fluidized beds. Energy Fuels. 2001;15(6):1488–1497.

[48] Tsai W, Lee M, Chang Y. Fast pyrolysis of rice husk: product yields and compositions. Bioresour Technol. 2007;98(1):22–28.

[49] Onay O, Beis SH, Ko¸cKar OM. Fast pyrolysis of rape seed in a well-swept fixed-bed reactor. J Anal Appl Pyrolysis. 2001;58:995–1007.

[50] Zanzi R, Sjostrom K, Bjornbom E. Rapid pyrolysis of agricultural residues at high temperature. Biomass Bioenergy. 2002;23(5):357–366.

[51] Onay O, Beis S, Kockar O. Pyrolysis of walnut shell in a well-swept fixed-bed reactor. Energy Sources. 2004;26 (8):771–782.

[52] Beis SH, Onay O, KocKar OM. Fixed-bed pyrolysis of safflower seed: influence of pyrolysis parameters on product yields and compositions. Renew Energ. 2002;26(1):21–32.

[53] Ates F, Putun E, Putun AE. Fast pyrolysis of sesame stalk: yields and structural analysis of bio-oil. J Anal Appl Pyrolysis. 2004;71(2):779–790.

[54] Encinar JM, Gonzalez JF, Gonzalez J. Fixed-bed pyrolysis of Cynara cardunculus L. Product yields and compositions. Fuel Process Technol. 2000; 68(3):209–222.

[55] Agblevor FA, Besler S. Inorganic compounds in biomass feedstocks. 1. Effect on the quality of fast pyrolysis oils. Energy Fuels. 1996;10(2):293–298.

[56] Dupont C, Commandre J-M, Gauthier P, et al. Biomass pyrolysis experiments in an analytical entrained flow reactor between 1073 and 1273 K. Fuel. 2008; 87 (7):1155–1164.

[57] Nunn TR, Howard JB, Longwell JP, et al., Product compositions and kinetics in the rapid pyrolysis of milled wood lignin. Ind Eng Chem Process Des Dev (United States). 1985;24(3):844–852.

[58] Fagbemi L, Khezami L, Capart R. Pyrolysis products from different biomasses: application to the thermal cracking of tar. Appl Energy. 2001;69(4):293–306.

[59] ¸Sensoz S, Can M. Pyrolysis of pine (Pinus brutia Ten.) chips: 1. Effect of pyrolysis temperature and heating rate on the product yields. Energy Sources. 2002;24 (4):347–355.

[60] Balci S, Dogu T, Y€ucel H. Pyrolysis kinetics of lignocellulosic materials. Ind Eng Chem Res (United States). 1993;32(11):2573–2579. 8 S. Mondal et al.

[61] Barooah J, Long V. Rates of thermal decomposition of some carbonaceous materials in a fluidized bed. Fuel. 1976;55(2):116–120.

[62] Uzun BB, Putun AE, Putun E. Fast pyrolysis of soybean cake: product yields and compositions. Bioresour Technol. 2006;97(4):569–576.

[63] Di Blasi C, Signorelli G, Di Russo C, et al. Product distribution from pyrolysis of wood and agricultural residues. Ind Eng Chem Res. 1999;38(6):2216–2224.

[64] Della Rocca P, Cerrellaa EG, Bonellia PR, et al., Pyrolysis of hardwoods residues: on kinetics and chars characterization. Biomass Bioenergy. 1999;16 (1):79–88.

[65] Purwanto WW, et al., Effect of biomass types on bio-oil characteristics in a catalytic fast pyrolysis process with a Ni/ZSM-5 catalyst. International Journal of Technology. 2015;7:1069–1075.

[66] Demirbas A, Bafail A, Ahmad W, et al. Biodiesel production from non-edible plant oils. Energ Explor Exploit. 2016;34(2):290–318.

[67] Anitha A, Dawn SS. Performance characteristics of biodiesel produced from waste groundnut oil using supported heteropolyacids. Int J Chem Eng Appl. 2010;1 (3):261.

[68] Saidur R, Abdelaziz EA, Demirbas A, et al. A review on biomass as a fuel for boilers. Renew Sust Energ Rev. 2011;15(5):2262–2289.

[69] Guo Z, et al. Catalytic cracking characteristics of bio-oil molecular distillation fraction. In: World Renewable Energy Congress-Sweden; 8–13 May; 2011; Link eA {ping; Sweden; Link oping University Electronic Press; 2011.

[70] Faizal H, et al. Physical and combustion characteristics of biomass residues from palm oil mills. In: New Aspects of Fluid Mechanics, Heat Transfer and Environment: Proceedings of the 8 th International Conference on Heat Transfer; Thermal Engineering and Environment; 2010.

[71] Supple B, Howard-Hildige R, Gonzalez-Gomez E, et al. The effect of steam treating waste cooking oil on the yield of methyl ester. J Am Oil Chem Soc. 2002;79 (2):175–178.

[72] Zhang Y, Dube MA, McLean DD, et al. Biodiesel production from waste cooking oil: 1. Process design and technological assessment. Bioresour Technol. 2003;89 (1):1–16.

[73] Haas MJ. Improving the economics of biodiesel production through the use of low value lipids as feedstocks: vegetable oil soapstock. Fuel Process Technol. 2005;86(10):1087–1096.

[74] Kumar A, Prakash O, Kaviti AK. A comprehensive review of Scheffler solar collector. Renew Sust Energ Rev. 2017;77:890–898.

[75] Shouman ER. International and national renewable energy for electricity with optimal cost effective for electricity in Egypt. Renew Sust Energ Rev.2017;77:916–923.

[76] Hafez AZ, Attia AM, Eltwab HS, et al. Design analysis of solar parabolic trough thermal collectors. Renew Sust Energ Rev. 2018;82:1215–1260.

[77] Ummadisingu A, Soni MS. Concentrating solar power technology, potential and policy in India. Renew Sust Energ Rev. 2011;15(9):5169–5175.

[78] Munir A, Hensel O, Scheffler W. Design principle and calculations of a Scheffler fixed focus concentrator for medium temperature applications. Solar Energy. 2010;84(8):1490–1502.

[79] Flores V, Almanza R. Direct steam generation in parabolic trough concentrators with bimetallic receivers. Energy. 2004;29(5–6):645–651.

[80] Jaramillo OA, Borunda M, Velazquez-Lucho KM, et al. Parabolic trough solar collector for low enthalpy processes: an analysis of the efficiency enhancement by using twisted tape inserts. Renew Energ. 2016;93:125–141.

[81] Bellos E, Tzivanidis C, Antonopoulos KA, et al. Thermalenhancement of solar parabolic trough collectors by using nanofluids and converging-diverging absorber tube. Renew Energ. 2016;94:213–222.

[82] Bouvier J-L, Michaux G, Salagnac P, et al. Experimental study of a micro combined heat and power system with a solar parabolic trough collector coupled to asteam Rankine cycle expander. Solar Energy. 2016;134:180–192.

[83] Xiao X, Zhang P, Shao DD, et al. Experimental and numerical heat transfer analysis of a V-cavity absorber for linear parabolic trough solar collector. Energy Convers Manag. 2014;86:49–59.

[84] Wang Y, Liu Q, Lei J, et al. A three-dimensional simulation of a parabolic trough solar collector system using molten salt as heat transfer fluid. Appl Therm Eng. 2014;70(1):462–476.

[85] Selvakumar P, Somasundaram P, Thangavel P. Performance study on evacuated tube solar collector using therminol D-12 as heat transfer fluid coupled with parabolic trough. Energy Convers Manag. 2014;85:505–510.

[86] Padilla RV, Fontalvo A, Demirkaya G, et al. Exergy analysis of parabolic trough solar receiver. Appl Therm Eng. 2014;67(1–2):579–586.

[87] Balghouthi M, Ali ABH, Trabelsi SE, et al. Optical and thermal evaluations of a medium temperature parabolic trough solar collector used in a cooling installation. Energy Convers Manag. 2014;86:1134–1146.

[88] Richert T, Riffelmann K, Nava P. The influence of solar field inlet and outlet temperature on the cost of electricity in a molten salt parabolic trough power plant. Energy Procedia. 2015;69:1143–1151.

[89] Wang F, Feng H, Zhao J, et al. Performance assessment of solar assisted absorption heat pump system with parabolic trough collectors. Energy Procedia. 2015;70:529–536.

[90] Mussard M, Nydal OJ. Influence of solar tracking inaccuracy and sun rays modeling on the efficiency of a small-scale parabolic trough. Energy Procedia. 2014;57:1508–1515.

[91] M€uller C, EcoAndina F, Arias C. Solar community bakeries on the Argentinean Altiplano. In: International Solar Food Processing Conference. Indore, India; 2009.

[92] Jafari Mosleh H, Jahangiri Mamouri S, Shafii MB, et al. A new desalination system using a combination of heat pipe, evacuated tube and parabolic trough collector. Energy Convers Manag. 2015;99:141–150.

[93] Larcher M, Rommel M, Bohren A, et al. Characterization of a parabolic trough collector for process heat applications. Energy Procedia. 2014;57:2804–2811.

[94] Tyroller M, Br€ucke S, Werdenbergstr G. Solar steam sterilizer for rural hospitals. In: International Solar Cooker Conference, Granada, Spain; 2006.

[95] Munir A. Design, development and modeling of a solar distillation system for the processing of medicinal and aromatic plants. 2010.

[96] Chandak A, Somani S. Design of multistage evaporators for integrating with Scheffler solar concentrators for food processing applications. In International Solar Food Processing Conference, Indore, India; 2009.

[97] Reddy KS, Kumar Kvi. Solar collector field design and viability analysis of stand-alone parabolic trough power plants for Indian conditions. Energy Sustain Dev. 2012;16(4):456–470.

[98] Fahmi R, Bridgwater AV, Donnison I, et al. The effect of lignin and inorganic species in biomass on pyrolysis oil yields, quality and stability. Fuel. 2008;87(7):1230–1240.

[99] Demirbas A. Production of gasoline and diesel fuels from bio-materials. Energ Source Part A. 2007;29 (8):753–760.

[100] Chintala V, Kumar S, Pandey JK, et al. Solar thermal pyrolysis of non-edible seeds to biofuels and their feasibility assessment. Energy Convers Manag. 2017;153:482–492.

[101] Chintala V, Kumar S, Pandey JK. Assessment of performance, combustion and emission characteristics of a direct injection diesel engine with solar driven Jatropha biomass pyrolysed oil. Energy Convers Manag. 2017;148:611–622.

[102] Al Arni S, Bosio B, Arato E. Syngas from sugarcane pyrolysis: An experimental study for fuel cell applications. Renew Energ. 2010;35(1):29–35.

[103] Mondal, S., Mondal, A. K., Chintala, V., Tauseef, S. M., Kumar, S., & Pandey, J. K. (2018). Thermochemical pyrolysis of biomass using solar energy for efficient biofuel production: a review. Biofuels, 1-10.

[104] Mondal, S., Sharma, A. K., & Sahoo, P. K. (2014). Solar thermal biomass pyrolysis-a review paper. Int J Sci Eng Res, 5, 635-642.

[105] Mondal, S., Pandey, J. K., & Kumar, S. (2019). Solar Thermal Pyrolysis of Karanja Seeds for a Sustainable Approach for Liquid Biofuel Utilization. Nature Environment and Pollution Technology, 18(3), 941-948.

[106] Chiaramonti, David. "Bioethanol: role and production technologies." Improvement of crop plants for industrial end uses. Springer, Dordrecht, 2007. 209-251.

[107] Nuttens, Timothy, Alain De Wulf, Lander Bral, Bart De Wit, Leen Carlier, Marijke De Ryck, Cornelis Stal, Denis Constales, and Hans De Backer. "High resolution terrestrial laser scanning for tunnel deformation measurements." In FIG Congress, vol. 2010. 2010.

[108] Elliott, D. C., Beckman, D., Bridgwater, A. V., Diebold, J. P., Gevert, S. B., & Solantausta, Y. (1991). Developments in direct thermochemical liquefaction of biomass: 1983-1990. Energy & Fuels, 5(3), 399-410.

[109] Z'Graggen, A., & Steinfeld, A. (2009). Heat and mass transfer analysis of a suspension of reacting particles subjected to concentrated solar radiation–Application to the steam-gasification of carbonaceous materials. International Journal of Heat and Mass Transfer, 52(1-2), 385-395.

[110] Nzihou, A., Flamant, G., & Stanmore, B. (2012). Synthetic fuels from biomass using concentrated solar energy–a review. Energy, 42(1), 121-131.

[111] Fenwick, D. L., & Hopkins, J. D. (1984). U.S. Patent No. 4,479,041. Washington, DC: U.S. Patent and Trademark Office.

[112] Flechsenhar, M., & Sasse, C. (1995). Solar gasification of biomass using oil shale and coal as candidate materials. Energy, 20(8), 803-810.

[113] Welch, R. A., Burland, V., Plunkett, G. I. I. I., Redford, P., Roesch, P., Rasko, D.& Stroud, D. (2002). Extensive mosaic structure revealed by the complete genome sequence of uropathogenic Escherichia coli. Proceedings of the National Academy of Sciences, 99(26), 17020-17024.

[114] Piatkowski, N., Wieckert, C., & Steinfeld, A. (2009). Experimental investigation of a packed-bed solar reactor for the steam-gasification of carbonaceous feedstocks. Fuel processing technology, 90(3), 360-366.

[115] Li, J., Galley, M., Brockett, C., Spithourakis, G. P., Gao, J., & Dolan, B. (2016). A persona-based neural conversation model. arXiv preprint arXiv:1603.06155.

[116] Czamara, M. P., Morales, O. P., & Ross, P. G. (2014). U.S. Patent No. 8,638,553. Washington, DC: U.S. Patent and Trademark Office.

[117] Zeng, H. B., He, Y., Wu, M., & She, J. (2015). New results on stability analysis for systems with discrete distributed delay. Automatica, 60, 189-192.

[118] Ou, S. H. I., Ahn, J. S., De Petris, L., Govindan, R., Yang, J. C. H., Hughes, B. G. M., ... & Mekhail, T. (2015). Efficacy and safety of the ALK inhibitor alectinib in ALK+ non-small-cell lung cancer (NSCLC) patients who have failed prior crizotinib: An open-label, single-arm, global phase 2 study (NP28673).

[119] Y.L. Tan, A.Z. Abdullah, B.H. Hameed, Product distribution of the thermal and catalytic fast pyrolysis of karanja (Pongamia pinnata) fruit hulls over a reusable silica-alumina catalyst, Fuel, Volume 245, 2019, Pages 89-95.

[120] Krushna Prasad Shadangi, Kaustubha Mohanty, Thermal and catalytic pyrolysis of Karanja seed to produce liquid fuel, Fuel, Volume 115, 2014, Pages 434-442.

[121] Niraj Kumar Nayan, Sachin Kumar, R.K. Singh, Characterization of the liquid product obtained by pyrolysis of karanja seed, Bioresource Technology, Volume 124, 2012, Pages 186-189,

[122] Krushna Prasad Shadangi, Kaustubha Mohanty, Co-pyrolysis of Karanja and Niger seeds with waste polystyrene to produce liquid fuel, Fuel, Volume 153, 2015, Pages 492-498.

[123] Pankaj Shrivastava, Tikendra Nath Verma, Arivalagan Pugazhendhi, An experimental evaluation of engine performance and emisssion characteristics of CI engine operated with Roselle and Karanja biodiesel, Fuel, Volume 254, 2019.

[124] Kotaiah Naik Dhanavath, Md. Sakinul Islam, Satyavathi Bankupalli, Suresh K. Bhargava, Kalpit Shah, Rajarathinam Parthasarathy, Experimental investigations on the effect of pyrolytic bio–oil during the liquefaction of Karanja Press Seed Cake, Journal of Environmental Chemical Engineering, Volume 5, Issue 5, 2017, Pages 4986-4993.

[125] Rupesh L. Patel, C.D. Sankhavara, Biodiesel production from Karanja oil and its use in diesel engine: A review, Renewable and Sustainable Energy Reviews, Volume 71, 2017, Pages 464-474.

[126] Perini Simoni, Tonnellier Xavier, King Peter, Sansom Christopher, Theoretical and experimental analysis of an innovative dual-axis tracking linear Fresnel lenses concentrated solar thermal collector, Sol. Energy, 153 (2017), pp. 679-690.

[127] Yao Yingxue, Hu Yegaung, Gao Shengdong, Yang Gang, Du Jinguang A multipurpose dual-axis solar tracker with two tracking strategies Renew. Energy, 72 (2014), pp. 88-98.

[128] Fathabadi Hassan Comparative study of two novel sensorless and sensor based dual-axis solar trackers Sol. Energy, 138 (2016), pp. 67-76.

[129] Flores-Hernandez D.A., Palomino-Resendiz S., Lozada-Castillo N., Luviano-Juarez A., Chairez I. Mechatronic design and implementation of a two axes Sun tracking photovoltaic system driven by robotic sensor, Mechatronics, 47 (2017), pp. 148-159.

[130] Away Yuwaldi, Ikhsan M., Dual-axis sun tracker sensor based on tetrahedron geometry, Autom. Constr. (2016).

[131] Abdallah Salah, Nijmeh Salem, Two axes solar tracking system with PLC control Energy Convers. Manage, 45 (11–12) (2004), pp. 1931-1939.

[132] Khalifa abdul-jabbar n., Al-mutawalli salman s. Effect of two-axis sun tracking on the performance of compound parabolic of compound parabolic concentrators, Energy Convers. Manage., 39 (10) (1998), pp. 1073-1079.

[133] Chen Jui-Ho, Yau Her-Terng, Hung Tzu-Hsiang, Design and implementation of FPGA-based Taguchi-chaos-PSO Sun tracking systems Mechatronics, 25 (2015), pp. 55-64.

[134] Song Jifeng, Zhu Yong, Jin Zhou, Yang Yongping, Daylighting system via fibers based on two-stage sun-tracking model Sol. Energy, 108 (2014), pp. 331-339.

[135] Roth P., Georgiev A., Boudinov H. Design and construction of a system for Sun-tracking Renew. Energy, 29 (2004), pp. 393-402.

[136] Oner Yusuf, Cetin Engin, Ozturk Harun Kemal, Yilanci Ahmet Design of a new three degree of freedom spherical motor for photovoltaic-tracking systems Renew. Energy, 34 (2009), pp. 2751-2756.

[137] Zhang Peng, Zhou Gongbo, Zhu Zhencai, Li Wei, Cai Zhixiong Numerical study on the properties of an active Sun tracker for solar streetlight, Mechatronics, 23 (2013), pp. 1215-1222.

[138] Sungur Cemil, Multi-axes Sun-tracking system with PLC control for photovoltaic panels in Turkey, Renew. Energy, 34 (2009), pp. 1119-1125.

[139] Barker Laughlin, Neber Matthew, Lee Hohyun, Design of a low profile two-axis solar tracker, Sol. Energy, 97 (2013), pp. 569-576.

[140] Yilmaz Saban, Ozcalik Hasan Riza, Dogmus Osman, Dincer Furkan, Akgol Oguzhan, Karaaslan Muharrem, Design of two axes Sun tracking controller with analytically solar radiation calculations, Renew. Sustain. Energy, 43 (2015), pp. 997-1005.

[141] Sinha Sunanda, Chandel S.S., Analysis of fixed tilt and Sun tracking photovoltaic -micro wind based hybrid power systems, Energy Convers. Manage., 115 (2016), pp. 265-275.

[142] Skouri Safa, Ali Abdessalem Ben Haj, Bouadila Salwa, Salah Mohieddine Ben, Design and construction of Sun tracking systems for solar parabolic concentrator displacement, Renew. Sustain. Energy, 60 (2016), pp. 1419-1429.

[143] Rahimi Masoud, Banybayat Meisam, Tagheie Yaghoub, Valeh-e-Sheyda Peyvand, An insight on advantage of hybrid Sun-wind-tracking over Sun-tracking, Energy Convers. Manage., 105 (2015), pp. 294-392.

[144] Al-Soud Mohammed S., Abdallah Essam, Akeyleh Ali, Abdullah Salah, Hrayhat Eyad S., A parabolic solar cooker with automatic two axes Sun tracking system, Appl. Energy, 87 (2010), pp. 463-470.

[145] Abdollahpour Masoumeh, Golzarian Mahmood Reza, Rohani Abbas, Zarchi Hossein Abootorabi, Development of a machine vision dual-axis solar tracking system, Sol. Energy, 169 (2018), pp. 136-143.

[146] Seme Sebastijan, Srpcic Gregor, Kavsek Domen, Bozicnik Stane, Letnik Tomislv, Praunseis Zdrravko, Stumberge Bojan, Hadziseimovic Miralem, Dual-axis photovoltaic tracking system-design and experiment investigation, Energy (2017).