Energy and Life Cycle Assessment of Solar Assisted Microwave Pyrolysis of Waste Biomass

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Abstract. In this proposed work focused on energy efficient solar assisted pyrolysis for biofuel synthesis from different biomass. In recent days solar-powered microwave assisted pyrolysis in increasing the research attention towards higher energy recovery from the waste biomass. Microwave-assisted pyrolysis has promoted by different researchers due to lower energy consumption, faster heating rate and uniform volumetric heating of feed. Compare to electrical and thermal pyrolysis; microwave assisted pyrolysis in increasing the process efficiency due to higher energy recovery and higher hydrogen production. Thus, Microwave-assisted pyrolysis combined with solar energy increase the economic feasibility of the pyrolysis process. To recover more energy from the waste, one must reduce the input power supply and has to improve the process efficiency. So, this proposed project concentrates on solar-powered microwave pyrolysis which will eliminate the need for input power supply. Concentrator Photo-Voltaic (CPV) systems are most likely to produce a massive amount of energy per rated power and module active area. CPV system produces around 2.5 times higher energy per module active area and around 1.3 times higher energy per rated power. Char and ash obtained from the pyrolysis process will be converted into activated carbon and further sintering at a higher temperature for converting into brick form. This reusable solid activated carbon may decrease the processing time by 50%, and raise the temperature around double the time faster compared to the conventional pyrolysis. Compared to the conventional pyrolysis, it is expected that the liquid fuel may increase by 30% due to the fast heating rate. Pyrolysis oil comprises of different chemical functional groups such as sulphur, carbonyls. The phenolic carboxyls compounds provide potentials simultaneously challenging for commercial usage. The hydrocracking and catalytic cracking are the recent technologies used in current research. The usage of hydrogen and catalyst degradation are the major challenges in current technology. To solve this problem, oxidation with ozone would be used as an efficient way for upgradation of biofuel. The life cycle assessment for the entire process is necessary to determine the carbon feet print to the environment.

Keywords: Waste to energy; Microwave pyrolysis; Solar assisted pyrolysis; Energy recovery; Life cycle assessment.
1. Introduction

The recent statistics 2016 shows, The continuous increasing fuel and oil consumption from 1999, has increased the research attention and curiosity for the energy demand as well as alternate fuel research more up-to-date than ever before. In recent days, the science community was focused on finding the new supplementary fuel from the waste to full fill society’s increasing energy demand. The waste generation was increased proportionally to the population growth, with some municipal and agricultural wastes fraction was difficult to recycle; some fraction of waste may be utilized to fulfill the energy demand by direct combustion and other thermochemical conversation methods. The thermochemical conversation methods were further investigated to improve process efficiency [1]. Massive amount of energy from oil, coal, biogas, and natural gas were combusted daily to attain the ever-growing energy demand. These fossil fuels are rapidly depleting and cause environmental pollution [2]. Much waste is also generated in an ever-growing economy in various forms. Hence new sustainable technologies are needed to convert the waste generated from various sources into useful energy which is renewable. Thermo-chemical conversion is one such technology and methods like pyrolysis are providing ways to generate clean energy from waste materials, thereby avoiding pollution as well as producing alternative fuels [3].

Waste-to-energy conversion by the thermochemical process is a contemporary technology with the eco-friendly and cost-effective process. Several thermochemical conversions methods such as gasification, incineration, and pyrolysis can reduce waste volume and toxicity. However, all these conversion methods have certain limitations and drawbacks [4]. The thermochemical conversion processes like incineration, gasification, and pyrolysis were well-known methods for the management of waste. Combustion, gasification and direct incineration resulted in higher hydrocarbon emission, brominated dioxins, metal oxides and aromatic hydrocarbons. The pyrolysis is the best way of recovering both chemical and energy value of the waste without releasing any toxic oxidized species (i.e., NOx, dioxins) on the environment [5]. Direct combustion and incineration recover the only heating value of the waste materials. Different chemical values of the waste materials were not recovered in the incineration due to oxidation causes for greenhouse gas emission and toxic emissions [6].

The external heat source is necessary to convert the waste material and biomass into chemically potential biofuel. Traditional external heating source (heat delivered from the electric heaters and flue gas) has been used for the biomass pyrolysis in the last two decades [7, 8]. There are different methods that are existing for heating the waste materials in the pyrolysis. Among them, conventional pyrolysis and microwave assisted pyrolysis are currently used for waste conversion. In conventional pyrolysis process, the pyrolysis process efficiency was lower due to its slower heating mechanism based on conduction and convection heat transfer. Whereas, In modern microwave pyrolysis technique, the heat was generated equally on the pyrolysis feed due to diffused characteristics of electromagnetic field on the substance [9]. The microwave pyrolysis gives some advantage over conventional pyrolysis, which offers a faster heating rate, volumetric heating of feed, selective material heating, improve heating efficiency [10]. Paradela et al., [11] investigate the co-pyrolysis of pine waste biomass mixed with e-waste plastics to improve the maximum pyrolysis fuel yield. The prime objective behind the co-pyrolysis of biomass was to increase the pyrolysis fuel fraction and its physiochemical properties.

Traditional pyrolysis techniques are conventional and consume higher input energy for the pyrolysis. The emerging pyrolysis such as MAP has been introduced in recent days. The microwave will generate the heat depends upon the feed and susceptor used in the pyrolysis process. The activated carbon, Graphene and Silicon carbide were used as the susceptor for the different microwave pyrolysis process [12]. The microwave pyrolysis with the addition of different susceptor has decreased the energy consumption compared to the conventional pyrolysis process. Also, it decreases the production
cost while improving the quality of biofuels. The MAP technique provides rapid and selective heating of the biomass due to water vapour present in the biomass. Compared to the conventional process, the MAP was cleaner, which enhances the chemical reaction and saves energy utilization, consequently decreases the production cost [13]. So far, little research work has been carried out related to the solar thermal conversion of biomass conversion. Most of the work was carried out for the higher production of carbon monoxide and hydrogen using solar radiation. The solar pump laser and solar/microwave hybrid system furnace has been used for this process [14-16].

In recent days hydrotreating and catalytic cracking were wildly used for fuel upgradation and enrichment of hydrogen in the fuel. Higher hydrogen pressure and high-temperature hydrocracking in the presence of metal-based catalyst will lead to the formation of useless water vapour at the end of the reaction. The demerits of catalytic cracking is that massive amount of hydrogen consumption and degradation of the catalyst after the several trials which is increasing the barrier for scale up the process. several researchers have attempted for the improving of pyrolysis fuel by different purification techniques and esterification with excess alcohol. They have identified uses of alcohol decrease the acid value and carbonyl constituents in the presence of different acid catalysts [17]. The harmful constituents of pyrolysis fuel such as aldehydes cannot be removed and it leads to affect the physicochemical characteristics of pyrolysis fuel. The aldehydes undergo oligomer reaction spontaneously to form the phenol containing molecular structure during the storage. To resolve this problem, ozone treatment can be used as an efficient way to transform the aldehydes into corresponding acids. Then, the pyrolysis fuel will be treated using alcohol in the presence of a heterogeneous acid catalyst for the conversion of aldehydes into corresponding esters at the end of the reaction [18]. The ultra-sonication treatment has used in recent days for upgradation pyrolysis fuel. The life cycle analysis is essential for the analysis of the environmental impacts of the pyrolysis process and upgradation process and its environmental impacts and carbon footprint of the pyrolysis process.

2. Experimental setup and procedure

2.1. Microwave pyrolysis process

In this experiment, the pyrolysis of waste was carried out in the microwave pyrolysis reactor using four magnetrons. Each magnetron was capable of generating the microwave frequency of 2450MHz. The pair of magnetrons was operated to heat the pyrolysis oven. The Euro-Therm microcontroller was used to control the magnetron power corresponding to the required pyrolysis temperature. Only one pair of magnetrons was powered at 3mins of operation time. Then, the power was exchanged to other pair of the magnetron to avoid magnetron failure due to overheating. The separate switch was provided to control the number of magnetrons has been used for the pyrolysis process, which can control the power rating. Each magnetron was consumed a maximum of 1.1 kW at the initial stage of the pyrolysis process. The maximum power of 2.2 kW was utilized to generate the microwave at the initial stage. The power rating was controlled by a separate switch provided for control the number of magnetrons which can be operated at the same time. The minimum power rating of 1.1 kW and the maximum power rating of 2.2 kW was used for the waste pyrolysis. The quartz vessel with 1.8 L capacity was used as a pyrolysis reactor due to excellent microwave transmittance. 1 kg of waste precisely weighted and mixed with activated carbon in the weight ratio of 40%, which facilitates the microwave to heat energy conversion. The temperature was maintained at 300 °C to 400 °C to determine the maximum yield and energy conversion of the pyrolysis process. The nitrogen was used as the carrier and inert gas and its flow rate was adjusted from 2 L/min to 5 L/min for determined the minimum required a quantity of Nitrogen flow rate. The temperature was measured using K-type thermocouple and send the signal to the Eurotherm data acquisition system corresponding to the time. A stirrer is set into the reactor at a speed of 10 rpm. The experiment is conducted at different temperatures and nitrogen flow rates. The residue (char) was quantified after the end of the
The non-condensable gases (NCG) were evicted into the water to control the release of soot and particulate matters.

![Diagram of microwave pyrolysis setup](image)

**Figure 1.** Schematic layout of microwave pyrolysis setup.

2.2. *Activated carbon preparation from char*

This proposed work involves preparation of Activated carbon from char from the pyrolysis process. The microwave susceptor composites will be prepared in a brick form with the addition of different ceramics using high-pressure sintering. Thermal stability and dielectric properties of susceptor will be analysed to predict the microwave absorbing capability. Activated carbon (AC) derived from the agro waste can be used as a cleaning agent to remove tar and other impurities present in the producer gas. This proposed project overcomes the challenges associated with susceptors reusability and purification of producer gas. Activated carbon (AC) derived from the waste can be used as a cleaning agent to remove tar and other impurities present in the producer gas and pyrolysis fuel. Char, ash, and slag collected from the pyrolysis and gasification process will be dried in a furnace at 150 °C for 24 hrs. The dry powder will be activated with 66% H₃PO₄ for 2 hrs at 80 °C and dried at 110 °C for 24 hrs after that calcinated at 800 °C in at N₂ atmosphere for 5 hrs for obtaining the activated carbon.

3. *Effect of pyrolysis parameter on pyrolysis yield*

3.1. *Microwave pyrolysis fuel yield*

Figure 2 shows the effect of various temperature and different nitrogen supplied rate on the microwave pyrolysis fuel yield. Pyrolysis fuel yield improved with an increase in temperature to some extent. Due to the localized concentration of heat by microwave decrease pyrolysis oil yield at a higher temperature. The optimal temperature at which the supreme percentage of pyrolysis oil obtained was 350°C. It is also observed that due to the increase in nitrogen flow rate beyond 2 L/min, the pyrolysis
fuel yield was decreased. This is due to a reduction in the retention time of pyrolysis gases inside the condenser beyond specific nitrogen flow rate (i.e., 2 L/min).

**Figure 2.** Comparison of pyrolysis oil yield with varying different parameters.

It was observed that when the nitrogen flow rate was increased from 2 L/min to 3 L/min, the pyrolysis fuel yield decreased by 4% at 350 °C and increased to 5 L/min the pyrolysis fuel yield decreased by 8%. At 300 °C the pyrolysis fuel obtained from the entire nitrogen flow rate nearly the same. Compared to 350 °C pyrolysis temperature, the pyrolysis fuel yield obtained at 300 °C was less due to higher retention time enhances the secondary cracking of the pyrolysis gas. At 400 °C pyrolysis temperature, the kinetic energy of the gases is slightly high compared to 350 °C. The higher kinetic energy of the gases decreases the retention time of gases in the condenser and affect the pyrolysis fuel yield.

3.2. **Microwave pyrolysis char yield**

**Figure 3.** Comparison of char yield with varying different parameters.
The formation of char percentage in the microwave assisted pyrolysis was less. The heat generation on the susceptor leads to a higher localized temperature, which causes lower char formation. Figure 3 shows the effect of an increase in temperature on the char yield. Microwave pyrolysis improves the localized heat generation, the temperatures generated at particular region were high in which even carbon absorbs the microwave energy and evaporates. Hence, the char yield was decreased in the microwave assisted pyrolysis. The char formation was decreased when the temperature and nitrogen supplied rate was increased at 10 rpm stirrer speed. The char formation was nearly the same for the all nitrogen flow rate at the same pyrolysis temperature. The char formation decreased from 18% to 10% when increased the temperature from 300 to 400 °C.

3.3. Microwave pyrolysis non-condensable gas yield

Figure 4 shows the variation of non-condensable gas yield on the microwave-assisted pyrolysis with various temperature and different nitrogen supplied rate and a constant stirrer speed of 10 rpm. Non-condensable gas proportions were increased with increase in pyrolysis temperature and nitrogen supplied rate due to the higher kinetic energy of the molecule and localised heat generation, which decreased the retention time. The lower retention time causes for the reduction in condensation time and instantaneously carried away the pyrolysis gases from the condenser, which causes increased Non-condensable gases. Figure 4 it can be observed that the least NCG was obtained at 350°C with the nitrogen flow rate of 2 L/min. when the nitrogen flow rate was increased from 2 L/min to 5 L/min, the NCG yield decreased by 6% at 350°C. NCG at 300 °C remains same at the entire nitrogen flow rate. The higher NCG was noticed at the temperature reaches 400 °C with the nitrogen flow rate of 5 L/min because of its higher kinetic energy and higher internal heat generation compared to other temperature. Hence it can be concluded that microwave assisted pyrolysis improved the amount of non-condensable gases obtained at higher nitrogen flow rates.

![Figure 4](image_url)

**Figure 4.** Comparison of non-condensable gas yield with varying different parameters.

4. Effect of heating rate and temperature on energy recovery

The essential parameter which can be studied in the pyrolysis process was energy recovery. It can be calculated from pyrolysis process time, the Energy consumption of the pyrolysis process, pyrolysis fuel yield and higher heating value of the pyrolysis fuel. The pyrolysis fuel yield, calorific value and process time varied depending upon the temperature and heating rate. Figure 5 depicts the energy recovery of the microwave assisted pyrolysis with varying temperature and power rate or heating rate.
In this process, the maximum energy recovery was attained at 1.1 kW power rating because of higher pyrolysis fuel yield, lesser power consumption and increased heating value of the obtained pyrolysis fuel. In microwave assisted heating, at 2.2 kW power rate, secondary cracking was decreased the amount of pyrolysis oil yield production. The amount of pyrolysis oil produced in 2.2 kW was less, and energy consumption was high compared with 1.1 kW heating is the reason for decreased energy recovery. The combined effect of fuel yield, energy supply and calorific value decreased the energy recovery in the microwave pyrolysis with a 2.2 kW power rating compared to 1.1 kW power rating. The higher energy recovery of 29274 kJ was attained in microwave assisted pyrolysis with 1.1 kW power rate at pyrolysis temperature 400°C. The maximum energy recovery is 15.75% higher than microwave pyrolysis with a 2.2 kW power rating at a similar temperature. Also, the energy recovery was 9% and 30% higher than 350 °C and 300 °C respectively at microwave assisted pyrolysis with 1.1 kW power rating. The energy recovery was improved with a rise in temperature due to a decrement in the processing time and hiked in the heating value of the pyrolysis fuel.

5. Solar assisted pyrolysis for better energy recovery

In solar thermal reactor for the pyrolysis process was classified into two types such as direct passionate and indirect passionate system. The direct, passionate pyrolysis reactor exposed directly in the solar radiation at the bright sun which fascinating the absorbed energy from the solar radiation. An indirect passionate system, the incident sunlight was transferred to the reactor from an opaque surface and generated the heat to the reactor surface [19]. Besides, the solar heating system further classified into the partial heating system and continues heating system. In the partial heating solar system, the pyrolysis reactor was passionate at a particular temperature using solar concentrator and further heated by the system like thermal, electrical or microwave. Moreover, the continuous heating solar system is passionately unremitting using solar radiation coupled with another system to complete the pyrolysis cycle.

Solar concentrators are classified into 4 types they are

1. parabolic-dish collector or concentrator (PDC);
2. parabolic-trough collector or concentrator (PTC);
3. double-concentration collector or concentrator (DCC);
4. heliostat-field collector or concentrator (HFC).
Furthermore, solar PV can be used as the power generation for solar pyrolysis. Concentrator Photovoltaic (CPV) systems are most likely to produce a massive amount of energy per rated power and module active area. CPV system produces around 2.5 times higher energy per module active area and around 1.3 times higher energy per rated power. These four types of solar concentrators are used to convert solar energy into thermal energy. It will be used for direct and indirect heating of the biomass. Solar PV can be used for direct power generation from the power source and it can be stored in the batteries and further used for the pyrolysis process may be the increasing the energy recovery by 2.5 times [20].

6. Essential properties for different biomass for the pyrolysis process

6.1. Ultimate analysis

The ultimate analysis used for determining the elemental composition of biomass and municipal solid waste. Table 1 shows the elemental composition of different biomass, and it will help to analysis the molecular formula and theoretical air requirement for oxidation. Also, the life cycle analysis will be carried out using the carbon percentage in the elemental analysis. Further, the N and S levels and its effect on the environment also studied in the biomass fuel. Moreover, C,H,O value used to determine the higher heating value of the biomass and pyrolysis fuels [21]. The organic contents, along with moisture ash, were analyzed using the final analysis. The elemental analysis was given the uniform system to analysis and compared the pyrolysis fuel. The chemical composition and generalized chemical formula were determined from the elemental analysis [22]. In addition to that, the ASTM standards are available for reassurance of elemental analysis of biomass pyrolysis fuels [23].

| Biomass         | C   | H   | O   | N   | S   |
|-----------------|-----|-----|-----|-----|-----|
| Hazelnut shell  | 51  | 6   | 42  | 1   | 0   |
| Tobacco stack   | 49  | 6   | 43  | 1   | 1   |
| Almond shell    | 49  | 6   | 43  | 1   | 1   |
| Rice husk       | 48.6 | 9  | 42  | 0.1 | 0.04 |
| Lignite         | 66  | 8   | 21  | 1   | 4   |
| Corn Stover     | 49  | 6.6 | 43.7| 0.6 | 0.1 |
| Corn cob        | 49  | 6   | 44.2| 0.8 | 0   |
| Saw dust        | 53.9| 7   | 37  | 2   | 0.1 |
| Spruce wood     | 51.4| 7.1 | 41.2| 0.3 | 0   |

6.2. Proximate analysis

The essential characteristics of biomass and pyrolysis fuel are determined by ultimate and proximate analysis. The proximate analysis was used to determine the combustible and non-combustible constituents present in the biomass and pyrolysis fuel. In this analysis helped to predict the carbon life cycle assessment in the entire pyrolysis process. The commercial value of the pyrolysis fuel and biomass was determined from the proximate analysis. The proximate analysis investigation was critical to anticipate the burning phenomenon of pyrolysis fuel and biomass [22]. The gross value of composition in the biomass and biofuels also measure quickly. The biomass fuel E 870-06 standards are used to analyze the fixed carbon, volatile matters and Ash. Different ASTM standards used separately to find the individual components of biofuel and biomass. The fixed carbon value deviates from the elemental analysis of carbon content. The char yield was determined in the proximate analysis without including the volatile matters. Table 2 shows the proximate analysis of the different biomass sample [23].
Table 2. Proximate analysis of various biomass at dry basis (wt. %) [24].

| Biomass          | Fixed carbon | Volatile matter | Ash  |
|------------------|--------------|-----------------|------|
| Wheat straw      | 17.71        | 75.27           | 7.02 |
| Switch grass     | 14.34        | 76.69           | 8.97 |
| Willow wood      | 16.07        | 82.22           | 1.71 |
| Rice hulls       | 16.22        | 63.52           | 20.26|
| Alfalfa stems    | 15.81        | 78.92           | 5.27 |
| Sugar cane bagasse | 11.95      | 85.61           | 2.44 |
| Rice straw       | 15.86        | 65.47           | 18.67|
| Almond shells    | 20.71        | 76              | 3.29 |
| Hybrid poplar    | 12.49        | 84.81           | 2.7  |

7. Pyrolysis fuel Upgradation

7.1. Ozone Treatment
Pyrolysis oil and tar comprise different chemical constituents and functional groups like sulphur, carbonyls; The phenolic carboxyls compounds which afford potentials benefits at the same time challenges for commercial usage. Due to physical and chemical changes, the pyrolysis oil becomes more viscous at storage. This is because the reaction may continue during the period, and volatile components might be lost because of ageing. It would involve a decrease in the heating value of pyrolysis fuel and also increase the risks of the separation of phases. Today, these undesirable compounds are eliminated by several distillations. However, this method of purification increases the cost of fuel. At present, the techniques most widely used are the enrichment of the pyrolysis oil by hydrotreating, catalytic cracking and esterification. The hydrotreating forms the undesirable water at high hydrogen pressure and high temperature, under in the presence of catalysts. The hydrotreating was not economical due to the consumption of higher hydrogen consumption and finally increase the useless water content in the reaction. The disadvantage of catalytic cracking is the degradation of the catalyst, which constitutes an essential barrier to marketing. The aldehydes can be spontaneously involved in oligomer reactions to form the phenol composition during the storage. The resolve this issue, the ozone can be used as the oxidizing agent to convert the aldehydes into corresponding acids in an effective way. After that, the oxidized pyrolysis oil will be treated with alcohol in the presence of a heterogeneous acid catalyst. The aldehydes will be converted to the corresponding esters at the end of the process. Ozone has the potential of very high oxidation, just behind the free radical hydroxyl. This is derived from the oxidising activity of ozone and the oxidizing spaces produced by ozone, such as the radicals OH. Consequently, ozone can oxidise many organic compounds and inorganic. Moreover, because of its unstable composition, there breaks up with time, it is thus no residues after the treatment. For these reasons, ozone is used at many ends, such as disinfection, discolouration, and deodorisation. Finally, the pyrolysis oil and tar will be converted into corresponding hydrocarbons and esters.

7.2. Ultrasonic Treatment
The ultrasonic method is an effective method for upgrading the heavy pyrolysis oil mixed with a mutual solvent. However, low-cost ketones and long-chain hydrocarbons have been chosen for the mutual solvent for this study. Ultrasonic treatment widely used in the field of mixing of pyrolysis oil with mutual solvent improves stability due to high effectivity and short treated time. Different ultrasonic power, the different solvent ratio, different solvent type and different exposure time has been chosen for upgrading the pyrolysis oil. Initially, acetone, ethyl acetate, and n-octanol have been chosen for preliminary study. Further, the experiment will be carried out by the different solvent to find the maximum upgradation of the pyrolysis oil. Afterwards, the blend which had been treated with ultrasonic was put into the centrifuge tube. The sludge and heavy metals are separated at the bottom
of the centrifuge the upgraded oil was collected from the top. The water dispersed in the pyrolysis fuel cab be removed when the ultrasonic wave passed in the pyrolysis fuel. The fuel-water interface destroyed during the ultrasonic sound propagation due to the cavitation effect. The cavitation effect decreases the surface tension of the fuel and mechanical vibration enhance the proper mixing and form the vortex to enhance the blending and stirring operation. The heavier hydrocarbon molecules break down into smaller molecules during the ultrasonic treatment, which causes increasing the calorific value of the fuel. Further, ultrasonic can lead to enhance then-octanol and acids reaction to synthesise the high energy dense esters. The small molecules constituents which are decamped in volatile material leaving the blend as gaseous form due to mechanical vibration and cavitation effect during the ultrasonic treatment.

8. Life Cycle Assessment
The direct and indirect environmental impacts of the pyrolysis process, biomass and waste feed and pyrolysis products were analysed using Life Cycle Assessment (LCA) models. The carbon footprint during the process and energy consumption and recovery along with source emissions also tabulated for accurate analysis of LCA. The different process flow diagram can be prepared, and a suitable model has been chosen for an exact prediction of LCA value. It includes accounting, assessing, manipulating and interpreting the environmental and carbon impacts generated from the LCA including source material, production time, energy consumption, waste utilization and emission reduction. The LCA for the biofuel analysis demonstrates the excess energy required to turn the energy availability in the raw material to convert the useful energy of the pyrolysis fuel. Also, The LCA provides evaluation and sustainability of pyrolysis fuel and its production. In this proposed project, the life cycle assessment of pyrolysis and gasification will be carried out and compare them for prediction of a suitable energy efficient, eco-friendly process for alcohol and biofuel synthesis.

9. Conclusion.
From this study, the important conclusions were mentioned below from the experimental results by different pyrolysis process.

- The energy consumption was decreased when activated carbon combined with waste by 40% of the weight. The energy recovery is 4 times higher than microwave assisted pyrolysis without susceptors.
- The optimal microwave pyrolysis temperature was attained at 350 °C process temperature with power supplied rating of 1.1 kW to attained maximum pyrolysis fuel yield and maximum energy recovery.
- The proper design of solar assisted pyrolysis with CPV will increase the energy recovery rate by 2.5 times.
- Ozone and ultra-sonication method used for fuel upgradation to decrease the energy supplied.
- Life Cycle analysis will be needed to find the carbon footprint on each and every process.

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