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# Fabrication and Analysis of a Solar Assisted Plastic Pyrolysis Reactor

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## Abstract

*This paper discusses the fabrication of a solar-assisted pyrolysis reactor that uses concentrated solar energy to preheat the process. It mainly focuses on reducing the substantial energy consumption associated with conventional pyrolysis processes. As traditional methods mostly depend on electric or infrared cookers for heating, a large quantity of electricity is needed. Experiments comparing conventional and solar-assisted pyrolysis processes showed that the solar-assisted reactor reduced electricity consumption by 30% when compared to conventional methods. This experiment demonstrates a solar-assisted pyrolysis reactor in which a parabolic dish collector provides the initial heat required for the pyrolysis process by concentrating solar light. This solar heating minimizes overall electricity consumption. Rice husks and polypropylene are used as feedstock in this experiment, resulting in pyro oil with a calorific value of 38.89 MJ/kg and a viscosity of 24 cp, closely resembling diesel fuel properties. Biochar, a valuable byproduct, was also produced, highlighting the reactor's versatility. The comparative analysis between the solar-assisted pyrolysis and the conventional pyrolysis shows that the solar-assisted process is more effective. This study promotes the idea that integrating solar energy with conventional heating techniques not only enhances energy efficiency but also supports the viability of renewable energy sources in industrial applications. The findings highlight a practical and scalable approach to improving pyrolysis efficiency, waste management, and renewable energy adoption.*

**Keywords:** CSP, Parabolic dish collector, HDPE, Pyro oil, Pyrolysis, Rice Husk, Solar Energy, Plastic.

## 1. Introduction

Fossil fuels are depleting rapidly, making it crucial to shift to renewable green energy sources instead of relying on finite fossil fuels. Solar energy, being a clean and limitless resource, offers a sustainable alternative. On the other hand, plastic pollution poses a significant environmental challenge. Due to its non-degradable nature, plastic and polythene have become major threats to the ecosystem. A report shows that in 2019 plastic waste is emitted to the ocean 0.15 kg per person. The data shows that the number of emissions is highest in Philippines, and it is 3.3 kg per person [1]. Focusing on these two major issues, Solar Assisted Pyrolysis is a feasible solution. This study will collaborate the CSP (Concentrated Solar Power) technology with the pyrolysis process. In recent years, the urgency of finding the sources of sustainable and renewable energy has increased to attenuate the unfavorable effects of greenhouse gas production from burning fuel. On the contrary, the sources of non-renewable energy sources are going to run out today or tomorrow. Bangladesh has been struggling with an acute energy problem for years. The nation's proved natural gas reserves in 2017 were estimated to be 7.25 trillion cubic feet equivalent to 7.0 times its annual consumption [2]. That means the natural gas reserves of this country are very near to an end. So, it is high time to think about an alternative source of fuel which is sustainable. Bangladesh has access to vast solar energy resources. Bangladesh's location between 20.308 degree and 26.388-degree north latitude and 88.048 degree and 92.448-degree east longitude, along with its area of 1,47,570 sq km, makes it an optimal location to get the most out of the use of solar energy [3]. Bangladesh receives significant amount of solar radiation with 1,900 kWh/m$^2$ per year and daily this figure translates to 4 to 6.5 kWh/m$^2$ [4]. This data shows that Bangladesh has a significant amount of solar potential.

### Concentrated solar power

Concentrated Solar Power (CSP) has lately been recognized as a feasible and environmentally friendly choice to produce renewable energy. In these systems, sunlight is focused onto a receiver by means of mirrors or lenses, where it is then transformed into heat energy. There are several types of CSP technologies based on their collectors: Parabolic Trough Collector, Parabolic Disc Collector, Frensel Lense Collector, Molten Salt Tower.

### Pyrolysis

Pyrolysis is the process of chemical decomposition of organic compounds at high temperature and pressure. According to Nzihou et. al the pyrolysis process may mainly be classified into conventional pyrolysis and solar assisted pyrolysis depending on the operating circumstances and source of heat supply. In traditional pyrolysis, heat is produced by burning fossil fuels or biomass, whereas in solar-assisted pyrolysis, heat is generated by concentrating sunlight, which helps minimize environmental pollutants. Moreover, solar-assisted pyrolysis offers several benefits compared to conventional pyrolysis, as the by-products typically found in traditional pyrolysis are not present in the products generated by solar pyrolysis. Solar pyrolysis often produces high temperatures and rapid heating rates, resulting in the formation of pyrolysis gas products with greater calorific values than those produced by conventional pyrolysis [5]. In this process, the plastic goes through thermal breakdown and changes into a variety of compounds, such as gas, char, and liquid oil. Critical factors of the pyrolysis process are temperature, pressure, catalysts. According to Miskolczi et al., extending the pyrolysis temperature from 350°C to 550°C, more liquid oil is produced when polyethylene is burned. The liquid oil produced, however, has started decreasing at temperatures over 550°C because of an increase in cracking reactions, the production of more gas, and the formation of more solid char [6]. Usage of Catalysts Zeolite, metal oxides (CaO, MgO, NiFe, $Na_2O_3$, $Al_2O_3$) increases the quality of liquid oil and reduces the temperature range. According to Al-asadi et al., the high-molecular-weight polymers are converted into smaller hydrocarbon molecules due to the zeolite catalyst's enhanced cracking reactions, which boosted the amount of liquid oil produced [7]. According to Bridgwater et al. higher liquid yields and a reduction in gas and char production are the results of raising pressure from atmospheric to 10 bar [8].

### Solar assisted pyrolysis

Though conventional pyrolysis is one of the best alternative solutions of renewable energy, this process has some drawbacks also. Global warming and a decreasing energy supply due to the need for additional energy sources to heat the reactor are two key issues with pyrolysis systems. In that situation, Solar assisted pyrolysis can be a feasible solution. The key benefits of the proposed pyrolysis reactors are waste management solution, solar energy utilization, reduction the dependency on electricity to run the pyrolysis process.

### Objectives

This study's main goal is to design, build, and evaluate a solar-assisted pyrolysis reactor that incorporates concentrated solar power (CSP) technology to drastically cut down on the amount of electricity used during the pyrolysis process. To address the twin issues of energy scarcity and environmental sustainability, this study intends to investigate pyro oil as a sustainable alternative energy source that is made from waste materials like polypropylene and rice husks. The study aims to advance a sustainable and effective approach to waste management and energy generation by contrasting the performance of solar-assisted and traditional pyrolysis techniques.

## 2. Experimental setup and methodology

### Experimental setup

The setup is divided into two portions: the parabolic dish for solar energy concentration and the conventional infrared heating system (main heating system). In Fig. 1, a parabolic dish with a reflecting surface is shown. It was used to concentrate solar energy onto the heating surface of the pyrolysis reactor.

The main heating system, shown in Fig. 2(a), consisted of a pyrolysis reactor, an argon gas cylinder, an infrared cooker, temperature sensing devices, a condensation chamber, and an oil collector. The pyrolysis reactor is shown in Fig. 2(b).



**Fig. 1.** Parabolic dish collector for solar preheating to the pyrolysis chamber



(a)



(b)

**Fig. 2.** a) Setup of main heating system; b) Pyrolysis chamber with insulation

## Material preparation

In this study, recycled High-Density Polyethylene (HDPE) plastic chips were used as the main feedstock for the pyrolysis process. Additionally, rice husk and sugarcane threshing were used as biomass to improve the quality of the pyrolysis oil.

## Experimental procedure

The experiment was conducted in two distinct stages: the preheating stage and the main heating stage. The methodologies for each of these segments are described below.

**1.Preheating process:** The preheating process was carried out using a parabolic dish concentrator. The process was fully dependent on sunlight. The average outdoor temperature during the experimental days was 33°C. The parabolic dish concentrator was placed on a manually adjustable stand, allowing for proper movement and focusing. The following procedures were followed for the preheating process: Firstly, recycled High-Density Polyethylene (HDPE) chips, rice husk, and sugarcane threshing were mixed in varying ratios to prepare the feedstock. The feedstock was then loaded into the chamber of the pyrolysis reactor. Secondly, the argon gas cylinder was connected to the copper tube, and the tube was attached to one port of the cylinder. The reactor was placed on a holder, and both the reactor and parabolic dish were manually adjusted so that the heating surface of the reactor was aligned with the focal point of the parabolic dish to maximize heating efficiency.

The preheating process was monitored, and temperature readings were taken at regular intervals to track the change in temperature over time. Once the reactor reached the maximum temperature achievable from the solar concentrator, it was quickly transferred to the infrared cooker for main heating to minimize heat loss.

**2.Main heating process:** The main heating process was conducted using an infrared cooker. Initially, the infrared cooker was set to a power of 1000 W, and the temperature began to increase, with the change in temperature being recorded on the monitor. This heating process continued for 80 minutes.

At the end of this period, pyrolysis oil was collected after condensation in a bottle. After the reaction, the reactor was allowed to cool down. Once the reactor had cooled sufficiently, the two parts of the reactor were separated. The collected pyro oil was then analyzed to determine its quality.

## Co-pyrolysis products

In this study, from the decomposition of the HDPE two products were produced. The products were pyro oil and biochar.



(a)



(b)

**Fig. 3.** a) Pyro-oil; b) Bio char

Pyro Oil shown in Fig. 3(a) was the main product of this experiment. The sample color was light yellow in color. The Bio Char shown in Fig. 3(b) was produced from the decomposition of rice husk and sugarcane threshing. It was a byproduct of the experiment.

## 3. Data collection, calculation and analysis

In this study two types of Co-Pyrolysis were done for analysis purposes: conventional co-pyrolysis using infrared heating, solar assisted co-pyrolysis using solar preheating and infrared heating system.

### Data collection

In Conventional Co-Pyrolysis, no solar preheating was used. Three types of mixture of feedstock were used and three different experiments were conducted, one for each type of feedstock. The data obtained from these experiments were tabulated in Table 1. From the table all experiment's ending temperature, percentage of production of pyro oil can be found.

Table 1: Amount of products produced from all experiments of conventional and solar assisted co-pyrolysis

| No. | Feedstock and ratio | Feedstock mass | End temp. | Pyro oil | Bio char | Gas | Percentage of pyro oil |
|---|---|---|---|---|---|---|---|
| - | - | $m_f$ (gm) | Θ (◦c) | $m_p$ (gm) | $m_b$ (gm) | $m_g$ (gm) | $(\frac{m_p}{m_f} \times 100\%)$ |
| | | | Conventional Co-Pyrolysis | | | | |
| 1 | HDPE | 40 | 339 | 6 | 5 | 29 | 15 % |
| 2 | HDPE+Rice Husk+ Sugarcane Threshing (2:1:1) | 40 | 335 | 8 | 11 | 21 | 20 % |
| 3 | HDPE+Rice Husk (2:1) | 40 | 311 | 11 | 9 | 20 | 27.5 % |
| | | | Solar Assisted Co-Pyrolysis | | | | |
| 4 | HDPE+Rice Husk (2:1) | 40 | 310 | 8 | 13 | 19 | 20% |

### Comparative analysis between conventional and solar assisted method

In this project, both Conventional and Solar Assisted Co-Pyrolysis processes were conducted using a common feedstock of HDPE + Rice Husk (ratio 2:1).

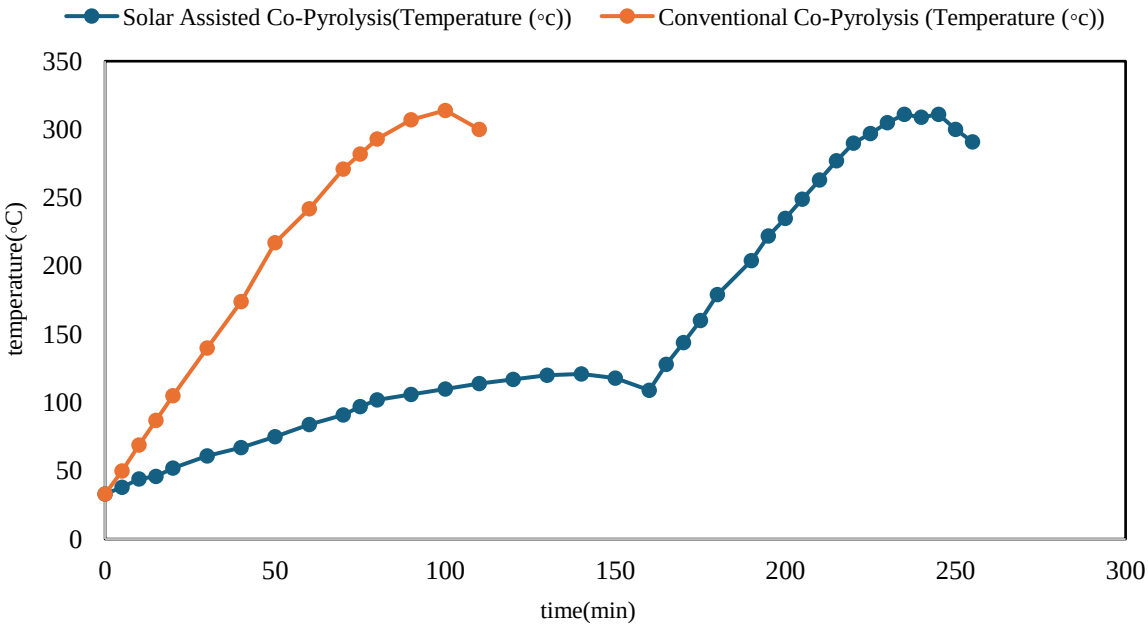



**Fig. 4.** Time vs temperature graph of conventional and solar assisted co-pyrolysis

Data from these experiments were collected for a comparative analysis between two processes. For Comparing the time range and temperature rise of Solar Assisted Co-Pyrolysis and Conventional pyrolysis, a graph was plotted in Fig. 4. From Fig. 4, it was found that conventional process took less time than solar assisted for the completion of co-pyrolysis. Overall electric energy consumptions by infrared cooker during Conventional Co-Pyrolysis and Solar Assisted Co-Pyrolysis have been tabulated in Table 2.

Table 2: Overall electric energy consumption in conventional and solar assisted method

| No. | Process | Start time | End time | Time difference | Used power of Infrared Cooker | Electric energy consumption |
|---|---|---|---|---|---|---|
| - | - | $t_1$ (min) | $t_2$ (min) | $\Delta t$ (min) | P (W) | $W_c = P.\Delta t/60$ (W. h) |
| 1 | Conventional Infrared cooker heating | 0 | 100 | 100 | 1000 | 1666.67 |
| 1 | Solar preheating | 0 | 154 | 154 | 0 | 0 |
| 2 | Conventional Infrared cooker heating | 160 | 230 | 70 | 1000 | 1166.67 |

Electric energy saved by Solar Assisted Co-Pyrolysis over Conventional Co-pyrolysis have been calculated, $\Delta W = W_c - W_s = (1666.67 - 1166.67) = 500$ W. h=0.5 KW. H. It was found from the analysis that almost 30% of electric energy was saved by Solar Assisted Co-pyrolysis process.

So, the comparative study can be concluded by saying that though solar assisted co-pyrolysis is slower than the conventional process, it is more electric energy saving technique than the conventional process. That is why solar assisted co-pyrolysis is better than Conventional Co-pyrolysis.

### Determination of quality of the pyro oil

After getting the pyro oil from the experiment some properties of the oil have been measured. The higher calorific value was determined by using a digital bomb calorimeter and it was found 38.89 MJ/kg.

The viscosity of the pyro-oil was measured by viscometer. It was measured at room temperature 33°C. Spindle number and spindle rotation were taken L3 and 100 rpm respectively. The viscosity of the pyro-oil was found 24 cp. The density of the pyro oil was measured 875 kg $m^{-3}$.

A qualitative comparison of pyro oil and Diesel Oil is tabulated in Table 3. The properties of pyro oil indicate that it could serve as a viable alternative fuel in the future. Its characteristics are similar to those of diesel oil. With proper extraction methods, the quality of pyro oil can be enhanced for commercial use.

Table 3: Qualitative comparison of Pyro oil and Diesel oil

| Parameter | Pyro oil | Diesel oil [9] |
|---|---|---|
| Density (kg/$m^3$) | 875 | 827 |
| Viscosity (cp) | 24 | 6 |
| Higher calorific value (MJ/kg) | 38.89 | 45.18 |

## 4. Conclusion

This study examined the co-pyrolysis of rice husk, sugarcane threshing, and HDPE (High-Density Polyethylene) while building a solar-assisted plastic pyrolysis reactor. Solar-assisted co-pyrolysis is more energy-efficient than conventional co-pyrolysis with infrared heating, saving about 30% of electrical energy, according to a comparative analysis. A 2:1 blend of HDPE and rice husk was determined to be the optimal feedstock combination, producing a pyro oil with characteristics similar to diesel oil (calorific value: 38.89 MJ/kg, viscosity: 24 cp, density: 875 kg/m³). This implies that pyro oil may be a viable alternative fuel that is sustainable. But the study also found that the process generated a lot of smoke emissions, which might be bad for people's health. Improvements in insulation and reactor design can help reduce these emissions. In conclusion, although the solar-assisted method is slower, it offers significant energy savings and environmental benefits, making it a promising approach for waste plastic recycling and renewable energy production.

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