

**FUEL PRODUCTION FROM BIOMASS AND WASTE PLASTIC (POLYETHYLENE) BY CO-PYROLYSIS PROCESS****Hitesh L. Jadav<sup>1</sup> and Dr. Nimit Patel<sup>2</sup>**<sup>1</sup>PHD Scholar, CVM University, Vallabh Vidyanagar, Anand, Gujarat India<sup>2</sup>Assistant Professor, ADIT, CVM University, Vallabh Vidyanagar, Anand, Gujarat India<sup>1</sup>hlj.auto@gmail.com and <sup>2</sup>nimit.patel@cvmu.edu.in**ABSTRACT**

*The primary objective of this research has been to produce and analyze bio-oil through co-pyrolysis, which involves the use of Mahua seeds and waste plastic (polyethylene) as feedstocks. The biofuel production from sources of biomass is believed to decrease the dependence on fossil fuels as well as lower costs. This study aimed to investigate the impact of adding plastic to biomass during pyrolysis on the product yield as well as quality. Experiments have been carried out using a pyrolysis reactor with several parameters such as rate of heating, temperature, and blending ratio. The study's findings revealed that the optimal conditions for the highest 74% bio-oil yield were a temp of 500°C, a blend ratio of 1:1, and a heating rate of the 20°C/min. The quality of the fuel after the co-pyrolysis of MS (Mahua Seeds) and waste plastic has been compared to that of conventional diesel fuel after purification to assess the similarity between the two. The fuel samples were analyzed using FTIR, and the components were identified. The study's findings suggest that co-pyrolysis of plastic waste along with Mahua seeds is a viable method for producing bio-oil as a sustainable biofuel.*

*Keywords: Bio-oil, co-pyrolysis, Pyrolysis, Characterization, FTIR, waste plastic*

**INTRODUCTION**

The most significant global challenge is the increasing demand for energy, which has led to an energy crisis. Traditional sources of energy, like coal, natural gas, and petroleum, cannot meet the growing energy demands. The widespread use of fossil fuels has outcomed in several negative environmental impacts, involving the GHGs (Greenhouse Gases) emissions, climate change, and global warming. As a result, there has been considerable interest in alternative energy sources, including lignocellulosic biomass, for the production of biofuels as well as bioenergy [1,2]. Lignocellulosic feedstocks could be converted into valuable products using biochemical, chemical, or thermochemical routes [3]. Chemical procedures involve the use of chemicals as well as catalysts to create products such as biodiesel through transesterification and esterification reactions. Living microorganisms like bacteria are used in biochemical processes to decompose biomass and convert it into biodegradable products, mainly through anaerobic digestion as well as fermentation [4]. Thermal approaches utilize heat & thermal energy and encompass processes like torrefaction, drying, gasification, pyrolysis, and combustion [5–7]. Among these processes, pyrolysis has gained considerable attention because of its cost-efficient and eco-friendly nature [8]. Biomass pyrolysis is a thermochemical procedure which produces biochar, bio-oil, and syngas without the presence of oxygen [9].

Fossil fuels utilization leads to the release of GHGs, which, in turn, exacerbates change in climate and results in extensive environmental pollution. Moreover, the improper disposal of significant waste components, such as plastic, biomass residue, tires, rubber, and refuse-derived fuel, poses substantial environmental challenges when they reach their final destinations. Incineration or disposal of these wastes in landfills releases toxic biogas, which includes methane and other greenhouse gases. As traditional energy reserves continue to decline, and the need for environmental protection becomes increasingly urgent, researchers are actively seeking alternative energy sources. Among the renewable energy options, biomass and solid waste are widely available, with minimal carbon emissions into the environment.

Globally, extensive research is carried out to create advanced technologies that harness alternative energy from renewable sources, like biomass. The primary objectives are to enhance energy efficiency as well as decrease

emissions during the fossil fuel conversion. Biomass, known for its affordability, abundant availability, and eco-friendliness, currently ranks as the fourth largest global energy source, contributing to approximately 15% of the world's energy consumption [10].

Energy can be generated from biomass using thermochemical and biological conversion methods. Thermochemical methods encompass direct combustion, pyrolysis, liquefaction, gasification, and supercritical water extraction. [11]. Among these techniques, pyrolysis has emerged as the most promising thermochemical method because it can convert approximately 75% of the overall biomass into the liquid form [12]. Though, the bio-oil stability produced through biomass pyrolysis is often inadequate because of its higher water as well as oxygen content, which leads to lower calorific value, corrosion concerns, and instability. As a result, ongoing research efforts have focused on addressing and overcoming these challenges.

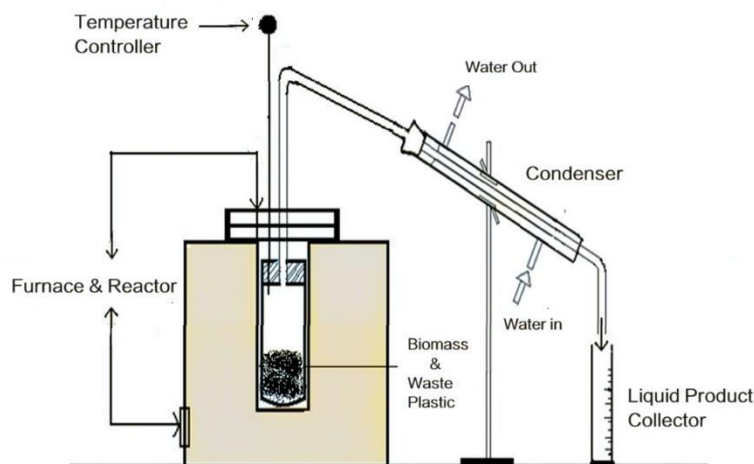
In this context, the use of plastics presents a noteworthy opportunity due to their higher hydrogen content than biomass and the absence of water in their pyrolysis liquid. By co-pyrolyzing biomass and plastic, the bio-oil stability as a fuel can be improved, as plastic could supply the hydrogen which lacks the biomass. Therefore, the primary objective of the current study is to enhance the bio-oil quality as well as decrease its content of water through the co-pyrolysis of MS & waste plastic. Specifically, the study examines the effects of the heating temperature as well as product yield than the pyrolysis of MS alone.

#### **MATERIALS AND METHODS**

In this research, Mahua seed biomass & plastic waste were used. Mahua seeds were collected and dried under the sun for 15 days to eliminate any moisture content. Thereafter, they were placed in a hot-air oven for an hour and subsequently ground into a powder using a grinder. To prevent moisture absorption, Mahua seed powder samples were sealed in airtight plastic containers.

In order to create a refined Mahua bio-oil with reduced oxygen content and increased levels of carbon and hydrogen, co-pyrolysis of MS heating rate of the 20°C/min and a range of temperature 400-600°C. The blending ratios used were 1:1, 2:1, 3:1, and 4:1, and the blend with the highest bio-oil yield was determined through various physical and chemical property analyses, including FTIR and GC-MS. Prior to pyrolysis, the powdered Mahua seeds and waste plastic samples were blended by tumbling them for 30 minutes to ensure a uniform mixture. Similarly, the waste plastic was processed into powder form using a grinder.

The experimental setup for pyrolysis is depicted in Figure 1. The pyrolysis reactor is comprised of main units such as the furnace, pyrolysis reactor, and vapor-condensing unit. The pyrolysis reactor was a cylindrical stainless-steel vessel with a 0.5 liter capacity, and the feed was inserted vertically into an electrically heated furnace. The vapors produced by the reactor have been condensed using a water-cooled condenser, and the resulting liquid has been gathered in a measuring cylinder. The residual char, also referred to as pyrolytic char, was gathered following the cooling of the reactor. A highly sensitive proportional-integral-derivative (PID) controller was used to regulate the temperature of the furnace. An electrically heated furnace was positioned at the center of the setup.



**Fig. 1** Pyrolysis Unit

### CHARACTERIZATION OF RAW MATERIAL:

#### Proximate Analysis:

Proximate Analysis offers data on the content of moisture, the content of ash, the content of volatile matter, and the fixed carbon content of materials. Fixed carbon is found out by subtracting the sum of ash, moisture, and volatile matter from 100% as it remains solid when heated without air. Thus, comprehending the moisture and ash contents of the material is crucial for economic purposes. Ash in coal does not add to its heating value but is typically viewed as an unwanted byproduct and a pollution source. However, in certain cases, the existence of mineral matter might be necessary, such as for chemical feedstocks or liquefaction. Generally, the heat value of a material is derived by excluding the volatile matter, moisture, and carbon fixed content. To measure the actual amount of heat released after combustion, the ASTM D3172 - 07a method was used.

#### Ultimate Analysis

The ultimate analysis aim was to evaluate the material composition in terms of its elemental makeup. Specifically, the levels of hydrogen, carbon, sulfur, nitrogen, ash, and oxygen in the material were determined. In some cases, additional chemical analyses may be performed to identify the forms of sulfur present, such as sulfate minerals, sulfide minerals, or organically bound sulfur. Furthermore, trace elements may be analyzed to assess the suitability of the material for specific purposes, including reducing environmental pollution. The ultimate analysis has been performed by utilizing a CHNSO elemental analyzer (Variael CUBE, Germany), which provided the percentage composition of hydrogen, carbon, oxygen, sulfur, and nitrogen. The oxygen percentage composition has been computed by subtracting the sum of these compositions from 100.

#### Thermo-Gravimetric Analysis:

The method of Thermogravimetric analysis, also referred to as Thermal Gravimetric Analysis, is a kind of testing that evaluates variations in the weight in response to a temperature program in a controlled atmosphere. This technique necessitates a higher precision level for both temperature and weight measurements. A derivative weight loss curve can pinpoint the stage at which weight loss is most noticeable, despite the similarities in many weight loss curves. Additional analysis is required to comprehend these overlapping peaks. By conducting Thermogravimetric analysis, the composition and purity of a substance can be determined by measuring its mass in a mixture. The Thermogravimetric analysis of the sample seeds has been performed by utilizing a DTG60 instrument.

## RESULTS AND DISCUSSION

The outcomes of the proximate and ultimate analyses for MS & WP are presented in Tables 1 and 2, respectively. The proximate analysis demonstrated that both feedstocks had a high percentage of volatile compounds. Meanwhile, the ultimate analysis revealed that MS has an oxygen content of 24.56 wt%, which is significantly more than that of WP, while WP has no oxygen content at all. The higher oxygen content in MS suggests that it has a lower caloric value than “WP”.

### Proximate and Ultimate Analysis of Mahua Seed:

**Table no. 1** Proximate analysis of MS and WP

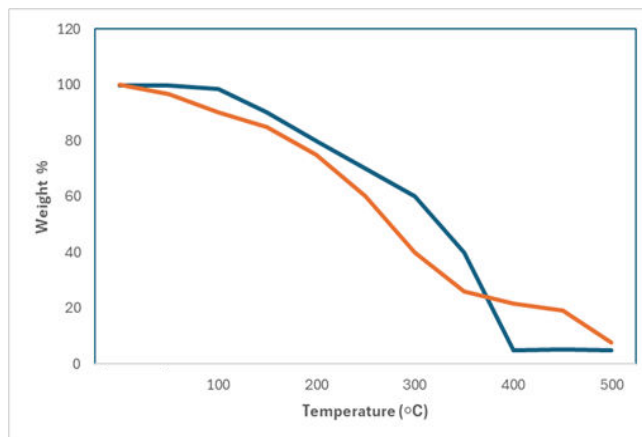
| Characteristics | Proximate analysis |       |
|-----------------|--------------------|-------|
|                 | MS                 | WP    |
| Moisture        | 8.2                | 0.35” |
| Volatile        | 78                 | 98.25 |
| Fixed carbon    | 5.1                | 0.66  |
| Ash             | 1.5                | 0.50  |

**Table no. 2** Ultimate analysis of MS and WP

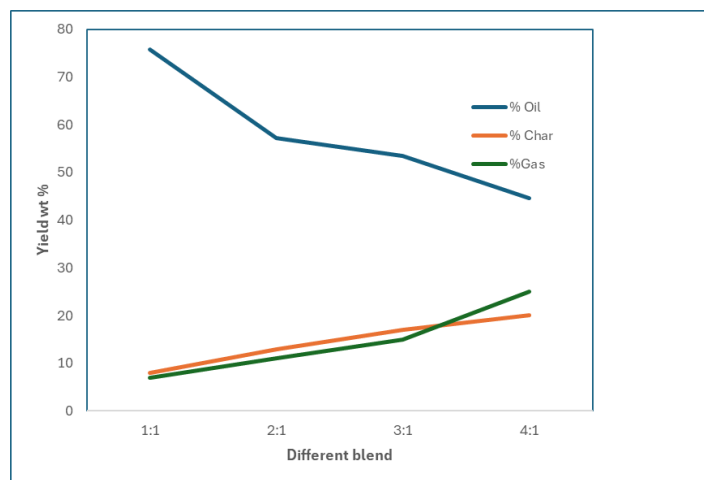
| Characteristics | Ultimate analysis |       |
|-----------------|-------------------|-------|
|                 | MS                | WP    |
| C               | 60.30             | 86.20 |
| H               | 8.10              | 12.50 |
| N               | 3.90              | 1.15  |
| S               | 1.12              | -     |
| O               | 24.56             | -     |
| HCV [MJ/Kg]     | 25.4              | 39    |

### Thermogravimetry Analysis of Mahua seed and WP:

The figure shown in Figure 2 depicts the thermographs for MS & WP at a heating rate of 20°C/min. The thermograph for MS indicates the initial decomposition stage from 37°C-212°C, that is ascribed to the moisture vaporization. The MS decomposition 2<sup>nd</sup> stage took place between 218°C and 432°C, with a weight loss of about 60.28%. At 432°C, there was a steady decrease in weight for MS until it reached 500°C, resulting in a residue of roughly 16percent of the initial sample mass because of the degradation of lignin as well as residual charcoal from the hemicellulose and cellulose. In contrast, the main decomposition of WP occurred between 280°C and 400°C, having a weight loss of approximately 90% because of the volatile compounds decomposition. Total decomposition of WP was found at 400°C, and no residue was detected afterward.



**Fig 2:** TGA Plots of Mahua seeds and Waste plastic



**Fig 3:** Co-pyrolysis yield with different blends

### Pyrolysis Yield:

Experiments on the pyrolysis of MS (mahua seeds) were conducted using a batch reactor with a temperature range of 450°C to 600°C in increments of 25°C and a constant heating rate of 20°C/min, as depicted in Fig 2. Oil production was 33% at 450°C during pyrolysis and peaked at 48.6percent at the optimal temp. of 525°C. The highest amount of liquid produced at 525 °C was caused by secondary reactions like thermal cracking, recondensation, and repolymerization, with the purpose of enhancing the liquid yield. However, “co-pyrolysis of MS and polystyrene (PS) having various blending ratios of (1:1, 2:1, 3:1, and 4:1) has been performed at 525 °C, as depicted in Figure 3. The highest bio-oil” yield (approximately 74%) has been attained with the 1:1 blend. The increased addition of PS contributed to this outcome by serving as a high-quality hydrogen source during the thermal co-processing with the biomass. The research indicates that adding PS to mahua seeds significantly increases oil yield and decreases aqueous phase yield.

### PHYSICOCHEMICAL CHARACTERIZATION:

#### Physical Properties of CPO:

The findings of this study disclosed that the co-pyrolysis oil derived from the MS: PS 1:1 blend showed more favorable outcomes than those obtained from biomass pyrolysis oil. Though, to use it in the industry of chemicals and as a substitute for conventional fuels, it is vital to know its physical properties. The performance of bio-oil is greatly influenced by its fuel properties when it is utilized for various applications. Therefore, to gain a better comprehension of fuel characteristics, specific physical properties need to be analyzed. These physical properties involve heating value, viscosity, pH, water content, distillation range, density, fire point, flash “point, pour point, and carbon residue of MS, PS, and MS: PS 1:1 blend pyrolytic” oils, that were compared with those of conventional petroleum fuels, as shown in Table 3.

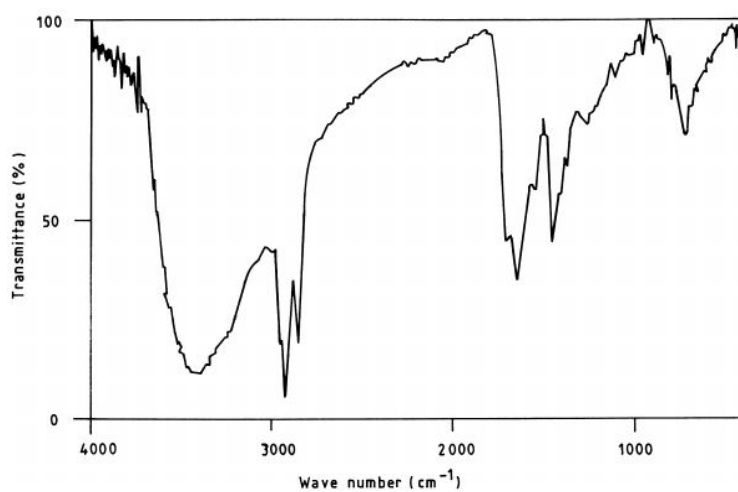
**Table no. 3** Physical properties of Bio-oil

| Properties                           | MS/WP 1:1 | Diesel |
|--------------------------------------|-----------|--------|
| Density at 15°C (kg/m <sup>3</sup> ) | 908       | 830    |
| Kinematic viscosity at 40°C (cSt)    | 1.90      | 2.58   |
| Flashpoint (°C)                      | 58        | 50     |
| Pour point (°C)                      | 6         | -28    |
| Fire point (°C)                      | 60        | 56     |
| Carbon residue (Wt. %)               | 0.813     | 0.1    |
| Water content (Wt. %)                | 0.50      | 0      |
| pH                                   | 4.8       | ---    |

The pyrolysis oil density created from a mixture of MS:WP is greater in comparison to conventional fuel because it contains a significant amount of water as well as macromolecules like hemicelluloses, cellulose, phenolic, and oligomeric compounds[16], as indicated by the results. The kinematic viscosity of the bio-oil was 1.943 cSt at 40°C, which is less than that of conventional diesel fuel. The Mahua pyrolysis oil has a pH of 4.8, indicating its acidic nature. It is consistent with the general characteristic of biomass pyrolysis oils, which typically have a pH between 2 and 4. The high acidity of the pyrolytic oil is because of the existence of acetic acid, carboxylic acid, and formic acid [17]. The co-pyrolysis oil had a flash point of 58°C, exceeding that of diesel. The oil's pour point is the lowest temperature at which it can flow under typical conditions. In this study, the pour point obtained was 6°C, slightly higher than that of conventional fuel. The pyrolysis oil had slightly higher flash point and fire point values compared to conventional diesel.

#### FTIR Analysis:

The FTIR spectra of the MS/WP blended bio-oils are illustrated in Figure 4.



**Fig 4:** FTIR analysis of Pyrolysis oil

The existence of phenol and alcohol groups, including oxygen, is indicated by the spectral peaks in the 3600-3100 $\text{cm}^{-1}$  range in the bio-oil. The 2850-2800 $\text{cm}^{-1}$  range corresponds to the existence of an aldehyde with a C-H stretch, while the peaks in the 1300-1000 $\text{cm}^{-1}$  range represent the existence of ether groups. These groups do not exist in the co-pyrolysis oil, but the oil demonstrates the presence of aromatic rings in the 1600-1580 $\text{cm}^{-1}$  range of peaks. There was a major decrease in the amount of aliphatic, phenolic, and acid groups in the co-pyrolysis oil and a significant increase in the amount of aromatic groups.

**Table no. 4** FTIR analysis of pyrolysis oil

| Frequency ( $\text{cm}^{-1}$ ) | Wavelength range ( $\text{cm}^{-1}$ ) | Type of vibration        | Functional group  |
|--------------------------------|---------------------------------------|--------------------------|---|
| 3082, 3063, 3030               | 3010 - 3100                           | =C-H Stretching          | Alkene  |
| 2955, 2925, 2856               | 2960 - 2853                           | C-H Stretching           | Alkane  |
| 1944, 1875, 1804               | 2000 - 1800                           | C=C stretching           | The aromatic ring (aryl) group, aromatic combination bond |
| 1743                           | 1735-1750                             | C=O Stretching           | Ester   |
| 1629, 1602, 1575               | 1650-1580                             | C=C stretching           | Alkene, Aromatics   |
| 1494                           | 1500-1400                             | C-C=C Asymmetric Stretch | Benzene   |



|                |           |                   |  |
|----------------|-----------|-------------------|--|
| 1455,1412,1379 | 1470-1350 | C≡C<br>Stretching | Alkyne   |
| 1285,1028,900  | 1300-950  | C-O Stretching    | Ester, Ether                                     |
| 900,776,698    | 1000-650  | O-H bending       | Mono and polycyclic substituted aromatics groups |

**CONCLUSION**

This study demonstrates that the pyrolysis of MS and waste plastic is a potential process to produce bio-oil. The research found that a maximum co-pyrolysis oil yield of 74% could be achieved with a 1:1 blend at 525 °C temperature, a constant rate of heating of 20°C per min, and a rate of nitrogen flow is 30ml/min. As the waste-plastic ratio increased, the oxygen content of the co-pyrolysis oil decreased. Co-pyrolysis oil's viscosity has been observed to be similar to conventional fuel, indicating that it could be a valuable chemical and fuel source. Physical property studies suggest that the co-pyrolysis of PS & MS is an environmentally approachable process for making valuable fuels and chemicals.

Co-pyrolysis oil derived from plastic & biomass could be valuable for diverse chemical & industrial uses and can function as a viable alternative to conventional fuels. The benefits of this co-pyrolysis process are that it reduces the use of fossil fuels, improves energy security, and environmental problem-solving, and promotes efficient waste management practices. Furthermore, this process is straightforward in design and economically feasible, as it can be performed at a low cost without requiring specialized equipment. Thus, it can be concluded that this is a viable solution for increasing the nation's energy security as well as decreasing its reliance on fossil fuels.

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