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Pyrolysis of Sawdust for Bio-Oil Production using Infrared Heat Source

Md. Rabiul Islam, Muhammad Mostofa Kamal Bhuiya, Bably Das,Mostafizur Rahman and Amir Hamza Limon*
Department of Mechanical Engineering, Chittagong University of Engineering & Technology (CUET), Chittagong 4349, BANGLADESH

ABSTRACT

An experimental investigation was carried out to produce bio-oil from sawdust using pyrolysis process (infrared induction cooker). The experiments were performed for varieties of infrared cooker heat inputs at a particular moisture content. To complete the pyrolysis process, a conical flask type reactor was used in this experiment. The experimental results demonstrated that the maximum of 7% bio-oil, 83% char and 10% gas were obtained at a moisture content of 25%. The properties of produced bio-oil were characterized and compared to other biomass products. The calorific value, density, viscosity, flashpoint and fire point of 10.7 MJ/kg, 922.71 kg/m^3, 20 mm^2/sec 64°C and 68°C were obtained, respectively, when the produced bio-oil was tested. This paper provides a clear information about how to produce bio-oil from biomass resources at a greater extent using infrared induction cooker. It can be noted that the production and usages of bio-oil is one of the roots to produce low-carbon energy.

Keywords: *Infrared induction cooker, Pyrolysis,Bio-oil, Calorific value*

1. Introduction

Renewable energy is one of the most important form of energy which is of growing valuable environmental concerns over fossil fuel usage and it’s contributed to greenhouse effect [1]. The renewable energy so called “Green Energy” which is produced conversion of biomass using pyrolysis technology and this conversion of biomass has gained more popularity because of their zero net CO_2 emission to the environment. The biomass resources considered as a potential source of energy as these are economical, non-toxic and reduce dependency on crude oil. In addition, the increasing awareness of the depletion of fossil fuel resources and the environmental concerns has made biomass resources more attractive to produce bio-oil using pyrolysis process.Today, modern world facing the problem of scarcity of fossil fuels, increasing their manufacturing cost and this fossil fuels have more impact to the environmental pollution which will make renewable energy source more useful to the users. Petroleum products such as fuel oil, gasoline or valuable chemicals are used in every aspect of life today. With rapid increase in world population, the demand for petroleum products is increasing day by day. But the world’s oil supply is fixed since petroleum is naturally formed far too slowly in millions of years to be replaced at the rate at which it is being extracted [2]. With the concern of depletion rate and price increase, there is rapidly growing interest in renewable energy source like biomass to be used as an alternative to petroleum. Biomass is biological material from living, or recently living organisms, most often referring to plants or plant-derived materials. Biomass can be converted to higher value products or energy. They include wide range of materials such as: virgin wood from forestry, energy crops specially grown for energy applications, agricultural residues from agriculture harvesting, food waste from food and drink preparation and processing, and post-consumer waste, or industrial waste and co-products from manufacturing and industrial processes [3].Pyrolysis is one of thermo-chemical process which converts the solid biomass in to liquid (bio-oil), gas and solid and liquid product, pyrolytic oil, approximates to biomass in elemental composition, and is composed of a very complex mixture of oxygenated hydrocarbons [4]. Pyrolysis conversion technology for biomass has been investigated over the last three decades and used commercially [5]. Bio-oil derived from agricultural wastes has moderate GCV ranging from 15-38 MJ/kg with some advantages in transportation, storage, combustion, retrofitting and flexibility in production and marketing [6]. Sawdust is available in our country because there are lot of sawmills besides us. Sawdust has a great potential source of chemical energy which comes from various kinds of wood. The bio-oil contains more than a hundred of organic compounds that belong to alkanes, phenols, aromatic hydrocarbon, acids, aldehydes, ketones, alcohols, esters, furans [7]. Plant biomass mainly comprises of celluloses, hemi celluloses and lignin making it an ideal source of renewable energy for producing bio-oil and power [4]. Several factors like environmental benefit, economic benefit and availability of source need to be considered for selection of proper alternative energy [9]. The agro-based biomass is usually produced in the rural area where a largescale pyrolysis plant can be installed [10]. Sawdust is more easily suitable for pyrolysis process to produce bio-oil. Biomass conversion techniques including thermo-chemical and biochemical conversion are employed for power generation and production of liquid biofuels, chemicals and charcoal, which can be used as activated carbon. Biochemical conversion can be made using the enzymes of bacteria and other micro-organisms to break down biomass. Mostly micro-organisms are used to perform the conversion process: anaerobic digestion, fermentation and composting [11]. Waste materials such as sawdust, coconut shell, scrap tire, rice husk, plastic and biomass waste are being generated every year around the world. Some of these wastes are effectively collected and recovered for using as an energy source or chemical feedstock while some

* Corresponding author. Tel.: +88-01784353193
E-mail addresses: mkamalcuet@gmail.com

are simply discarded or burned in ways that can pollute the environment.Improper disposal of these waste materials may constitute and environmental hazard due to the presence of undesirable species such as metals, soot and polycyclic aromatic hydrocarbons. In present days, the treatment of these waste materials represents a significant challenge in the real world. Pyrolysis is also used in the creation of nanoparticles, zirconia and oxides utilizing an ultrasonic nozzle in a process called ultrasonic spray pyrolysis. Another form of waste disposal is achieved by thermal means through incineration. In this process, the combustion of wastes in the release of greenhouse gas such as Carbon di oxide that contribute to climate change. Besides, incineration can lead to toxic emissions that pose a direct hazard to the environmental and human health. Incineration recovers only calorific value of the waste but does not allow or the recovery of any of the chemical value of waste, and so this method is being impracticable due to concerns of greenhouse gas release and associated with environmental pollution and toxic emissions. Infrared pyrolysis is a relatively new process. Conventional thermal heating usually employs an external heating source to transfer heat to material through a surface. In contrast, microwave heating constitutes a unique way of heating where the heating effect arises from the interaction of electromagnetic wave with the dipoles within the material being heated. By such heating mechanisms, heat is generated within the material rather than from an external source, thereby giving a more efficient heating process compared to conventional surface heating respect to even distribution of heat and easier control over the heating. In addition, high temperatures and heating rates can be obtained through infrared heating [12].It can be noted that bio-oil produces using infrared heat source pyrolysis process has a great significant to the energy conversion technology in the field of renewable energy source. Therefore, the goal of this investigation is to produce bio-oil from sawdust using infrared induction cooker.

2. Experimental facility

2.1 Materials

Sawdust is domestically available which was used for the pyrolysis. The sawdust materials were collected from a sawmill (Pahartoli, Raozan). In every experiment, the amount of sawdust was weighted by a weight machine to get the accurate result. The sawdust can provide more crude oil than other pyrolysis materials.

2.2 Experimental parameters

To conduct the experiment to produce bio-oil from sawdust using infrared induction cooker there are lot of equipment were used

An infrared cooker of MODEL VSN-INF 2083 was used to complete the pyrolysis process. It can provide up to 2000W power and 600ºC temperature. Infrared radiation is a type of electromagnetic radiation, as are radio waves, ultraviolet radiation, X-rays and microwaves.A conventionally used conical flask of 500ml was used in this experiment. The conical flask made of glass was used to carry the sawdust and a cylindrical pot made of stainless steel was used to receive the gas produced during the pyrolysis process of the sawdustPieces of ice were given around the stainless- steel cylindrical condenser and a large plastic bucket carried the condenser. There were enough ices around the condenser to liquefy the gases and the gases which cannot be liquefied are set to be out by a small hole to the environment. The hole was at the upper portion of the condenser which was not drown to the condensing water.A thermocouple is a temperature measuring device. It can measure high temperature. In this experiment a thermocouple which was run by electricity. It has a wire which outer point is attached to the measured temperature medium and other side is connected to the thermocouple. The thermocouple shows two values one is setting value & other variable values.The gas produced in the conical flask by heating was transferred to the stainless-stain cylindrical tube by using the cooper tube. For this kind of study, the tube used to transfer hot gases is usually made of copper. Because, copper tube can bear more heat than any other metals and don't get corroded by water-gas mixture.In this study, the stainless-steel cylindrical pot was used for condensing because it can easily condensate. The height and radius of the stainless-steel cylinder are eight and two inches. There was enough space inside the steel cylinder so that the hot gases can get more time during condensing. As steel is a conductive material so it can easily cold.

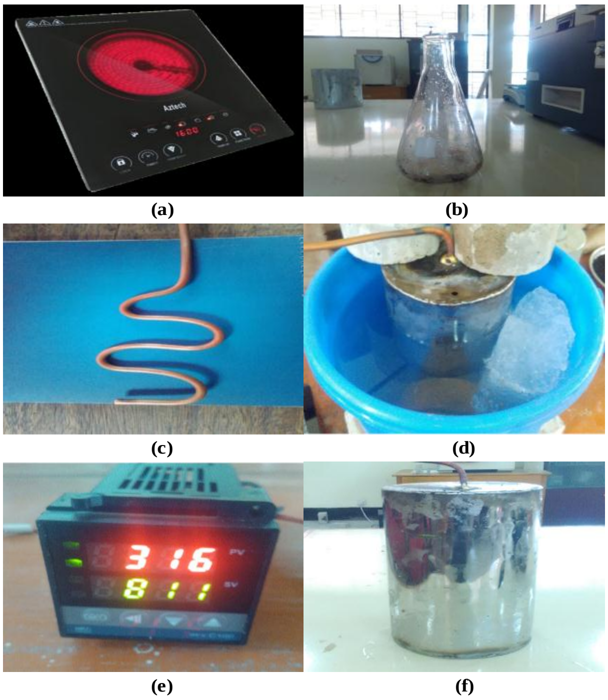

Fig. 1 (a)Infrared Cooker;(b)Conical flask; (c)Coper tube; (d) Ice bath; (e)Temperature monitor; (f)Stainless steel cylinder.

2.3 Pyrolysis

Pyrolysis process carries out in the pyrolysis reactor. Finally, energy was recovered from pyrolysis of oil. Analysis of the obtaining charcoal and pyro-oil. An infrared cooker of MODEL VSN-INF 2083 is used to complete the pyrolysis process which can provide up to 2000W power and 600°C temperature. Pyrolysis means the thermal cracking of larger hydrocarbons into smaller one in the absence of oxygen or any other oxidizing components. Nitrogen gas is used as carrier gas to keep the pyrolysis condition inert. It also helps quick removal of hot gas from the pyrolysis chamber thus preventing secondary cracking of hot gas and increases liquid product of pyrolysis. Nitrogen gas is supplied to the pyrolysis and hot pyrolysis product condensation chamber by copper tubes of 6mm diameter. Both chambers are made from conical flask of 500 ml capacity and condensation chamber are submerged in an ice bath.

2.4Experimental setup

The experimental facility consists of conical flask, stainless steel condenser, copper tube, ice bath, nitrogen gas cylinder, infrared cooker, thermocouple etc. These were used to complete the experiment that means for pyrolysis of sawdust. The schematic diagram of the experimental set up is shown in Fig. 2[13].

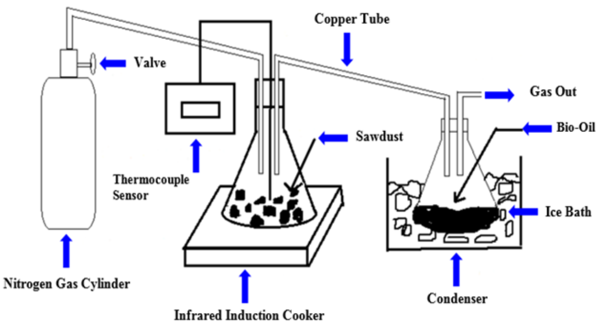

Fig. 2 Schematic diagram of experimental set up

2.5 Experimental procedure

At first, the sawdust is kept on the conical flask reactor with known weight of sawdust for infrared pyrolysis. Theschematic diagram of the experimental setup is shown in Fig.2.When the microwave heating is started, the sawdust begins to pyrolysis after certain temperature evaluation. Pyrolysis products (vapor & gases) will be passed through the steel pipe to the ice water cooled condenser, where the condensable products will be condensed in the bottom of the condenser and gaseous products will be passed through the hole of the condenser. The temperature of the pyrolysis product will be recorded in a certain time interval. The microwave heating will be held for a time interval to get desired pyro-oil and bio-char which has a certain calorific value and viscosity of the liquid oil. In this study, the gaseous product will be released to the atmosphere. Liquid nitrogen will be used in this study to create inert atmosphere and carrier gas.

Fig. 3 Photograph of sawdust pyrolysis process

Ice cooled water can be used to condense the vapor in order to maximize the oil yield. The condensate oil is accumulated at the bottom of the condenser then it is stored for further analysis. The aim of this study is to obtain pyro-oil from sawdust by heating. The heating of sawdust is held in a 2000W infrared cooker. The infrared cooker is used for this study, has a capacity of 20 litters and it is taken from VISION, Model-VSN-INF 2083. The output power of this infrared cooker is 2000W and temperature is up to 600ºC. The size of the copper tube was 6mm.

2.6 Product yield percentage

In this study, inert gas was produced inside the infrared wave reactor. To remove these inert gases, nitrogen gas was supplied from a nitrogen cylinder. For condensation the gas product one ice-bath condenser was used. In this pyrolysis process sawdust is fed, no activated carbon is mixed to enhance the infrared wave absorption. In the product yield, 7% pyro-oil is recovered, which have a good calorific value. The char produced 83. % of the total weight at a certain time till the oil being produced from the sawdust.

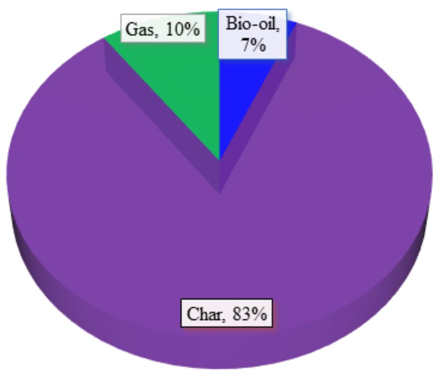

Fig. 4 Percentage of product yield

The high percentage of the gases and losses may be attributed to some leaks from some gaps in the apparatus. Furthermore, the water used in the condensing unit might not be cold enough thus reducing the oil yield. Uncondensed volatile vapor would flow out of the condensing unit along with others. It can be seen that once the pyrolysis started to occur, brown vapor immediately filled up the condenser flask and flew out of the condenser top. The pyrolysis process created an irritable odor of the vapor and the vapor would start to condense in the stainless-steel condenser. After the oven was turned off volatile matter was still seen to be released from the sawdust sample.

2.6.1Bio-Oil

The pyro-oil obtained from the sawdust pyrolysis is shown in Fig.5(a) below. For every 100 gm of sawdust the pyro-oil is obtained almost 4-8 gm. The pyro-oil increases to produce from sawdust in every time interval. It contains some chemical compounds which can be known by chemical test. The pyro-oil is darkish in color and smells bad.

2.6.2 Charcoal

Sawdust charcoal obtained from the pyrolysis process is shown below in the Fig.5(b). The standard time to produce the charcoal is about 60 minutes. During this time the sawdust gets burnt by the heat of infrared cooker inside a conical flask and converted into char giving up the gas and liquid.

2.6.3 Gas

During the pyrolysis of sawdust gases are produced in the conical flask. These gases are provided to condenser by the action of nitrogen gas because the pressure of nitrogen gas was 100 KPa. But all the gases are not condensed to the condenser because there are some non-condensable gases like light hydrocarbon and gaseous materials.

(a) (b)

Fig. 5 (a)Bio-oil; (b) Charcoal.

3 Data collection and analysis

3.1 Pyrolysis products

The weight of produced char and pyro-oil was weighed in the digital weighing machine. From this weight of gas product was calculated.

Weight of the gas product = weight of the sawdust sample – (weight of the produced char + weight of the produced pyro-oil)

3.2 Moisture content

The moisture percentage was calculated by using the equation given below:

$$Moisture\ Content\ (\%) = \frac{a-b}{a} \times 10(1)$$

Where, a = Initial mass of sawdust = 1000g

b = mass of sawdust after drying =754g

3.3 Calorific value

By using bomb calorimeter higher calorific value of produced pyro-oil was determined.

$$\text{Higher Calorific value} = \frac{W\Delta T}{m} (2)$$

$$= \frac{3320.83 \times 0.74}{0.96} \text{ cal/g}$$

= 10751.18 J/g

Where, energy equivalent of calorimeter (considering error), determined under standardization, W= 3320.83 cal/°C. Temperature rise, ΔT = 0.74°C. Weight of the pyro-oil, m = 0.96 gm.

3.4 Flashpoint and Fire Point

The flashpoint of pyro-oil is 64°C.

The fire point of pyro- oil is 68°C

3.5 Viscosity

From viscometer it is found that the dynamic viscosity of the pyro-oil,

μ = 18.5 Cp

$= 18.5 \times 10^{-3}$ Ns/m²

Density:

Mass of beaker = 99.55gm

Mass of beaker with 70ml pyro-oil = 164.14gm

∴ Mass of 70ml of pyro-oil = 64.59gm

$= 64.59 \times 10^{-3}$kg

1000 ml = 1liter

∴70 ml = 0.07 liter

Again, 1000 liter = 1 m³

∴ 0.07 liter $= 0.07 \times 10^{-3}$

∴ Density, $\rho = (64.59 \times 10^{-3}) / (0.07 \times 10^{-3})$ Kg/m³

= 922.71 Kg/m³

The kinematic viscosity of the pyro-oil, $\nu = \mu/\rho$

= 0.00002 m²/s

4 RESULTS AND DISCUSSION

4.1 Calorific value

The energy contained in a fuel or food, determined by measuring the heat produced by the complete combustion of a specified quantity of it. The amount of energy available from an item of food when digested, mostly from carbohydrates and fats. That depends on the state of water in the product of combustion it’s refers to higher heating value (HHV) when liquid water exists in the combustion products and lower heating value (LHV) when water vapor exists in the combustion products. From the Fig. 6, it can be seen that the calorific value of sawdust is higher than the rice husk whereas the value is lower than the coconut shell and rice straw.

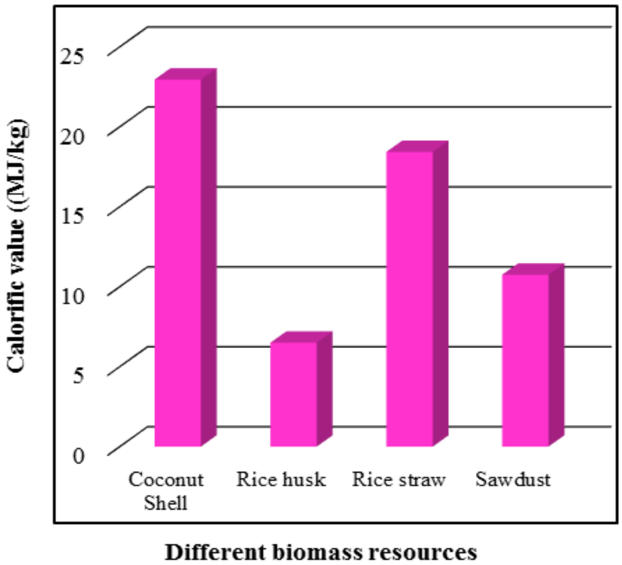

Fig. 6 Comparison of calorific value for different biomass resources

4.2 Density

Density of the biodiesel is comparatively less than other oil such as date seed oil, heavy fuel oil and saw dust etc.

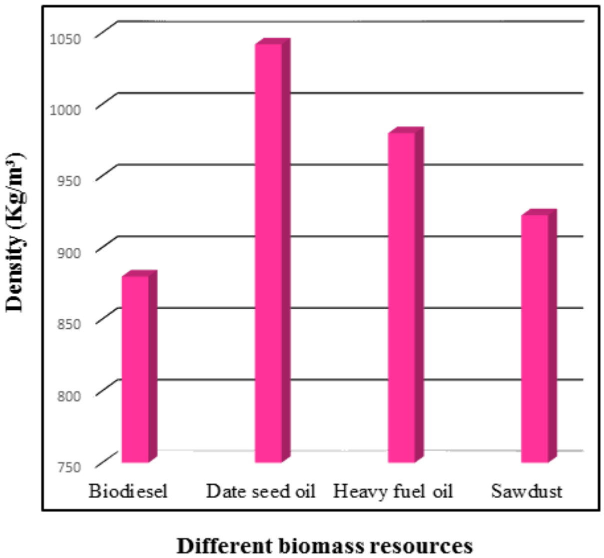

Fig. 7 Comparison of density for different biomass resources

4.3 Viscosity

From Fig. 8, it can be noted that the viscosity of sawdust is significantly lower than the heavy fuel oil but bit higher than the biodiesel and date seed oil.

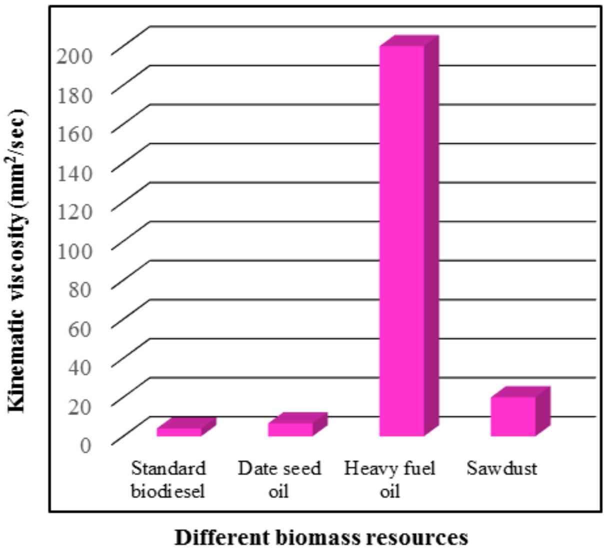

Fig. 8 Comparison of kinematic viscosity for different biomass resources

4.4 Flashpoint

Flash point, the lowest temperature at which a liquid (usually a petroleum product) will form a vapor in the air near its surface that will "flash," or briefly ignite, on exposure to an open flame.From the graph the flashpoint of the produced sawdust bio-oil is 64°C which is comparatively low. So, it causes danger as low flashpoint is hazardous. The fire point of a fuel is thelowest temperature at which the vapor of that fuel will continue to burn for at least 5 seconds after ignition by an open flame. From graph it indicates that the fire point of the bio-oil is 64°C because at this temperature point the vapor continue to burn at least five seconds.

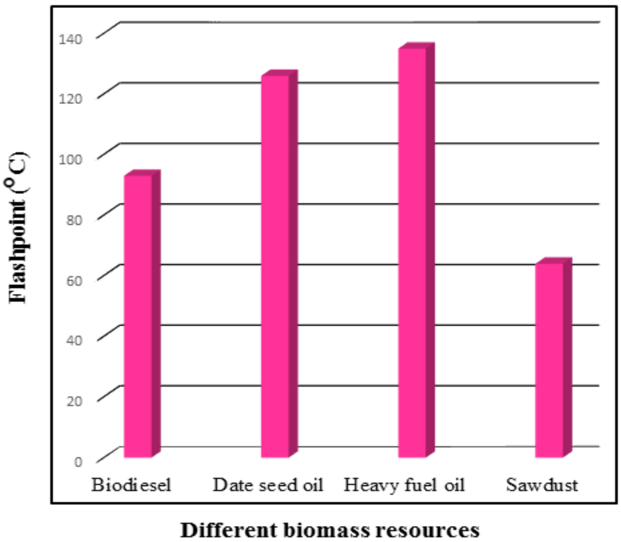

Fig. 9 Comparison of flashpoint for different biomass resources

At the flash point, a lower temperature, a substance will ignite briefly, but vapor might not be produced at a rate to sustain the fire. It can be illustrated from Figure 5.4, the flashpoint is lower in comparison to other biomass resources, such as biodiesel, date seed oil and heavy fuel oil etc.

4.5 Proximate and ultimate analysis

An analysis which reports volatile matter, fixed carbon, moisture content, and ash present in a fuel as a percentage of dry fuel weight. Not precise, but very useful for determining the commercial value. The proximate and ultimate analysis of different feedstocks with sawdust are shown in Tables 1 and 2, respectively.

Table 1 Proximate analysis of different feedstocks [1, 10]

Proximate Analysis (wt. %)	Coconut shell (%)	Pine Chips (%)	Wood (%)	Shredded Green Waste (%)	Sawdust (%)
Volatile matter	85.36	16	82	77.6	10
Air dried moisture	11.26	4.4	20	6.1	-
Ash	3.38	13.8	0.4	1.0	83
Oil	-	-	-	-	7
Fixed carbon	-	65.80	17	15.3	-

Table 2 Ultimate analysis of different feedstocks[1, 10, 9]

Ultimate Analysis	Coconut Shell (wt. %)	Rice Husk (wt. %)	Sawdust (wt. %)	Wood Pellet (wt. %)
Carbon	63.45	40.64	46.2	45.5
Hydrogen	6.73	5.09	6.6	6.6
Nitrogen	0.43	0.63	3.4	0.1
Oxygen	28.27	53.64	43.8	47.7
HHV(MJ/Kg)	22.83	17.02	12	18.6

5 Conclusion

This study represents an experimental investigation to produce bio-oil using pyrolysis (infrared induction cooking) process from sawdust. The produced bio-oil from sawdust has good properties in comparedto other feedstocks.Sawdust could be a prospective feedstock for bio-oil production as it is very cheap and available in sawmills in our country.The product yield of 7% bio-oil, 83% charcoal and 10% gas were obtained during infrared induction cooking pyrolysis process at a particular moisture content.The maximum bio-oil was obtained at a heat input of 800W during pyrolysis process.The calorific value, density, viscosity, flashpoint and fire point of 10.75 MJ/kg, 922.71 kg/m^3, 20 mm^2/sec, 64°C and 68°C are obtained, respectively, when the produced bio-oil was tested.

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