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Design, Fabrication and Performance Study of a Biomass Solid Waste Pyrolysis System for Alternative Liquid Fuel Production

Md. Akram Hossain^a, Md. Raquibul Hasan^σ & Md. Rofiqul Islam^p

Abstract- Now-a-days production of Bio-fuel is a prime concern in the world due to decrease other fuel source. The conversion of devdaru seeds into pyrolytic oil by fixed bed reactor has been taken into consideration in this study. A fixed bed pyrolysis system has been designed and fabricated for obtaining liquid fuel from biomass solid wastes. The major components of the system are: fixed bed reactor, liquid condenser and liquid collectors. The devdaru seeds in particle form is pyrolyzed in an externally heated 7.6 cm diameter and 46 cm high fixed bed reactor with nitrogen as the carrier gas. The reactor is heated by means of a cylindrical biomass source heater. Rice husk, cow dung and charcoal are used as the energy source. The products are oil, char and gas. The parameters varied are reactor bed temperature, running time and feed particle size. The parameters are found to influence the product yields significantly. The maximum liquid yield is 51 wt% at 5000C for a feed size of <1.18 mm at a gas flow rate of 5 liter/min with a running time of 90 minute. The pyrolysis oil obtained at these optimum process conditions are analyzed for some of their properties as an alternative fuel. We get the higher heating value of devdaru seeds oil is 24.22 MJ/kg. The heating value of the oil is moderate.

Keywords: biomass, *polyalthia longifolia* seeds, pyrolysis, fixed bed reactor.

I. INTRODUCTION

Biomass has been recognized as a major renewable energy source to supplement declining fossil fuel sources of energy. It is the most popular form of renewable energy and currently biofuel production is becoming very much promising. Transformation of energy into useful and sustainable forms that can fulfill and suit the needs and a requirement of human beings in the best possible way is the common concern of the scientists, engineers and technologists. From the view point of energy transformation, fixed bed pyrolysis is more attractive among various thermo chemical conversion processes because of its simplicity and higher conversion capability of biomass and its solid wastes into liquid product. In South Asian developing countries, especially in Bangladesh the generation of biomass waste is quite high. Along with other residues these waste accumulated is creating disposal problems. Also direct burning of these wastes creates a serious environmental

problem. As carbonaceous solid wastes are the source of energy, therefore, the potential of recovering these wastes into useful form of energy by pyrolysis into liquid fuel should be considered. In this way the waste would be more readily useable and environmentally acceptable. This liquid of high heating value can easily be transported, can be burnt directly in the thermal power plant; can easily be injected into the flow of conventional petroleum refinery, can be burnt in a gas turbine or upgraded to obtain light hydrocarbon transport fuel. The solid char can be used for making activated carbon. The gas has high calorific value, sufficient to be used for the total energy requirements of the pyrolysis plant.

a) Thermochemical Conversion Process

Due to high calorific value and ultimate analysis of plant based agro wastes it implies that these agro wastes are potentially useful for energy utilization in the form of combustible gas, tar oil (liquid fuel), char (solid fuel), steam or electricity when they are processed by using thermo chemical technologies for biomass conversion. There are four main thermo chemical methods of converting biomass. Such as (1) pyrolysis (2) liquefaction (3) gasification (4) direct combustion. Pyrolysis is one of the most important thermo-chemical conversion processes.

b) Pyrolysis

Pyrolysis is a thermal decomposition process that occurs at moderate temperature with a high heat transfer rate to the biomass particles and a short hot vapor residence time in the reaction zone. Several reactor configurations have been shown to assure this condition and to achieve yields of liquid products as high as 75% based on the starting dry biomass weight [16]. Pyrolysis of biomass produces a liquid product, pyrolysis oil or bio-oil that can be readily stored and transported. Pyrolysis oil is a renewable liquid fuel and can also be used for production of chemicals. Pyrolysis has now achieved a commercial success for production of chemicals and is being actively developed for producing liquid fuels. Pyrolysis oil has been successfully tested in engine, turbines and boilers, and been upgraded to high quality hydrocarbon fuels although at a presently unacceptable energetic and financial cost.

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c) *Direct Combustion*

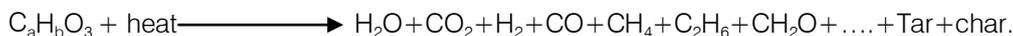
Direct combustion of biomass solid waste produces heat energy by direct burning of them. The products and applications of various biomass solid waste converting method are mentioned in Table 1.1

d) *Solid Particle Pyrolysis*

Pyrolysis is the heating of any fuel particle, droplet or gaseous molecule in the absence of oxygen and for solids it can be presented by the following equation:

Table 1.1 : Thermal conversion technologies, products and applications [4]

Technology	Primary product	Example application
Combustion	Heat	Heating
Gasification	Gas	Fuel gas
	Gas	Fuel gas
Pyrolysis generally	Liquid	Liquid fuel & chemical
	Char	Solid fuel/ fuel slurry
Very slow pyrolysis	Solid charcoal	Solid fuel
	Liquid	Liquid fuel
Fast pyrolysis (low temperature)	Gas	Gaseous fuel and chemical
Fast pyrolysis (high temperature)		



There are three classes of products of pyrolysis; they are volatiles, tar and char. The volatiles may or may not be condensable at ambient condition; however, in all practical combustion systems these component remains in the gas phase. The tar is generally a heavy hydrocarbon substance with an atomic H/C ratio > 1.0[15]. The char generally is a carbon rich solid with only minor fractions of hydrogen and heteroatom present in the fuel or waste. Although there are exothermic regions associated with some pyrolysis reaction, the overall solid particle pyrolysis is endothermic. This equation presents a summary of pyrolysis; however, it makes fundamental chemical process involved. Pyrolysis involves both chemical and physical changes. The physical changes include the potential for particle shrinkage. Further, pyrolysis changes the thermodynamic and transport properties of the fuel particles resulting in a material which is more isolative.

The project work is carried out with the following objectives:

- To simplify the design a fixed bed pyrolysis system,
- To fabricate the pyrolysis system,
- To produce liquid from biomass solid waste (Devdaru seeds) by pyrolysis process,
- To analyze the liquid product obtained from the pyrolysis system.

The scope of the work is as follows:

- Only Devdaru seeds are considered as feed materials for their availability at cheap price.
- The emphasis of the study is on the production of liquid. The char product is also quantified. The gas is flared to atmosphere.

a) *Selected Biomass Waste*

Devdaru seeds were selected as the feed material for this study. **Polythia Longifolia** (Devdaru) in the genus Switenia, is extensively cultivated in India, Sri Lanka, Bangladesh etc as avenue tree. It is a semi evergreen tree, about 30-35m tall. Fruit shape is oval, fruit length is 1 to 3 inches, fruit covering dry or hard, the fruit color is brown. In Bangladesh, a large amount (250000 tons/yr) of devdaru seeds are not utilized but the production of oil from it may provide the use of a

II. OBJECTIVES AND SCOPE OF THE PROJECT

The aim of the project is to design and fabricate an externally heated fixed bed pyrolysis system for the production of alternative liquid fuel from devdaru seeds.

renewable resource along with adding value to agricultural products.

Adapted from a number of literature an indicative picture of the chemical composition of the devdaru seed has been collated in the Table 1.2:

Table 1.2 : Approximate composition of devdaru seeds [16]

Moisture	5%
Crude Protein	31.6%
Oil	10-12%
Soluble sugar	5.15%
Fat	44.9%
Ash	4.5%



Figure 2.1 : Photograph of devdaru seeds

III. THEORY AND PRINCIPLES

a) Pyrolysis

Pyrolysis is the process of thermal decomposition to produce gases, liquids (tar), and char (solid residue). These pyrolysis products can be used as fuels, with or without prior upgrading, or they can be utilized as feed stocks for chemical or material industries. The types of materials which are candidates for pyrolysis processing include coal, plant biomass, animal and human waste, food scraps, paper, cardboard, plastics, and rubber. AFR has developed novel pyrolysis experiments (Series 101 TG/Plus Analyzer) and modeling techniques (FG-DVC Modeling Software). Pyrolysis is generally described as the thermal decomposition of the organic components in biomass wastes in the absence of oxygen at mediate temperature (about 500° C) to yield tar (bio oil, bio fuel,

bio crude), char (charcoal) and gaseous fractions (fuel gases)[18]. For convenience, there are two approaches to the conversion technology. The first approach referred to as conventional or traditional pyrolysis, is to maximize the yields of fuel gas at the preferred conditions of high temperature, low heating rate and long gas residence time or to enhance the char production at the low temperature and low heating rate. Another approach referred to as flash or fast pyrolysis is to maximize the yields of liquid product at the processing conditions of low temperature, high heating rate and short gas residence time. The heating approaches are as follows

Type 1: Part of the raw material burns inside the reactor to provide heat needed to carbonize the remainder.

Type 2: Direct heat transfer from hot gases produced by combustion of one or more of the pyrolysis products or any other fuel outside the reactor.

Type 3: Direct heat transfer from inert hot material (hot gases or sand introduced into the reactor).

Type 4: Indirect heat transfer through the reactor walls (i.e. external heat source due to combustion of one of or more pyrolysis products or any other fuel)

Due to the poor thermal stability and corrosivity in the use of the bio crude, the liquid products still need to be upgraded by lowering the oxygen content and removing residues by means of hydrogenation and catalytic cracking. Eventually the purified bio oil can be used as fuel in boilers, engines, turbines or processed into refineries as a feed stock is also being considered.

b) Pyrolysis Conversion

Among the various thermal conversion processes, pyrolysis has received much more attention, since the process conditions could be optimized to produce high energy density pyrolysis oils and chemicals in addition to derived char and gaseous products [4]. Research have been carried out on different stages of the process, from the pretreatment of the feed stock, the pyrolysis conversion process and technology, the utilization and the upgrading of the products and to the techno-economic assessment of the whole process. Different types of pyrolysis process have been studied and developed either in laboratory-scale or a pilot plant units and a small number of commercial-scale pyrolysis plants are installed. The results of this research have proved the feasibility of this technology and strongly suggested that pyrolysis is the most promising technology for solid waste treatment. Pyrolysis conversion of other organic solid wastes to liquid hydrocarbon have also been studied and reported extensively. Pyrolysis of municipal waste has been studied much earlier where initially the emphasis was on the waste disposal but gradually attention was shifted towards the liquid hydrocarbon recovery from the

process, as reported by Pober and Bauer (1977)[13]. Pyrolysis of sewage sludge to liquid hydrocarbon was also reported in literature and among the recent studies was demonstrated by Bellman et al. (1989) and Boocock et al. (1993)[2].

A possible reaction pathway of pyrolysis process is shown below:

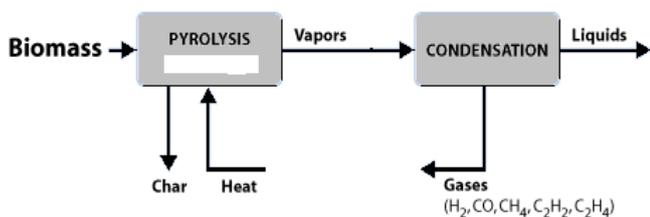


Figure 1.3 : A possible reaction pathway of pyrolysis of organic solid waste

c) Fixed Bed Pyrolysis

Pyrolysis may be either fixed bed pyrolysis or fluidized bed pyrolysis. In fixed bed pyrolysis, a fixed bed pyrolyser is used. The feed material in the reactor is fixed and heated at high temperature. As the feed is fixed in the reaction bed (reactor), it is called fixed bed pyrolysis. In this process, the feed material is fed into the reactor and heat is applied externally. Liquid petroleum or other inert gas is used for making inert condition and for helping the gaseous mixture to dispose of the reactor. The losses in fixed bed pyrolysis are relatively less than fluidized bed pyrolysis. Moreover, fluidized bed pyrolysis is more complex. This project work is based on fixed bed pyrolysis.

IV. DESIGN AND FABRICATION OF THE PYROLYSIS SYSTEM

The design and fabrication of the fixed bed pyrolyser is the major part of this project work and maximum time has been spent to design, construct and assemble the experimental setup. The main parts of the system are fixed bed reactor and condenser. The pyrolysis system has been designed based on the following considerations:

- Short vapor residence time in the reactor.
- Rapid condensation of the vapor product to promote high yield of pyrolysis liquid product.
- Reliable heat supply for heating the system.
- Rapid heat transfers into the reactor so that less heating material is required
- Adequate gas flow rate to dispose off the vapor mixture.
- Proper mass flow rate of vapor and water for proper condensation.

- Size of the system is such that sufficient amount of pyrolysis liquid can be produced.

a) Simplification of the design

For simplifying the fixed bed pyrolysis system the following factors may be considered:

- To eliminate leakage problem liquid gasket may be used.
- Passing of the Nitrogen gas through a heated pipe situated in the biomass heater may save fuel for preheating.
- Using ice instead of huge amount of water may be a better substitution for condensation.

b) Description of work

Due to corrosive nature of pyrolysis liquid, especially derived from biomass and high operating temperature of the process (400°C to 550°C), stainless steel of grade ASTM A 240 and AISI 340 has been selected as the material for the major component of the system. Oxy-acetylene gas welding has been used for joining the parts of each component using brass as filler metal in the fabrication of the rig. Lathe machine has been used for cutting the stainless steel pipes and sheets . Drilling operation has been done by the drill machine for drilling various sizes of holes in the steel pipes and flanges. Gas welding has been used for various joints in the setup. Oxygen and acetylene gas has been used here for welding. Grinding machine has been used for smooth surface finishing of the flanges.

c) Fixed Bed Reactor

The selection of the size of the fixed bed reactor depends primarily on the fixed bed. The gas flow rate and the volume of the reactor determine the apparent vapor residence time in the reactor and this vapor residence time is an important parameter in fast pyrolysis process for maximizing liquid product. For fast pyrolysis the residence time should not exceed 5 sec. For the ease of fabrication, a cylindrical reactor has been considered for the system using stainless steel pipe.

i. Design of Reactor

Let, Apparent vapor residence time, $t = 4$ sec

Diameter of reactor, $d = 7.6$ cm (Commercially available)

Reactor area, $A = \pi d^2/4 = 45.56$ cm²

Gas flow rate, $Q = 12.5$ lit/min
 $= (12.5 \times 1000 \text{ cc})/60 \text{ sec}$
 $= 208 \text{ cm}^3/\text{sec}$

Effective volume for gas flow $= Q \times T = 208 \times 4 = 833 \text{ cm}^3$

However it is about 40% of the total reactor volume.

As about 60% of the volume of the reactor is occupied by the feed, the total volume of the reactor, $V = 833 + 1.5 \times 833 = 2082.5 \text{ cm}^3$

$$\begin{aligned} \text{Length of the reactor, } L &= V/A \\ &= 2082.5/45.35 \\ &= 45.96 \text{ cm} \\ &= 46 \text{ cm} \end{aligned}$$

Thus the reactor length, $L = 46 \text{ cm}$

ii. *Design of Condenser*

A rapid quenching of pyrolysis vapor products promotes high liquid yield. The pyrolysis condensate, especially biomass derived liquid contains tarry substance, which rapidly forms and deposits in the condenser and pipelines. We have constructed a condenser which is made by copper pipe. The copper pipe is wound like a spring and placed within a plastic bottle. It is joint with the reactor by a joint connector nut.

Length of copper pipe = 14 ft
Diameter of copper pipe = 0.25 in

V. NECESSARY APPARATUS AND EQUIPMENT

a) *Pyrometer*

A pyrometer is used for taking the temperature reading. Temperature is measured between 400°C-600°C. The maximum temperature range of the thermometer was 1000°C.

b) *Biomass Heater*

The biomass heater system is used to heat the reactor externally. A body of cylindrical shape biomass heater is used to heat the reactor at desired temperature.

c) *Electric Blower*

The necessary oxygen required to burn the heating fuel in the biomass heater is supplied through an electric blower.

d) *N₂ gas flow meter*

This flow meter measures the flow of gas in liter per minute. Maximum rating of this flow meter is 40 liter per minute.

e) *N₂ gas cylinder*

A N₂ gas cylinder is used to supply N₂ gas.

VI. ARGUMENT OF MATERIAL SELECTION

With the anticipation of corrosive nature of pyrolysis liquid, especially liquid derived from organic solid and high operating temperature of the process, problems of corrosion has been envisaged. The material of various parts (reactor and their joining pipes) is stainless steel for its less corrosiveness and higher metallurgical limit. In condenser, copper pipe is used for its better work as a condensing device. As it is widely used is refrigerator for its good condensing quality. Plastic bottle is used to hold the copper pipe. Wolf bottle is used as liquid collector.

VII. ASSEMBLY OF THE RIG

The rig is assembled on a frame structure made of mild steel angle bar. The rig is mounted by making rack in frame, so that the position of the rig is fixed. They are joined with each other or with reactor and condenser by locking screw with flange. Liquid gasket is used to seal various joints. The biomass heater is set in a rack of frame, which supplied heat uniformly to the reactor externally. The assembly is shown in Figure 4.6. At the bottom of the reactor is connected a gas (inert) cylinder and there is a condenser also for cooling vapors. The schematic diagram and photograph of the setup is shown in Figure 1.4 and 1.5.

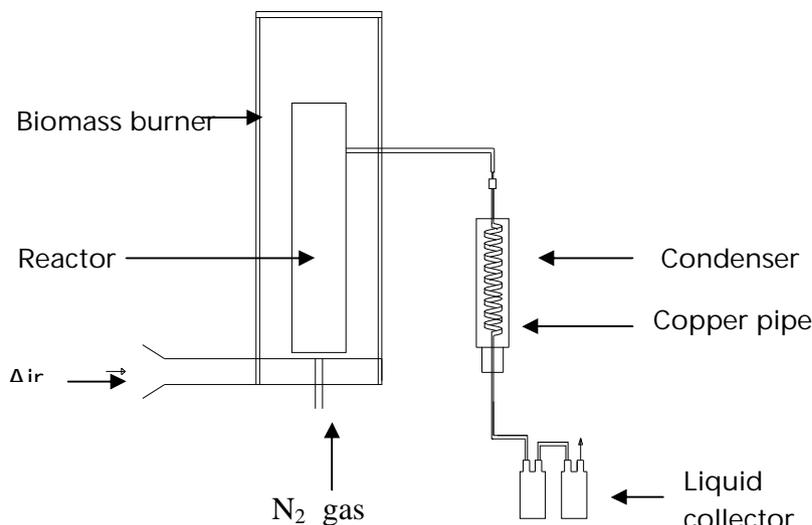


Figure 1.4 : Schematic Diagram of Fixed Bed Pyrolysis System



Figure 1.5 : Photograph of the pyrolysis system

a) Feed Preparation

The devdaru seed is collected and dried. It is then crushed into smaller sizes. These are <1.18mm, 1.18mm, 2.36mm, and 4.75mm in dia. It is dried with the help of oven. Thus the feed material is prepared.

b) Process Flow Chart

The flow path of the fixed bed pyrolysis of devdaru seed is given in Figure 1.6. The prepared feed material is taken into the reactor and heated. The gaseous vapor is passed through the condenser to separate the products into liquid and gas.

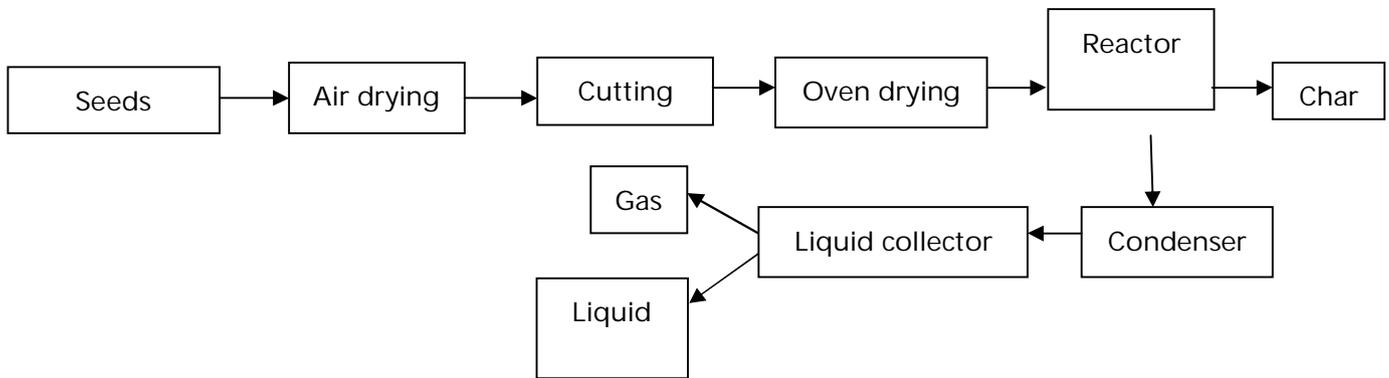


Figure 1.6 : Process flow chart for fixed bed biomass pyrolysis

VIII. EXPERIMENTAL PROCEDURE

At first, Feed material was weighed and filled into the reactor. The experimental set-up was assembled. High temperature adjustable gaskets were used to seal the joints and fittings of the hot parts of the connecting pipe, reactor and condenser. Ice was placed into the condenser. The reactor was heated externally by a biomass heater at different temperatures and these temperatures were measured by pyrometer. The N₂ gas was passed through reactor through a heated pipe and this flow was controlled by the use of a gas flow meter valve. The operation time was recorded by means of a stopwatch. When the operation was completed a small flow of N₂ gas was allowed to pass Seeds Air drying through the system to prevent back flow of air which might react with hot gases when the reactor was still hot. It is dismantle when the rig was cooled enough to be

handled. The char was collected from the reactor bed and weighed. All data are recorded in tabular form. All the parts of the system were cleaned and the heating value of the liquid and char was measured by a bomb calorimeter before reassembling for the next run.

a) Gas flow rate

Nitrogen gas is metered from gas cylinder. A multi-stage nitrogen gas pressure regulator of model MUREX N-10 is used to regulate the pressure of the gas from the cylinder. During the study, the outlet gage reading is set at atmospheric pressure. The gas entered at the bottom of the reactor through the heated pipe. Nitrogen gas is used in the study for its inertness and ease of availability and cheapness in cost. A nitrogen gas flow-meter of model MUREX 0011 with a variable control valve of capacity 0-40 liter/min is used to control

and measure the gas flow rate. The flow rate is varied between 4-12 liter/min.

b) *Temperature Measurement*

The reactor temperature of the rig is measured by a pyrometer. Its capacity for measuring temperature range is 0°C to 1000°C. The pyrometer is inserted into the reactor from the side to the almost bottom of the reactor where the pyrolysis conversion has taken place.

IX. STUDY OF PHYSICAL PROPERTIES OF PYROLYSIS OIL

a) *Higher Heating Value*

The higher heating value is a measure of the quantity of the heat released in the total combustion and therefore the energy content of a fuel. It is the most important fuel properties of any liquid fuel. The higher heating value of the derived oil is determined by using Parr adiabatic bomb calorimeter according to the test method of DIN 51 900. The test is conducted in the Heat Engine Laboratory of the Department of Mechanical Engineering of Rajshahi University of Engineering and Technology.

By using a Bomb calorimeter

$$H.C.V. = (TW - E_1 - E_2 - E_3) / M \text{ in the unit of MJ/kg}$$

Where, M = Weight of the liquid fuel = 1 gm

W = 2426 cal/gm k water equivalent

T = Temperature difference

E₁ = Correction in calories for heat of formation of nitric acid (HNO₃)= 23.9 Cal

E₂ = Correction in calories for heat of formation of sulfuric acid (H₂SO₄)= 13.9 Cal

E₃ = Correction in calories for heat of combustion of fuse-wire= 17.5 Cal

b) *Density*

The density of oil is a measure of aromatics in hydrocarbon oils, but not in biomass derived oils. It is a necessary parameter used to calculate the volumetric output of pumps and injectors needed to supply a given rate of delivered energy, because the heat of combustion is determined on a weight basis. Mass density means mass per volume.

c) *Kinematic Viscosity*

Kinematic viscosity is a measure of the resistance to gravity flow of a fluid. Viscosity of oil is an important property, since it affects for example the flow of the liquid through pipelines. The lower the viscosity of the liquid, the easier it is to pump and to atomize and achieve finer droplets. This is the major criterion upon which the oils are graded. The kinematic viscosity of the

pyrolysis liquids was determined using Glass Capillary Kinematic Viscometer, according to ASTM D445- IP 71- BS 2000 Part 71 test methods. This test was carried out at the Laboratory of the Department of Chemistry. By using a glass capillary kinematic viscometer

$$\text{Viscosity, } \mu = [(t^* \rho) / (t_o^* \rho_o)] * \mu_o$$

At 35°C, for water

t_o = 90 sec

ρ_o = 994.1 kg/m³

μ_o = 0.723 Pa.s

d) *Flash Point*

This measure the liquid temperature necessary for the vapors above a pool of the fuel to ignite by passing flame through the vapor. This is a measure of volatility of the oil as oil as its ease of ignition. The higher value is the safer the oil is to handle because the risk of accidental vapor ignition is reduced. Pyrolysis oil has a reported flash point of between 30°C and over 100°C, reflecting a wide variation in the content of volatiles. However, above temperature of 70°C to 75°C, water vapor from the pyrolysis oils start to disturb the analysis and a reproducible value is difficult to obtain. The flash point of the liquid was determined using Cleveland open cup tester, according to ASTM D 92-IP36 test methods.

e) *Fire Point*

Fire point is the temperature at which the oil, if once lit with flame, will burn steadily at least for 5 seconds. The fire point of the liquid was determined using Cleveland open cup tester, according to ASTM D 92-IP36 test method.

X. RESULTS AND DISCUSSION

a) *Experimental run*

A total of 12 experimental run has been taken in this study. Four sizes of devdaru seeds are used here. The sizes are <1.18 mm, 1.18 mm and 2.36 mm and 4.75mm. The experimental results of the run at different conditions with their effects are presented here.

i. *Effect of feed particle size*

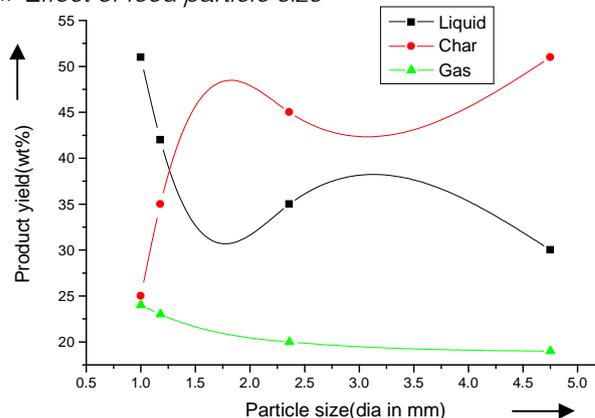


Figure 1.7 : Effect of feed particle size on product yield (<1.18 mm, 1.18 mm, 2.36 mm and 4.75mm) for reactor temperature 450~550°C

Figure 1.7 represents the percentage weight of liquid and solid char products for different particle size of feed at a bed temperature of 500°C and an operating time of 90 minutes. It is observed that at 500°C the percentage of liquid collection is a maximum of 51% of total biomass feed for particle size of <1.18 mm. A less amount of liquid is obtained from the larger particle size feed. This may be due to the fact that the larger size particles are not sufficiently heated up so rapidly causing incomplete pyrolysis that reduced liquid product yield.

ii. Effect of reaction temperature

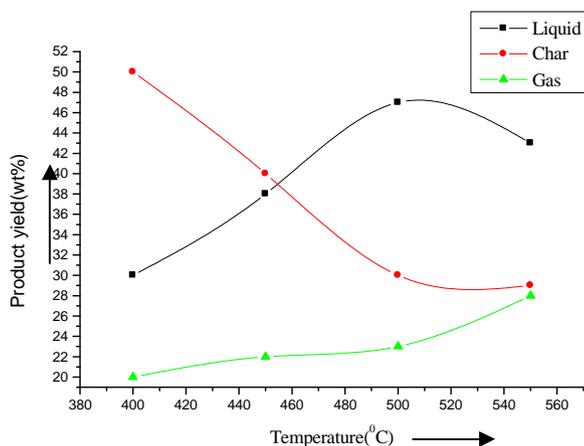


Figure 1.8: The effect of operating temperature on product yield

Figure 1.8 shows the variation of percentage weight of liquid, char and gaseous products at different bed temperature with particle size of < 1.18mm. From this it is found that the maximum liquid products yield is obtained at a temperature of 500°C, and this is 47%wt of total biomass feed. At lower temperature the liquid product yield is decreasing while with the increase of temperature above 500°C, the liquid product yield is again deteriorating. With the increase of temperature the solid char yield is decreasing above 500°C and increasing below 500°C. It may be caused at lower temperature less than 500°C, complete reaction cannot be taken place.

iii. Effect of Running Time

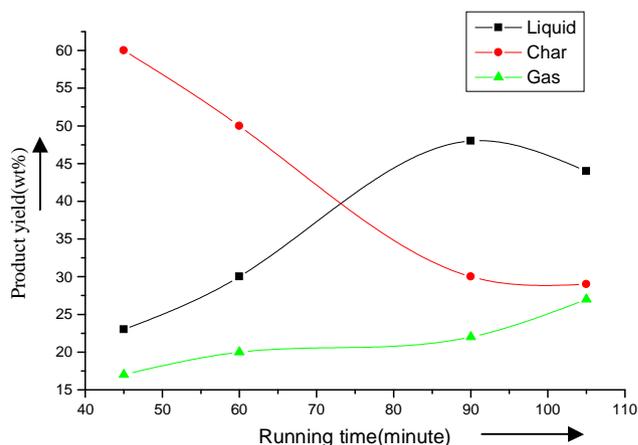


Figure 1.9: Effect of running time on product yield for reaction bed temperature 450~500°C and for feed particle size 1.18 mm

Figure 1.9 shows the variation of product yield (wt%) of liquid, solid char and gas products at a temperature of 500°C solid char product is 30wt% of < 1.18mm. The maximum liquid product is 48 wt% of biomass feed while the for feed particle of size of dry feed at 90 minutes. It is observed that lower and greater running time than of that of 90 minutes the liquid product yield is not optimum that may be due to insufficient pyrolysis reaction and higher rate of gas discharge respectively. Secondary cracking reaction taken place by which the amount of permanent gas product is increased. So at temperature higher than 5000C liquid product is decreased.

b) Physical Characteristics

The physical characteristics of the pyrolysis oil are shown in Table 1.3. The energy content of the oil is 24.22 MJ/kg. The oil is found to be heavier than water with a density of 1240 kg/m³ at 35°C. The flash point of the oil is 60°C and hence precautions are not required in handling and storage at normal atmosphere. The viscosity of the oil of 12.15 cSt at 35°C is a favorable feature in the handling and transportation of the liquid.

Table 1.3: Physical characteristics of devdaru seed oil

Analysis	Devdaru seed oil
Kinematic viscosity at 35 ⁰ C (cSt)	12.15
Density(kg/m ³)	1240
Flash Point(⁰ C)	60
Fire Point (⁰ C)	76
HHV of liquid(MJ/kg)	24.22
HHV of char(MJ/kg)	22.5
HHV of feed material(MJ/Kg)	20.7

Comparison of devdaru seed oil with petroleum products and biomass derived pyrolysis oil.

The comparison of physical characteristics of devdaru seed oil with other biomass derived pyrolysis oil and petroleum products is shown in Tables 1.4 & 1.5

Table 1.4 : Comparison of devdaru seed pyrolysis oil with biomass derived pyrolysis oil

Analysis	Devdaru Seed oil	Date Seed oil [12]	Waste paper oil [8]	Sugarcane bagasse oil [10]	Jute stick oil [9]
Kinematic viscosity at 35°C (cSt)	12.15	6.63	2.00	89.34	12.8
Density (kg/m ³)	1240	1042.4	1205	1198	1224
Flash Point (°C)	60	126	200	105	>70
HHV(MJ/kg)	24.22	28.636	13.10	20.072	21.091

Table 1.5 : Physical characteristics of the Devdaru seeds pyrolysis oil and its comparison

Analysis	Devdaru Seed oil	Fast Diesel [6]	Diesel [1]	Heavy Fuel Oil [14]	Wood Waste [1]
Kinematic viscosity at 35°C (cSt)	12.15	1.3-3.3 [#]	2.61 [*]	200 [#]	66.99
Density (kg/m ³)	1240	780	827.1 [*]	980 [*]	1180.2
Flash Point (°C)	60	75	53	90-180	59
HHV(MJ/kg)	24.22	45-46	45.18	42-43	19.80

[#]at 500C ^{*}at 200C

From the comparison it is shown that the viscosity of devdaru seed oil is favorable than other pyrolysis oils. It has HHV of 24.22 MJ/kg.

XI. CONCLUSION

The objectives of the study are fulfilled by using the biomass waste in the form of devdaru seeds with fixed bed pyrolysis system made of stainless steel pipes and sheets. The fixed bed pyrolysis of solid devdaru seed has a maximum oil yield of 51wt% of biomass feed particle size of <1.18mm at a reactor bed temperature

of 500°C and a gas flow of 5 liter/ minute with the running time of 90 minute. With increasing reactor bed temperature, percentage weight of char production is decreasing and the gas production is increasing. The physical properties analysis showed that the oil is heavy in nature with moderate viscosity. The oil possessed favorable flash point. The heating value of the oil is moderate.

XII. RECOMMENDATION

The liquid yield of devdaru seed from the fixed bed reactor is quite satisfactory. However, the performance of the system could be improved further, to produce more reliable and better results. The following recommendations are suggested for such improvement.

- a) The process bed temperature would be easier to control at uniform value if the system could be well insulated and supplied uniform rate of air by the blower.
- b) If only copper pipe is used for condenser, more liquid yield will be condensed.
- c) The char products from pyrolysis of devdaru seed is reasonably high. The high char yield has a potential values a solid fuel or as activated carbon or further characterization of the char are suggested. The energy content of the char could be utilized. The gaseous product may be taken into consideration.
- d) The consumption of expensive inert gas (nitrogen) was high. The gas product could be recycled as fluidizing gas. However, the effect of the use of recycling gas on the pyrolysis product yield and characteristics should be studied first.
- e) The external heating system (heater) should be insulated to reduce heat loss.
- f) The properties of different products of this research work can be found for comparison with other conventional fuels for alternative use.
- g) Finally after implementing product-upgrading process, the fuel may be tested in an internal combustion engine.

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