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Design & Construction of a Pyrolysis Reactor for Liquid Oil Production from Olive Seeds

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Abstract

Pyrolysis is one of the most important thermo chemical energy conversion methods for renewable energy sources. 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.Different types of pyrolysis process have been studied and developed either in laboratory- scale or a pilot plant units and a small number on 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. In this project the stainless steel will be selected for the construction of pyrolysis system and the olive seeds will be selected as feed material. Nitrogen gas will be used to maintain the inert atmosphere in the reactor where the pyrolysis reaction will take place.

Keywords: *Pyrolysis,Reactor, Condenser, Olive Seeds*

1. Introduction

Energy is the basic ingredient of the process of economic development and driving force the global economy. Now a day the standard of living of human being is correlated with per capita energy consumption. The more the energy is consumed, the higher the standard of living is considered. Conventional sources are being depleted at an alarming rate, world will be stopped when the supply of fuel energy is ended. Mainly a few countries like Middle-East countries supply the demand of mineral oils to whole world. The new emerging technology of pyrolysis for liquid fuel is a demand of time.

2. Pyrolysis principle

The pyrolysis of carbonaceous materials refers to incomplete thermal degradation resulting in char, condensable liquid or tar, and gaseous products. In its strictest definition, pyrolysis is carried out in the absence of air [1]. However, pyrolysis differs from gasification in that the products of interest are the char and a liquid, which is a result of incomplete nature of the process, retain much of the structure, complexity, and signature of the raw material undergoing pyrolysis .The relative proportions of the pyrolysis products depend on both process parameters as well as the composition of the feedstock. It is widely accepted that the most important process parameters are the operating temperature, heating rate, feed particle size, residence time of volatile and char, and the presence of catalyst Schoeters et al [2]. The physical and chemical constituent of the feedstock such as volatile, moisture and ash content also affect the product yield.

3. Objectives

- To design and fabricate a pyrolysis system.
- To produce pyrolytic oil from olive seeds and determine the properties of the pyrolytic oil.

4. Fixed bed pyrolysis

Pyrolysis may be either fixed bed pyrolysis or fluidized bed pyrolysis. Fluidized bed pyrolysis is more complex than fix bed pyrolysis. This project work was based on fixed 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. Thus feed material is converted into gaseous mixture which is then condensed for liquid production. Liquid petroleum or other inert (nitrogen) gas is used for making inert condition and for helping the gaseous mixture to dispose of from the reactor. The losses in fixed bed pyrolysis are relatively less than fluidized bed.

Following characteristics were considered:

- High operating temperature and corrosion resistance
- High thermal conductivity and Nontoxic.

After the theoretical analysis, the materials for various parts (reactor) were selected cast iron for its lower price and higher thermal conductivity. The condenser material was selected sheet metal by which making a cylindrical part. The sheet metal is easily available and lower cost.

5. Design criterion

- ❖ The process utilizes a fixed bed reactor and nitrogen gas to maintain inert condition.
- ❖ Short vapor residence time in the reactor and rapid condensation of the vapor
- ❖ Product to promote high yield of pyrolytic liquid product.
- ❖ Reliable heat supplies for heating the system and adequate gas flow rate to dispose of the vapor mixture.
- ❖ Proper mass flow rates of vapor and water for proper condensation.
- ❖ Size of the system is such that sufficient amount of pyrolytic liquid can be produced.

6. Description of work

Various operations were performed in different shops and laboratories of the university. In machine shops facing, turning, centering and boring etc. Operations were carried for various part of the rig in lathe machine and drilling of various flange and tubes were completed of various sizes in drill machine. The various parts of the setup were finished by grinding machine. Various joints as soldering was done for preventing leakages of the condenser after shim joining the sheet and for making a flame to hold the experimental set-up, gas welding was performed.

7. Mathematical arguments for design

(a) For Reactor

For proper functioning of the reactor,
Internal dia. d = 2 in. = 5.08 cm (easily available in the market)
Vapor Residence Time, t = 4 Sec (< 5 sec.)
Gas Flow Rate in the Reactor, Q =1 m3/hr (<1-6 m3/hr)
Now, $Q = A*V$ (continuity equation) Or, $Q = A*L/t$ (velocity, $V= L/t$)
Or, $L = Q*t/A = (Q* t*4/\pi d^2) = 1 * 4 *4/ [3600*\pi*(0.0508)^2] = 55.88$ cm.

(b) For Condenser Dimensions

Assume for proper cooling of the vapor
Water flow rate = 6 lit/min = 0.1 kg/sec; [mass= density x volume]
Mass flow rate of the vapor = 0.130 lit/min = 0.0025 kg/sec; [assumption]

(On the basis of reactor dimension, temperature and feed quantity)
Specific heat of water, C_w= 4.2 kJ/kg-K
Specific heat of vapor, C_V = 2.2 kJ/kg-K
Water inlet temperature, t_{w1} = 25 °C [assumption]
Inlet temperature of vapor, t_{g1}= 450 °C [assumption]
Outlet temperature of vapor, t_{g2}= 40 °C [assumption]
Water outlet temperature, t_{w2} = ?
The rate of flow of heat, $Q = mgC_V(t_{g1} – t_{g2}) = mwC_w(t_{w2}- t_{w1})$
$Q =0.0025 *2.2* (450-40) = 0.1 * 4.2 * (t_{w2}-25)$
Q =3.08 kW & t_{w2} = 32 °C

The overall heat transfer between water and vapor, $Q = U_oATm$
Where, U_o = Over all heat transfer co-efficient = 320 W/m2-K
A = Minimum area of condenser tube
ΔT = Min log mean temp difference = $(T_1-T_2)/ \ln (T_1/T_2)] = (425-8)/In71.87=132$ °C
Where,T_1 is the inlet temperature difference and$T_2$is the outlet temperature difference.
Using equation, $3080 = 320*132*A$ or $0.072 = \pi d_cL_c$
If the diameter of the condenser tube, d_c= 2 inch = 5.08 cm (Commercially available)
Condenser tube length, L_c= 0.4572m= 45.72 cm.

9. Major parts of pyrolysis System

a) Reactor

The reactor is the main part of this pyrolysis system. The feed material and supply gas were held in the reactor. The reactor had been heated externally. Its dimensions were selected on the basis of various suitable arguments such as gas flow, gas residence time and cost etc. It is made of cast iron tube of 5.08 cm ID and 55.88 cm in length.

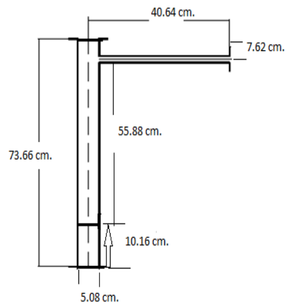

Fig.1. Sectional view of fixed bed reactor

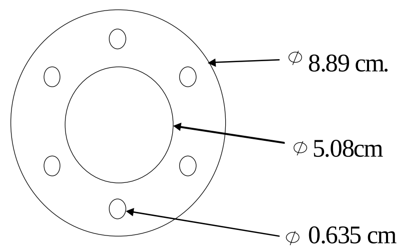

Fig.2. Sectional view of upper flange

b) Condenser

The condenser is another important part of the experimental rig. To cool down the vapor product for getting liquid and non-condensable gaseous yields, the vapor products from reactor were passed though water cooled counter flow condenser. Its dimensions were also chosen by various operating arguments.

c) Flow meter and liquid gasket

To measure the gas flow rate into the reactor, a flow meter was generally used at the top of the cylinder. But due to low gas pressure of liquid petroleum it was not possible to measure the gas flow by flow meter. The liquid gasket was used to make air tight between the flanges.

d) Pyrometer

Pyrometer was used for metallurgical temperature measurements and control. It performs satisfactory up to about 1000 °C.

e) Gas distributor

A simple nozzle-type gas distributor was adopted for proper distribution of gas into feed material. The gas distributor is shown in fig.4.

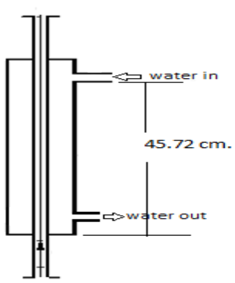

Fig. 3. Sectional view of condenser.

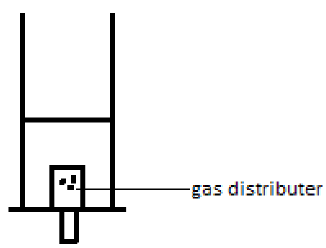

Fig.4. Gas distributor

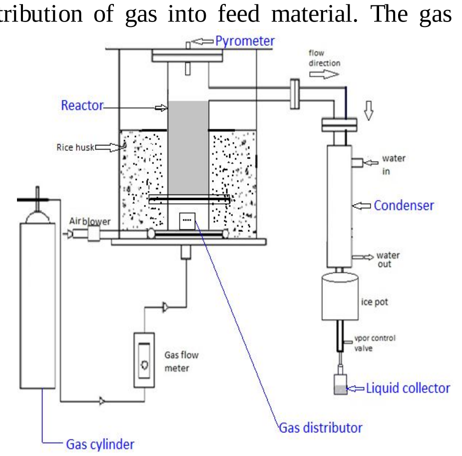

Fig.5.The schematic diagram of the fixed bed pyrolysis system

f) Assembly of the rig

The rig was assembled on a frame structure made of mild steel angle bar. The rig was mounted by making rack in frame, so that the position of the rig was fixed. They were joined with each other or with reactor and condenser by locking screws with flanges.

10. Experimental procedure

At first the feed material was dried in 110°C before taken into the reactor and weighted to find the net weight of feed material. After weighting all joints and parts are checked to start the experiment, the reactor was heated externally by a biomass heating source from 400-550^{0}c and this pressure was measured by thermometer. Nitrogen gas from cylinder was passed through the reactor at controlled rate. This high temperature with short residence time converts the feed stock into gaseous mixture and solid char. Nitrogen gas helps to disposed off the gaseous mixture (liquid and gas) to the collector though the condenser. The liquid product was collected in the liquid receiver and the non-condensable gas was collected in a water displacement collector to monitor gas flow rate and the gas volume. After the experimental run the biomass heating system was stopped and the amount of oil and char was measured. All the parts of the system were cleaned and the components were dried with air jet before reassembling for the next run.The fixed bed Pyrolysis system was run under the following operating conditions as-Operating bed temperature - 400 °C to 550°C; Pressure - Atmospheric; Gas -Nitrogen; Gas flow rate (L/min) - 4 to 8;Gas flow time (hr) -2 to 2.5; Apparent residence time less than 5.

11.Result

A total of twelve experimental runs were taken in this work by varying temperature, feed material size and running time. From figure 6 it is found that at the running time 150 min for operating temperature range 400 - 550^{0}C and for 600-650 µm size feed materials the maximum pyrolytic oil yield is 44 wt% at 500 0C. After this temperature the pyrolytic oil yield is reduced because of tertiary reaction take place and vapor is not condensed as a result vapor % is increased. It is also found that the powder form gives the maximum oil yield than the other two feed materials size (size 0.7-0.9 and size 1.1-1.3).

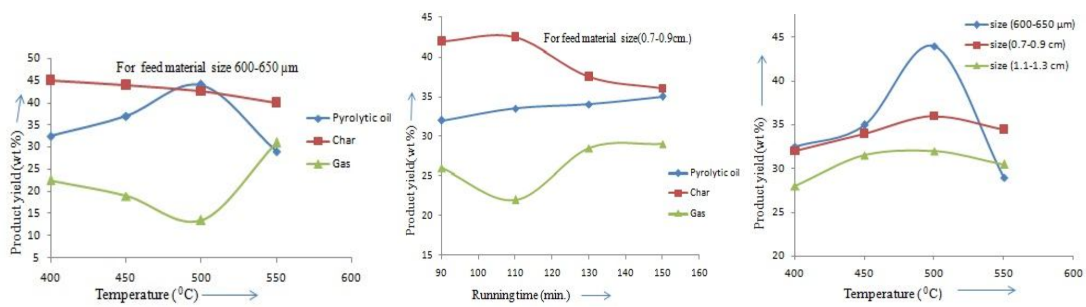

Fig.6. Effect of temperature, running time, feed materials size on product yield

After carried out the experimental studies by using biomass waste in the form of olive seeds and comparing this with the conventional diesel fuel it was found better & comparable results.

Analysis	Olive seed Oil
Kinematic viscosity at 270C (cSt)	5.81 (oasltwate viscometer)
Density (kg/m3)	1040
Flash Point (^{0}C)	70 (Cleveland open cup Tester)
Fire Point (^{0}C)	82
HHV of liquid(MJ/kg)	21.672 (oxygen bomb calorimeter)
HHV of char(MJ/kg)	22.692

Analysis	Pyrolytic oil	Kerosene (Wikipedia)	Fast Diesel [4]	Diesel (Wikipedia)	Heavy Fuel Oil [5]	Wood Waste [3]
Kinematic viscosity at 26^{0}C (cSt)	5.81	2.1	1.3-3.3 (50^{0}C)		200 (50^{0}C)	66.99
Density (kg/m3)	1040	800	780	860	980 (20^{0}C)	1180.2
Flash Point (0C)	70	38	75	66	90-180	59
HHV(MJ/kg)	21.672	35.0	44.5	44.5	42.5	19.80

12. Recommendation

The following recommendations are suggested for improvement:

- ❖ The process of supplying the heat to the reactor bed may be coal or other less costly fuels and the external heating system (heater) should be insulated to reduce heat loss.
- ❖ The heating rate and temperature control should be proper with thermostat or other suitable systems that maintain the required temperature level at the system.
- ❖ The reactor can be redesigned as such types that the char be disposed off and observed easily and the energy contain gaseous products such as heat may be used for drying feed materials.

13.Conclusion

A pyrolysis system was designed, fabricated and Olive seeds were chosen as feed material for pyrolytic oil production. After taking the experimental studies by using solid waste in the form of olive seeds, it was found that this system takes less time for more liquid production.The pyrolytic oil was also characterized and analyzed for their physical properties.The properties of the liquid were compared with those of conventional fuel. All properties were almost close to those of conventional fuel.

14. References

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