Design and Fabrication of Twin Screw Pyrolyzer for Pyrolysis of Biomass

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Abstract-The objective of this paper is design and fabrication of twin screw pyrolyzer for pyrolysis of biomass. It is well known that bio-oil obtained through pyrolysis can be of utility in a number of applications (non-conventional fuel, medicines, mosquito-repellent etc). The design of the screw pyrolyzer is adapted from [8] with a few modifications. As the screw is only required to push the feed material from one side to another, the detailed design of screw is not considered and the dimensions of both screws are assumed suitably. The screws are driven by variable rpm motor. Heating is carried by external heating nichrome coils to a temperature of around 500^0C. A temperature controller is attached to the coils to maintain and regulate the flow of current at the desired temperature. Volatile fluids are condensed in a shell and tube type heat exchanger.

Keywords- *Pyrolysis, Intermediate pyrolysis, screw pyrolyzer, residence time*

1. Introduction

Pyrolysis is a thermo-chemical decomposition of organic material in absence of oxygen. Biomass pyrolysis deals with thermal decomposition of biomass (e.g. wood, human waste, rubber, etc). Biomass contains different components having different thermal properties. Some of its major components are cellulose, hemicelluloses, lignin and small amount of other organics. Since these components have different thermal properties, these components pyrolyze or degrade at different rates by different mechanisms yielding a variety of products including bio-oil, char and gases. A detailed description of the pyrolysis process can be referred in [1].

2. Types of Pyrolysis

The quantity of bio-oil, bio-char and syn-gas obtained during pyrolysis largely depends upon the technique employed for the process of pyrolysis. Broadly pyrolysis can be classified as slow, fast and intermediate. This classification is based on the residence time of biomass in the pyrolyzer or the heating rate. Slow pyrolysis is the most efficient method of turning biomass into bio-char and is widely used in the production of bio-char. Slow pyrolysis requires a low-to-medium temperature between 350°-400°C at relatively long residence time typically taking hours or days [1,2].

While bio-char production is generally maximized with slow pyrolysis, fast pyrolysis offers the benefits of bio-oil production along with a small quantity of bio-char and syn-gas. This process is associated with short residence time and a temperature variation of 400°-600°C. Sometimes fast pyrolysis process is completed in less than 2 second and is termed as flash pyrolysis. Some excellent reviews on various types of fast pyrolysis reactors are published in [2, 3, 4, 5, 6].The drawback of this process is that it becomes very difficult to control the process parameters in such processes.

Intermediate pyrolysis is a modified pyrolysis technique somewhat in between fast and slow pyrolysis in which a low to moderate temperature is required for a shorter duration of time than for slow pyrolysis. The products which can be obtained by intermediate pyrolysis of biomass vary as char 30-40%, liquid 35-45%, gas 20-30% [2, 3]. This type of pyrolysis is generally performed in a screw pyrolyzer or pyroformer, with an optimum residence time. Since intermediate pyrolysis is a new concept and therefore is not in widespread use. Further, there is a relatively little literature on it, the technology is presently under research and development [7].

Intermediate pyrolysis provides an advantage of controlling the reaction rate which is the difficulty experienced while performing fast pyrolysis. In fast pyrolysis the reaction is completed in seconds. So it is very difficult to control the rate of reaction and design of pyrolysis reactor is also complex. Intermediate pyrolysis on the other hand has a residence time between fast and slow pyrolysis. So the reaction is neither too slow nor to fast. Though the quantity of bio-oil obtained during intermediate pyrolysis is less as compared to fast pyrolysis but the reaction can be controlled easily and can be monitored comfortably [7].

This research work focuses on design and fabrication of a twin screw pyrolyzer for intermediate

IJCSN International Journal of Computer Science and Network, May 2014
ISSN (Online) : 2277-5420
www.IJCSN.org
Conference Proceeding – RDFCORDGE - 2014

pyrolysis of biomass. It is a trial to search a suitable technology for efficient production bio-oil from biomass that can be useful as alternate non-conventional fuel, as medicine, as mosquito repellent and many more.

2.1 Design of Screw Pyrolyzer

As this technology is still under research, literature on the design of screw pyrolyzer is not available in plenty. Moreover the available literature focuses on the chemical aspects of pyrolysis and the mechanical design of the screw pyrolyzer has not been considered. In this work the design of the screw pyrolyzer is adapted from [8] with a few modifications. The dimensions are assumed suitably without any design analysis.

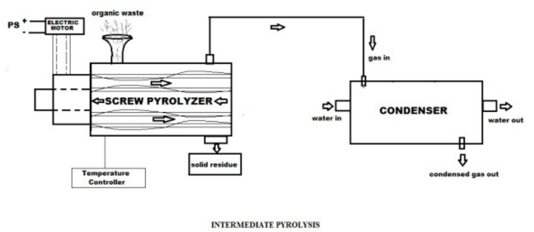

Fig. 1. Line diagram showing Intermediate pyrolysis process.

The experimental setup consists of a cylindrical shell, two coaxial conveyor screws, heating coil, temperature controller, screw driving unit and a condenser. The two co-axial screws provide a means to move the biomass across the reactor inside the shell (from proximal end to distal end). The biomass is first fed to the second (inner) screw auger to subject the biomass feedstock to pyrolysis from where it is dragged to the distal end and fall in the space between the shell and the first (outer) screw auger through the grooves provided for the purpose. The first screw auger then drag the material from distal end to the proximal end i.e., in opposite direction and the biomass feedstock falls through shell after pyrolysis in form of char.

During reaction topside of the pyrolyzer is kept closed by a cover-plate tightly secured to the flanged opening. This prevents the entry of atmospheric air thereby achieving pyrolysis. The exit pipe carries away the gases to the condenser. Thermal decomposition of biomass feedstock is caused by electrical resistance heating. Residence time for solid feed inside the pyrolyzer can be adjusted by changing the speed of screw (variable rpm motor is provided for the purpose). Chain drive transmission system is provided to drive the screws with two separate motors. The temperature inside the pyrolyzer is measured by thermocouple provided for the purpose. Design calculations of the screw is not done separately as they are required merely to drag the feedstock and load calculations are omitted as magnitude of load is negligible.

3. Fabrication

3.1 Pyrolysis Reactor

The pyrolysis reactor or screw pyrolyzer consists of a cylindrical shell with two co-axial screws inside it. The shell is provided with grooves for the entry and exit of biomass and volatile gases. The inner screw, outer screw and the cylindrical shell all are made up of C-40 mild steel. Flange coupling is used at both the ends to provide a provision for driving the screws, and ball bearings are used to provide provision for rotation of screws. The cylindrical shell is provided with three grooves on it, one for the entry of biomass, one for the collection of volatile gases and other for the biomass to leave the reactor after pyrolysis. To compensate increment in dimensions due to thermal expansion, diametrical clearance of 1.5 mm is provided between the shell and first screw auger and between the first and second screw auger respectively.

Dimension specifications used for the design and fabrication is given below:-

1. Dimensions of external screw conveyor:-
Outer diameter of shaft = 100mm
Inner diameter of shaft = 50mm Total length of shaft = 830mm Length of screw = 700mm
Pitch of screw = 40mm
Length of grooved part = 100mm

2. Dimensions of internal screw conveyor:-
Diameter of screw shaft = 47 mm
Total length of shaft = 1000mm
Length of screw = 830mm
Pitch of screw = 40mm

3. Dimensions of cylindrical shell:- Diameter of cylindrical shell = 103mm Length of shell = 730mm
Length of groove = 120mm

The individual components and their assembly view are shown in fig. :-

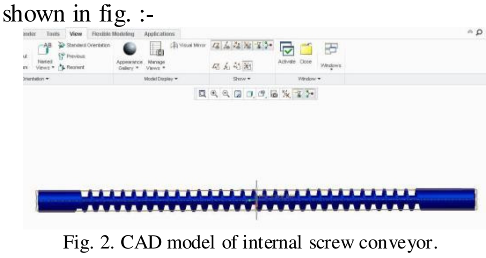

Fig. 2. CAD model of internal screw conveyor.

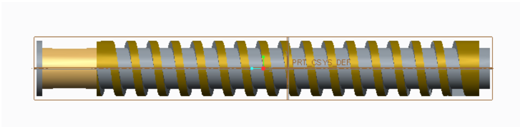

Fig. 3. CAD model of external screw conveyor.

Fig. 4. CAD model of external casing.

Fig. 5. All Components of Screw Pyrolyzer.

Fig. 6. Screw pyrolyzer with glass wool coating.

Fig.7 Screw Pyrolyzer assembled.

3.2 Heating Unit

It consists of nichrome wire covered with porcelain coating, wound across the cylindrical shell for heating the biomass feedstock to achieve pyrolysis. Porcelain coating acts as an insulator and prohibits the contact of the steel shell and nichrome wire, which otherwise would lead to short-circuit. The outer face of the pyrolysis reactor (i.e. the shell) is covered with glass wool as insulating material and asbestos coating on it to prevent the loss of heat.

3.3 Condenser

The condenser is provided to cool the gases evolving out of the pyrolyzer. The condenser used is a horizontal shell and tube type heat exchanger. The evolved gases from the pyrolyzer pass through the tubes and the cooling water is circulated on the shell side. The condenser used for the purpose has 1-shell and 1-tube pass cross flow type of arrangement and consists of a cylindrical shell of mild steel with coils of copper tubes passing through it. Copper is used to avoid rusting and corrosion of the tubes hence their long life is maintained. The cross flow arrangement is preferred due to less heating area required and efficient heat transfer rate. It is a recuperator with heat transfer through surface boundary without actual mixing of two working fluids. The cooling water is circulated by a water pump. Chilled water can also be supplied to increase the yield of bio-oil. However, a certain fraction of gases cannot be condensed and they are termed as non – condensable gases.

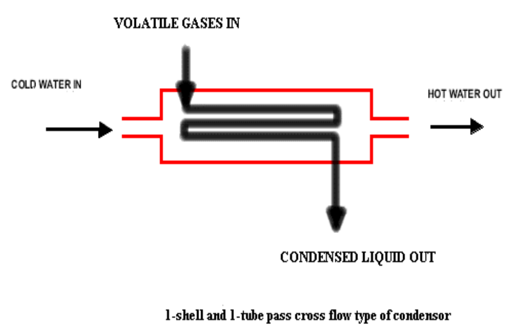

Fig. 8. Line diagram of condenser

Fig. 9. 1-shell & 1-tube cross flow condenser

3.4 Temperature Controller

To avoid over- heating of the feed stock and to maintain a constant temperature to achieve pyrolysis there is a need of a thermocouple and a thermo-controller. Thermocouple is a temperature measuring device consisting of two dissimilar conductors that contact each other at one or more spots. It produces a voltage when the temperature of one of the spots differs from the reference temperature at the other parts of the circuit. It is used as a type of temperature sensor for measurement and control, and also converts a temperature gradient into electricity. Thermocouple is attached to a thermo- controller which sense the temperature and bypass or short-circuit the device when temperature exceeds a pre-defined temperature. The device used for the purpose is "Pt-100 thermocouple" with coaxial wires, having a tolerance of 450*(degree)(both on the higher and lower side). One end of the thermocouple is connected to the shell (coated with nichrome wire) and the thermocouple is attached to the thermo-controller device to constantly show the temperature variation and to cut the flow of current through nichrome wire when temperature exceeds a limit defined.

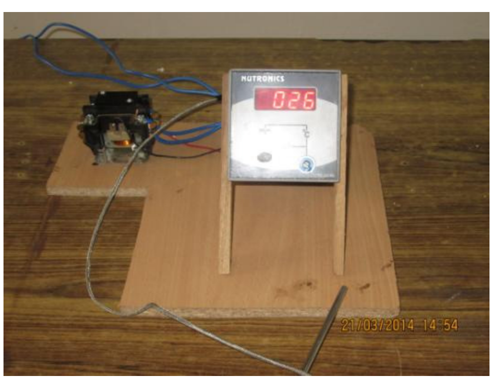

Fig. 10. Pt-100 thermocouple

3.5 Driving Arrangement for Screws

To drag the biomass feedstock across the pyrolyzer from the proximal end to the distal end there is a need of driving unit. Here variable rpm motor is used for this purpose with chain drive transmission system to drive the screws. two motors are employed for driving both the screws, as the two screws are to be rotated in opposite direction. The motor used for this purpose is "1 HP, 1500 rpm brushed and geared motor having a torque transmitting capacity of 10kg" as its load carrying capacity is high. Chain drive is used for the transmission of power to the screws from the motor.

3.6 Assembly

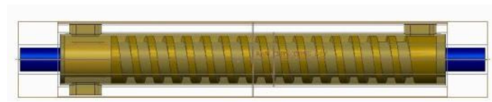

Fig. 11. CAD model of screw pyrolyzer.

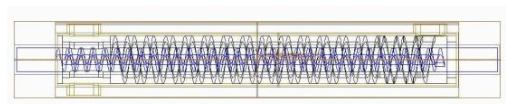

Fig. 12. Wireframe view of screw pyrolyzer.

Fig. 13. Experimental setup of intermediate pyrolyzer.

4. Conclusions

An experimental set up of a pyrolysis reactor for intermediate pyrolysis of biomass is fabricated. The setup consists of a cylindrical shell, two coaxial conveyor screws, heating coil, temperature controller, screw driving unit and a condenser. The set-up can be used for pyrolysis of different types of biomass like wood/ leaves of trees, agriculture waste etc to obtain bio-oil. This oil can be used in a variety of applications viz., as a non-conventional fuel (thus help in solving the problem of increasing energy crisis), it may be used in medicines or as a mosquito repellent.

5. Acknowledgements

The authors acknowledge their profound gratitude to the All India Council for Technical Education, New Delhi, for financial support through Research Promotion Scheme No. - 8023/RID/RPS-19/2011-12. We are highly indebted to Dr. Arun Arora, Principal Investigator of this above mentioned project for his valuable suggestions and Director, Dr. M. K. Kowar, Bhilai Institute of Technology, Durg, for providing facilities for research work.

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