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Evaluation of Suitability of Cyclone Reactor for Biomass Pyrolysis

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Abstract – *Numerous research and development efforts over more than two decades have led to development of various pyrolysis systems to produce both raw and upgraded bio-oil. The biomass which is available in plenty on our planet is considered as renewable source can undergo pyrolysis to yield oil along with some aerosols and bio char which has a potential to be used as a sustainable fuel in the future. Biomass being a source to fulfil the energy demand has an addition advantage of low Sulphur and nitrogen content. Several types of reactors can be used for carrying out pyrolysis such as fluidized and entrained bed reactors, vacuum devices, rotating cone etc. The cyclone, worldwide used for gas–solid separations can be also considered as a reactor for carrying out thermal reactions of solids. The cyclone reactor is used based on two concepts of the chemical engineering i.e. No slip condition and plug flow. Cyclone reactor is designed in such a way that it should work as a multifunctional reactor. The present work addresses to the experimental study on pyrolysis of wood sawdust in a designed cyclone reactor.*

Key Words: Biomass, Pyrolysis, Cyclone reactor, Bio-char, Carrier gas.

1. INTRODUCTION

With increase in demand of energy, various resources are constantly evaluated to fulfill the requirement. Continuous researches are being carried out to find a renewable source of energy and develop an economic process to obtain fuel from it. Biomass is a promising eco-friendly alternative source of renewable energy in the context of current energy scenarios.[1] The biomass which is available in plenty on our planet and is considered renewable source. With the help of pyrolysis technique, this biomass can yield oil along with some aerosols and bio char which has a potential to be used as a sustainable fuel in the future. Biomass being a source to fulfil the energy demand has an addition advantage of low Sulphur and nitrogen content. There are many types of biomass like sugar cane bagasse, rice paddy, wood sawdust etc.

Wood saw dust is a by-product or waste product of woodworking operation such as sawing, milling, planning, routing, drilling and sanding. It is composed of fine particles of wood which can be utilized as a raw material for pyrolysis process. Several types of reactors can be used for carrying out pyrolysis such as fluidized and entrained bed reactors, fixed bed reactor, vacuum devices, rotating cone, Auger reactor etc. They are usually optimized for the production of bio-oils in well define conditions.

The cyclone, worldwide used for gas–solid separations can be also considered as a reactor for carrying out thermal reactions of solids. Basically, the particles enter tangentially into the reactor and are then rapidly thrown against the heated walls along which they move and undergo heating and reaction.[2] The solid residues are automatically separated at the bottom, while the gaseous products leave the cyclone at its top. In the case of biomass, it is hence possible to perform both pyrolysis and separation in the same compact device. The flexibility of the cyclone reactor is such that according to the operating conditions it can be used either for the fast gasification or for the fast liquefaction of biomass.

The pyrolytic properties of biomass are controlled by the chemical composition of its major components, namely cellulose, hemicelluloses, and lignin and their minor components including extractives and inorganic materials. On heating at higher temperatures (300~5OO ^{0}C), the molecule is rapidly depolymerized to anhydro glucose units that further react to provide a tarry pyrolyze.[3] It is also possible to use the traditional cyclone reactor worldwide used for gas-solid separations. The particles flow against the heated walls, where they are heated and then pyrolyze. The solid residues are automatically separated at the bottom, while the gases and vapours leave the cyclone at the top.[4][5] The yield of the pyrolysis product phases was only slightly influenced by the structures. [6][7]

The present work addresses to the experimental study on pyrolysis of wood sawdust biomass in a designed cyclone reactor and suggest the potential advancements in process parameters to increase the sustainability of the process.

2. EXPERIMENTAL APPARATUS AND PRODURES

2.1 Description of the whole experimental set-up

The pyrolysis experiment was performed on lab scale set-up which included a feeding arrangement, carrier gas cylinder, cyclone reactor, heating assembly and a condenser.
The experimental setup assembly is shown in figure 1

Fig -1: Experimental set-up

2.1.1 Cyclone reactor
Cyclone reactor was fabricated using stainless steel (SS316). The cyclone reactor was in house designed and its design. Table 1 gives the specification of cyclone reactor and calculations are given by,
Diameter of cyclone reactor (D) = 6 x 10^{-2} m
Diameter of inlet pipe (Dd) = 0.5x D
Width of the inlet pipe (W) =0.25 x D
Outlet diameter (Do) = 0.25x D

Table 1: Specification of Cyclone reactor:

Sr. No.	Parameter	Value
1	Diameter of the cyclone(D)	6 x10^{-2}m
2	Height of the cyclone	32.19 x10^{-2}m
3	Height of the cone (Lc)	21.33 x 10^{-2}m
4	Height of the body (Lb)	10.86x 10^{-2}m
5	Internal surface area	3.7 x 10^{-2} m^2
6	Volume(capacity)	0.47 x10^{-3} m^3
7	Width of the inlet pipe (W)	1.5x10^{-2}m
8	Diameter of inlet pipe (Dd)	3x 10^{-2}m
9	Outlet diameter (Do)	3 x 10^{-2}m
10	Discharge diameter	1.5x10^{-2}m

From the above specification, the effective number of turns inside reactor was calculated as follows

No. of effective turn= 1/Dd (Lb+Lc/2)
=1/3(10.86+21.33/2)
=7.17 ≈ 7

The cyclone reactor was provided with a T-junction at inlet for feed which is to be carried with carrier gas.
The cyclone reactor is shown in figure 2.

Fig -2: Cyclone Reactor

2.1.2 Heating assembly
For heating cyclone reactor, ring shaped band heater is clamped around a cylindrical part of the cyclone body. The heat transfer from band heater occur via the conductive method. The band heater is cladded with ceramic insulation to prevent the heat loss to the environment. Temperature inside the rector was monitored by using 'K' type thermocouple which is connected to the controller used to maintain temperature at constant value. [Model-DTE+PID 96]

2.1.3 Carrier gas
Since it is pyrolysis reaction, to prevent fire and burning; the oxygen present inside the experimental assembly is purged completely using nitrogen before start of pyrolysis.

Nitrogen gas is also used as a carrier gas for feeding wood saw dust. At T-junction the carrier gas because of its high velocity will carry wood saw from top. The flow of nitrogen at inlet of reactor is controlled by a nitrogen valve at top of cylinder. Stream of nitrogen carry the biomass inside the reactor. This biomass then gets separated from nitrogen gas by cyclone action, and exits from top of the reactor. The pressure and flow rates of nitrogen are the critical criteria to be maintained. The flow rate is maintained to provide sufficient contact time for biomass particle to go thermal cracking is controlled by a nitrogen valve at top of cylinder.

2.1.4 Condenser

The gases from pyrolysis reaction are passed though water chilled condenser. Water at 10 ^{0}C was used to circulate from condenser. Circulation rate is maintained such that maximum vapor will get condensed.

2.2 Experimentation

The biomass used is wood sawdust of teak wood purchased from Timber market. The biomass was first sun dried before it was used as feed to cyclone reactor. The Biomass get sucked in through T-junction when nitrogen gas is passed through junction. This carried biomass then enters tangentially into the cyclone reactor and then rapidly thrown against the heated walls along which they move and undergo heating and then pyrolyzed. The solid residues from pyrolysis because of cyclone action are automatically separated and collected at the bottom of the reactor. The gaseous products (condensable vapors, aerosols and permanent gases) leave from top of the reactor. The schematics of set up is shown in flow chart as shown in figure 3.

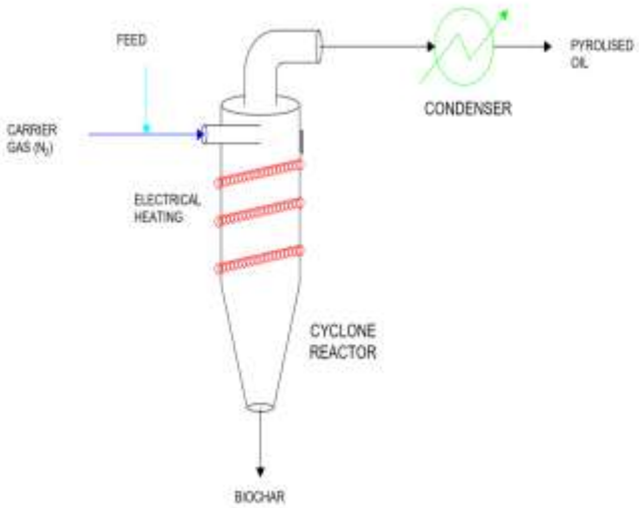

Fig -3: Schematic representation of experimental setup

2.2.1 Pilot Run

At first nitrogen gas is passed through assembly to make inert environment. Chilling water was then started to condenser. Then after some time port at T-junction is opened for addition of biomass. The sun-dried biomass was fed to cyclone reactor. The carrier gas nitrogen was injected along with biomass with high pressure. The reacted biomass was collected from bottom of the reactor. Other runs are carried out in same manner with change in carrier gas flowrate and reaction time. Actual process steps are given in figure 4 and Table 2 gives the process parameters of the experimental run.

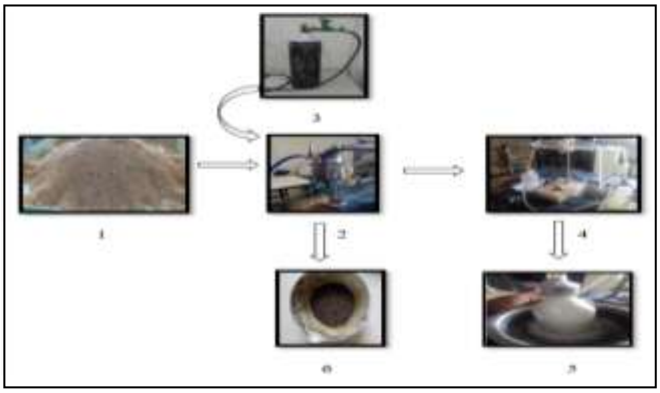

Fig -3: Process steps of experimental run

1.Biomass 2. Cyclone reactor 3. Carrier gas
4.Condenser 5. Collected vapors 6. Biochar

3. RESULT AND DISCUSSION

Table 2: Details of the process parameters

Run No.	Wt. of biomass (g)	Carrier gas flow rate (10^{-5} Kg s^{-1})	Inside cyclone Temperature (°C)	Time taken (s)	Wt. of char (g)
1	20	11.1	400	180	---
2	5	1.6	425	300	2.3
3	5	1.85	450	270	2.61
4	5	2	475	250	2.67

As discussed above, pyrolysis runs are conducted with change in carrier gas flowrate and run time. The biomass was found to be cracking inside the reactor. Out of 5 gm of biomass fed to the reactor, 2.67 gm of biomass is obtained at the bottom product (char) as shown in figure 6. The cracking of biomass yields a char and aerosols as shown in figure 7.

The oil was produced in small amount. The cyclone reactor can be used for the process of pyrolysis but residence time of biomass inside the reactor is very critical which is governed by the flowrate of carrier gas. From figure 5, it is apparent that with increase in flowrate of carrier gas, residence time decreases resulting in less contact time and hence lower pyrolysis product yield.

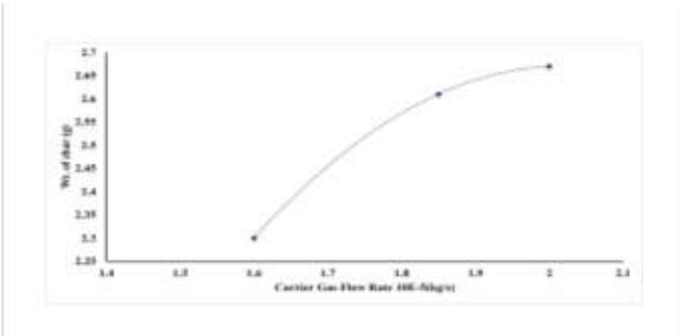

Fig-5: Biochar yield with change in gas flow rate

It is found that effective turns more than 10 are more advantageous for pyrolysis process. The tight sealing of reactor is also very important as the process has to carried out in the inert atmosphere. Since it is pyrolysis reaction, oxygen present inside the assembly should be purged completely otherwise biomass will simply burned and not thermally cracked. The bottom of the cyclone reactor should be properly sealed to reduce the vapor loss and to maintain no oxygen condition.

The temperature of the condensation assembly must be as low as possible because lower the temperature more vapors will get condensed. Using long condensation assembly can increase the overall yield of pyrolyzed biomass. The proper coolant must be used to generate sufficient temperature gradient and to condense the biomass vapors.

Fig -6: Biomass and bio-char after the pyrolysis

Fig -7: Non condensable gases with fraction of oil

4. CONCLUSIONS

In the present work several experimental runs are conducted. The cyclone, which is used for gas-solid separations can be used as a reactor to carrying out thermal cracking of solids. The particles of biomass enter into the reactor and then thrown against the heated walls of reactor along which they move and undergo heating and thermal reaction. The solid residues are automatically separated and collected at the bottom of the reactor. Based on the result and discussion following interferences can be drawn:

The present work has demonstrated the potential in pyrolysis of biomass in cyclone reactor. However, it is felt necessary to conduct more experimental runs followed by rigorous tests to validate the claims further.

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