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# A LAB-SCALE SEMI AUTO VERTICAL TUBULAR COMBUSTOR AS A POTENTIAL PYROLYSIS FOR BIOMASS BURNING

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**ABSTRACT**

This paper presents a new semi auto vertical fluidized bed tubular combustor for any biomass burning. The new semi auto system is suitable for the experimental and testing platform, particularly lacking in the area of laboratory facilities and individual exposed to the hazard. A fully integrated, easy to operate, inexpensive, movable, accurate temperature and flow rate control, flexible fluidised bed tubular furnace are fabricated and presented. The fluidized bed tubular furnace is operated at 2.6 kW and at temperatures ranging from 50 ºC to 1300 ºC, an open coil heating assembly which is surrounded by refractory ceramic fibre in the flexible orientation. The water chiller and condensers are integrated into the system for the simplicity design. The layout had been designed by using the SolidWorks CAD software.

**Keywords:** biomass, fast pyrolysis, fluidized bed tubular furnace.

## INTRODUCTION

Fast pyrolysis represents one of the interesting methods to convert biomass into highly valuable products (A. V. Bridgwater *et al.* 1999). In this process, the organic compounds in the biomass undergo rapid thermal decomposition in the absence of oxygen to produce bio-oil, char and biogas. Among the advantage of the fast pyrolysis method is that the yield of bio-oil can reach 75 wt% on a dry-feed basis if compared with other methods of biomass conversion (A. V. Bridgwater *et al.* 1999). As biomass fuels and residuals are gaining more recognition as significant alternatives to fossil-based sources, proper understanding of the process and its mechanisms is indispensable for successful commercial development.

The studies that focused on fast pyrolysis reaction are usually carried out in a small-scale tubular furnace experimental setup (Y. Peng, and S. Wu, 2011). The device is usually built to withstand high temperature operation and integrated with suitable controllers and analysers to analyse final pyrolysis products. The heating is usually carried out by an electrical element. The device must be flexible enough to study various operating characteristics of the process. For fast pyrolysis reaction, temperature and residence are among the most important variables for process performance (T.-A. Ngo *et al.* 2011). The temperature of the fast pyrolysis reaction can be as high as 750 ºC while the residence time can be as fast as 0.5 s. Therefore, it is important that the fabricated system must be able to withstand the severity of the operations that are usually encountered during experimental investigation.

The objectives of this study are to present the latest development of safety portable tubular furnace for experimental investigation of fast pyrolysis process to produce bio-char and liquid bio-oil products. Because most of the fast pyrolysis lab scale reactors were carried out in a Vycor glass reactor. The vertical tubular furnace is operated at 2.6 kW and at temperatures ranging from 50 ºC to 1300 ºC.

### Principles of Pyrolysis Process

In a typical fast pyrolysis process, the biomass material is first dried, grounded and sieved to reduce the particle size to less than 3 mm. The obtained products from the fast pyrolysis process can be used directly in a variety of applications or be used as an efficient energy carrier as shown in Figure-1.

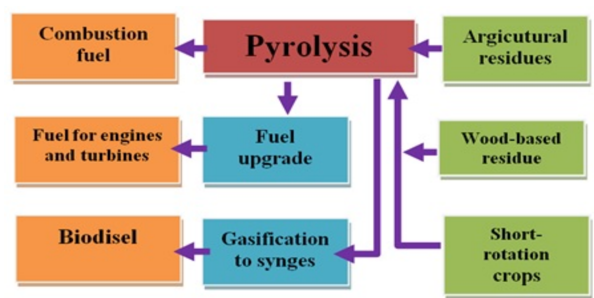


**Figure-1.** Feedstocks and products of fast pyrolysis of biomass.

Under this fast pyrolysis, the biomass that are being usually the mixture of hemicellulose, cellulose, lignin and minor amounts of other organic compounds decompose very quickly at very high temperature ranging around 550 ºC in the absence of oxygen according to the following reactions (T.-A. Ngo *et al.* 2011):

$$Biomass \rightarrow Tar \rightarrow Gas \quad (1)$$

$$Biomass \rightarrow Char \rightarrow Gas \quad (2)$$

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The reaction products consist mostly of vapours and aerosols and some charcoal and gas. The vapours are then condensed to yield bio-oil while the gas is sent for further combustion to extract useful heat. Depending on the thermal environment and final temperatures, the process will yield mainly biochar at low temperatures (less than 450 ºC) with relatively low heating rate, or gases at high temperatures (greater than 800 ºC) with high heating rates. At an intermediate temperature range and under relatively high heating rates, the main product of the fast pyrolysis reaction, i.e. bio-oil is obtained. The simplified flow diagram of the typical fast pyrolysis process as shown in Figure-2.

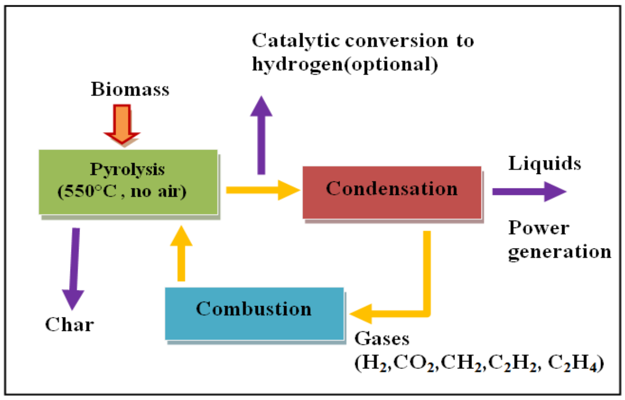


**Figure-2.** Simplified flow diagram depicting process conditions of the fast pyrolysis process.

There are several types of pyrolysis reactor to conduct experiments for the fast pyrolysis of biomass with the popular configurations being fluidized-bed and tubular furnace designs. The fabrication of portable tubular furnace for the fast pyrolysis in this work also takes into account the following essential characteristics of the process:

- Very high heating and heat transfer rates that require a finely ground biomass feed
- Carefully controlled temperature of around 500 ºC
- Residence time of pyrolysis vapours in the reactor that might be in between 1second to 2 seconds.
- Rapid cooling of the pyrolysis vapours to give final bio-oil products.

## RESEARCH METHODOLOGY

The procedures used to convert the variety of biomass into energy bio-oil and bio-char is discussed in Figure-3. It describes clearly on the preparation of biomass as well as the burning condition to be used to conduct the experiment methodology used throughout the research.

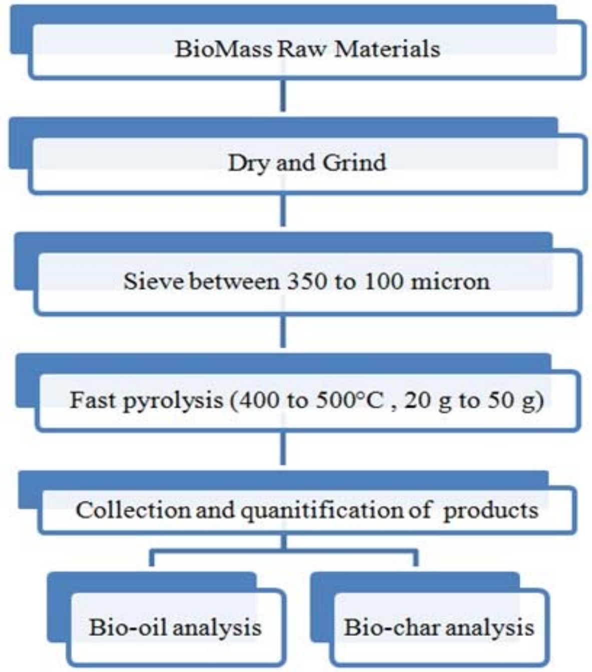


**Figure-3.** Steps and procedures used to convert the biomasses into energy bio-oil.

The biomasses had to be prepared first before it's to be pyrolyzed. The whole process can be categorized into four major steps in the process of preparing the sample for pyrolysis, which includes drying of samples, size reduction sample, grinding of the sample, and sieving of samples. Initial steps, the biomasses were dried under the sun before to be cut into pieces and place the biomasses in the oven for better removal of moisture. After the process of drying is completed, the empty fruit bunches to be grind continuously until it meets its specification using a blender to obtain the required size for the process of pyrolysis.

This procedure being carried out to aid a better yield bio-oil during the process of pyrolysis as the size of the biomass plays a vital role in this process. Afterward, the process of sieving being carried out with the specification of 300 microns by using a sieve shaker. The experiment will be conducted by using a single-zone tube furnace (Carbolite, Model CTF 12/75/700). The heating temperature that will be used during the fast pyrolysis is in the range of 400 ºC – 550 ºC. Before the pyrolysis process starts purging the nitrogen gas into the reactor in order to maintain an inert atmosphere in the reactor. The liquid products will be collected in the three condensers; which are combined and mixed in order for the determination of the total liquid yield obtained. This experiment conducted with approximately 30 grams of biomass being used in each of the running experiment.

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The biomass will be filling in the reactor before the reactor was placed in the furnace in the process of heating. The flow rate of nitrogen gas was regulated to avoid the sweeping gas to reduce the residence times of the bio-gas released which will aid in the yield of bio-oil. Then, the collected bio-oil in all three difference condenser were measured and mixed together to obtain the total yield. The manually setup for the existing pyrolysis system is shown in Figure-4. So, without the automation system, the person needs to manually handle, operate the pyrolysis system equipments and carry out the procedures which can expose the individual to the hazard.

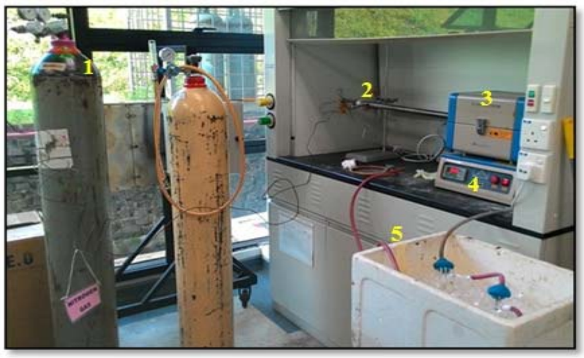


**Figure-4.** Horizontal fluidized-bed pyrolysis system and system flow. (1) $N_2$ cylinder gas; (2) Gas inlet; (3) Pyrolysis reactor; (4) Controller; (5) Condensers.

**New Pyrolysis System**

The building of a pyrolysis system was designed based on an integrated series of principles of pyrolysis. The operations starting from biomass preparation and place the biomass in the vertical fluidized bed reactor for combustion. The designed on a vertical fluidized bed pyrolysis system is shown in Figure-5 using SolidWorks CAD software. The main individual systems are shown in Figure-5.

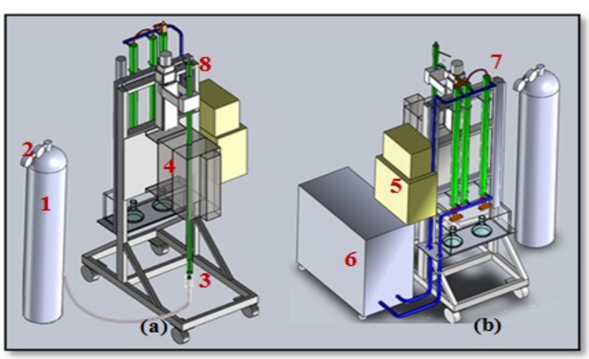


**Figure-5.** Vertical fluidized-bed pyrolysis system and system flow diagram. (a) Front view of pyrolysis system . (b) Rear view of pyrolysis system. (1) $N_2$ cylinder gas; (2) Gas flow meter control; (3) Gas inlet; (4) Pyrolysis reactor; (5) Controller; (6) Water chiller; (7) Vertical-shaped pipe condensers; (8) thermocouple.

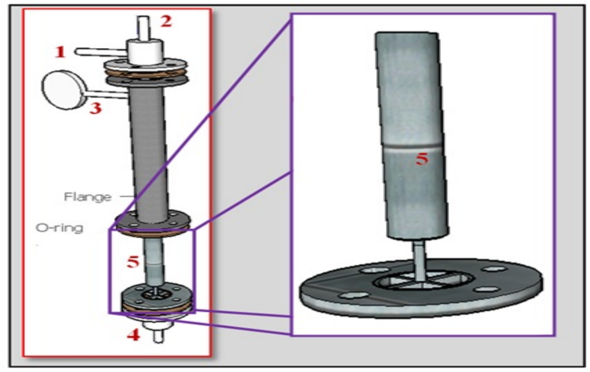


**Figure-6.** Fluidized-bed reactor design. (1) Gas outlet; (2) internal feedback thermocouple; (3) Pressure gauge; (4) Gas inlet; (5) Feedstocks station.

**Vertical fluidized-bed reactor**

Pyrolysis experiment can be carried out in a vertical tubular reactor as shown in Figure-6. The dry biomass raw material has to be grind first into small particle size because of the laboratory scale. The fluidized-bed reactor can only feed materials with a low particle size for the initial experiments. The fluidized-bed reactor was made of SUS 304 and SUS 316 with the type of flange mounting.

**Temperature control system**

The system able to heat up from 50 ºC temperature to 1000 ºC. The heating rate is based on the type of the controller such as sensitive PID controller (N. Katoh *et al.* 1989), (ZHANG Hai-feng *et al.* 1989) or adaptive PID controller (S. Matsumura *et al.* 1994). The temperature operates in the range of 400°C to 600 ºC in 25 ºC increments (N.Abdullah a et al. 2010). The residence time of feedstocks during the pyrolysis process is about 1 second to 2 seconds (N.Abdullah a *et al.* 2010), (N.Abdullah a *et al.* 2010). A programmable controller was applied to control the pyrolysis system on the parameter such as temperature and residence time.

**Condenser system**

The pyrolysis vapours flow into the cascading 3-PASS U-shaped trap condensers and are directed to condense using normal tap water as cooling heat conversion of the liquid pyrolysis oil. A recirculating chiller provides reliable liquid cooling performance.

**Gas nitrogen**

Nitrogen, as a carrier gas to carry the pyrolysis vapours from the reactor to the U-shaped condenser pipe as well as a fluidising medium. The dry biomass material was heated under gas nitrogen atmosphere at a certain heating rate from room temperature to 600 ºC.

**Comparison of Pyrolysis System**

The main differences between the manual and semi-auto pyrolysis system as shown in Table-1. From the tabular comparison can be observed that the semi-auto

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paralysis can be is able to be upgraded easily for other processes and gas detection in the future.

**Table-1.** Comparison of the type pyrolysis system.

| Condition | Pyrolysis system setup | |
|---|---|---|
| | Manual | Semi-auto |
| Hazards | High | Low |
| Human Handling | Multi steps | 2 steps |
| Condensers | Not systematic | Systematics |
| Coolant equipment | No | Yes |
| Reactor operation | Horizontal | Vertical/Horizontal |
| User friendly | No | Yes |
| Feedstocks holder | No | Yes |
| Process top up | Medium | Easy |
| Gas flow control | No | Yes |
| Cyclone | No | No |
| Gas meter | No | No |
| Operating Temperature | 1200°C | 1300°C |
| Reactor temperature | 800°C | 1200°C |
| Pyrolysis | Slow and fast | Slow, fast and flash |

**Electronic Control Design**

Figure-7 shows the installation of thermocouples for this furnace design. This Figure-7 also shows the measurement of the internal pipe temperature, at 50 °C until 1000 °C and also the open coil heater element with a chromel v. alumel thermocouple, in this installation, the thermocouple is extended to the control panel using extension leads made of chromel and alumel.

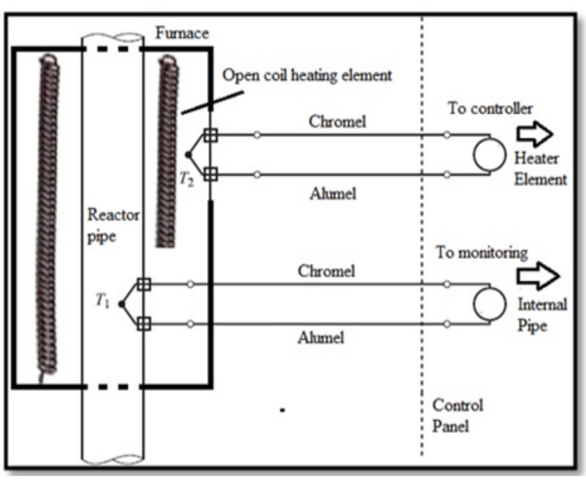


**Figure-7.** Thermocouples installation design.

Figure-8 shows the block diagram structure of monitoring measurement system for the internal reactor temperature. Figure-9 shows the block diagram structure of the feedback control measurement system for the open coil heater element temperature.

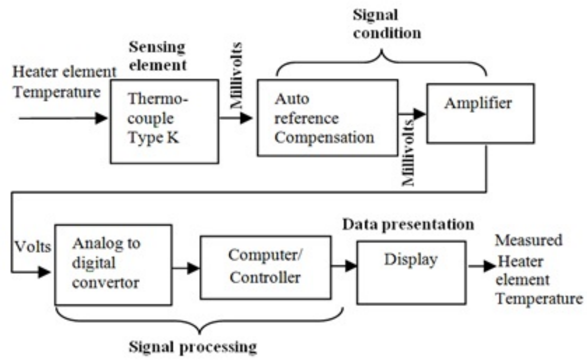


**Figure-8.** Block diagram structure of monitoring for the internal reactor temperature.

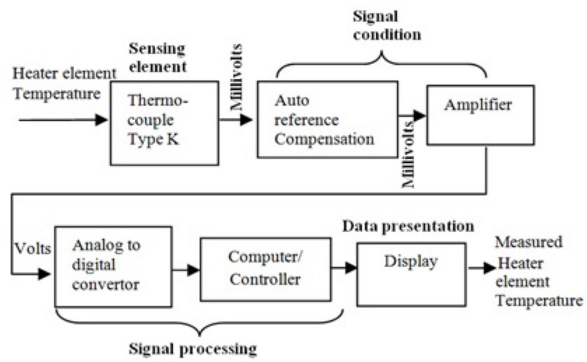


**Figure-9.** Block diagram feedback control measurement system for the open coil heater element temperature.

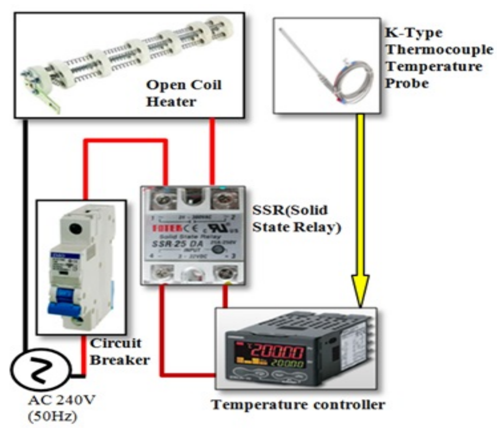


**Figure-10.** Control panel measurement system for the open coil heater element temperature.

Figure-10 shows the control panel measurement system developed for the open coil heater element temperature, which the design was based on BS standard and comply with IEEE regulation.

**CONCLUSIONS**

This pyrolysis automation system was successfully designed and developed. The pyrolysis will be the most versatile biomass conversion systems, which would offer semi-auto yields of liquid products that can be used directly or upgraded in future. This technology would offer considerable promise for fuels and chemicals. Consequently, the continued research and development is essential to realize the potential of the technology.

The next stage of the research would be the integrated system which includes the following works to collect data on biomass production, harvesting, conversion and upgrading processes, to collect data on transport and handling the costs of biomass and also to continue the techno-economic assessment studies for optimization of the design system. Finally, the plant design towards the low cost, safe and user friendly operation.

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## REFERENCES

[1] V. Bridgwater, D. Meier and D. Radlein. 1999. “An overview of fast pyrolysis of biomass,” Organic Geochemistry, Vol. 30, No. 12, pp. 1479-1493.

[2] V. Bridgwater. 2012. “Review of fast pyrolysis of biomass and product upgrading,” Biomass and Bioenergy, Vol. 38, pp. 68-94.

[3] Y. Peng and S. Wu, 2011. “Fast pyrolysis characteristics of sugarcane bagasse hemicellulose,” Cellulose Chemistry and Technology, Vol. 45, pp. 605-612.

[4] T.-A. Ngo, J. Kim, `.-S. Kim. 2011. “Fast pyrolysis of palm kernel cake in a closed-tubular reactor: Product compositions and kinetic model,” Bio-resource Technology, Vol. 102, No. 5, pp. 4273-4276.

[5] N. Katoh, K. Nakao and M. Hanawa 1989. “Learning control of a batch reactor" Computers & Chemical Engineering, Vol. 13, No. 11–12, pp. 1273–1276.

[6] ZHANG Hai-feng, ZHAO Ai-ling, HOU Jun, 2011. “Design of Fumigation Temperature Control System Based on Single-Chip Microcontroller". Advanced in Control Engineering and Information Science, Procedia Engineering, Vol. 15, pp. 246 – 250.

[7] S. Matsumura, K. Ogata, S. Fujii, H. Shioya H. Nakamura. 1994. “Adaptive control for the steam temperature of thermal power plants" Control Engineering Practice, Vol. 2, No. 4, August 1994, pp. 567-575.

[8] N.Abdullah a, H.Gerhauser and F.Sulaiman. 2010. "Fast pyrolysis of empty fruit bunches". Fuel 89, pp. 2166–2169.

[9] NM Mubarak, A Kundu, JN Sahu, EC Abdullah, NS Jayakumar. 2014. “Synthesis of palm oil empty fruit bunch magnetic pyrolytic char impregnating with FeCl 3 by microwave heating technique” Biomass and Bioenergy, Vol. 61, Feb 2014, pp. 265-275

[10] NM Mubarak, M Ruthiraan, JN Sahu, EC Abdullah, NS Jayakumar, NR Sajuni, J. Tan. 2013. “Adsorption and Kinetic Study on Sn 2+ Removal using Modified Carbon Nanotube and Magnetic Biochar” World Scientific Publishing Company, Vol. 61, Feb 2014, pp. 265-275

[11] Suchithra Thangalazhy-Gopakumar, Wail Mohammed Ahmed Al-Nadheri, Dinesh Jegarajan, JN Sahu, NM Mubarak, S Nizamuddin (2015). “Utilization of palm oil sludge through pyrolysis for bio-oil and bio-char production”. Bio-resource technology, Vol. 178, Feb 2015, pp. 65-69.

[12] Sabzoi Nizamuddin, Natesan Subramanian Jayakumar, Jaya Narayan Sahu, Poobalan Ganesan, Abdul Waheed Bhutto, Nabisab Mujawar Mubarak (2015). “Hydrothermal carbonization of oil palm shell”. Korean Journal of Chemical Engineering, Springer US, 2015, pp. 1-9.

[13] Jon Makibar, A. Ruth Fernandez-Akarregi, Maider Amutio, Gartzen Lopez and Martin Olazar, 2015. “Performance of a conical spouted bed pilot plant for bio-oil production by poplar flash pyrolysis”. Fuel Processing Technology, Vol. 137, pp. 283-289.

[14] N. Abdullah, H. Gerhauser. 2008. “Bio-oil derived from empty fruit bunches”. Science Direct, Fuel, Vol. 87, pp. 2606-2613.

[15] Javaid Akhtar, NorAishah Saidina Amin. 2012. “A review on operating parameters for optimum liquid oil yield in biomass pyrolysis”, Elsevier, Renewable and Sustainable Energy Reviews, Vol. 16, pp. 5101–5109

[16] J.C. Jones, 2010. “Type K thermocouples in a natural gas furnace”, Elsevier, Fuel, Vol. 89, No. 10, p. 3150.

[17] N. Katoh, K. Nakao, M. Hanawa. 2001. “Learning control of a batch reactor”, Elsevier, Computers & Chemical Engineering, 11-12, pp. 1273-1276.