CHAPTER 1
INTRODUCTION

1.1 Background of Study

A downdraft gasifier is a type of gasification system device which is used to generate a synthetic gas (syngas) from organic carbonaceous material through an incomplete combustion process. Gasification is a highly efficient method for obtaining energy from organic materials, and it can be used for waste disposing method. H_2 and CO are the primary combustible gasesous mixture of syngas produced by gasification.

Based on equilibrium and statistical analysis on gasification, the production of primary syngas components are affected by temperature and pressure. The gasification system requires high temperature in the whole reactor to thermally-cracks heavy hydrocarbon, tar, watery condensates and pyrolysis oil into simpler organic chemical components. It also promotes high quantities of H_2 to be produced and further converted into producing hydrogen-rich gas mixture (Moni et al., 2012). The heat will be generated and supplied by feedstock in combustion process, to increase temperatures sufficiently for drying, pyrolysis and reduction process of gasification. The exergy losses can occur during the gasification due to internal thermal energy exchanger (heat transfer from reaction products to reactants) (Karamarkovic et al., 2012). By using a high moisture content of feedstock in gasification, the high amount of water will jeopardize the quality and efficiency of combustion, as water is not a combustion agent. High moisture contents reduce the thermal efficiency since heat is used to drive off the water and consequently the energy is not sufficient for the reduction reactions and for converting thermal energy into the chemical bound energy in the gas. Therefore, high moisture contents result in low gas heating values. In downdraft gasifiers, high moisture contents give not only low gas heating values, but also low temperatures in the oxidation zone and this can lead to insufficient tar converting capability if the gas is used for engine applications.

Meanwhile, the internal thermal energy exchange which responsible for low gasification efficiency, can be reduced by the use of preheated air as a gasifying medium. The preheated air can help increasing the efficiency in a way like the use of less moisture content feedstock, where the preheated air will be able to maintain the temperature of combustion process in the reactor and not losing the combustion energy to the process of heating up air and water molecules that consume a lot of energy. By using the preheated air also, the energy released during the gasification process is sufficient to provide necessary temperature for complete gasification of the fuel, leading to a better efficiencies and high caloric-valued fuel gas (Pian et al., 2002)

1.2 Problem Statement

Previous studies proved that by having a lower moisture content of biomass fuel and preheating of gasifying air could improve the quality of the syngas produced and increase the efficiency of gasification. The acceptable moisture content for biomass fuel is 15% or lower (Moni et al., 2012). As a comparison, the use of 20% moisture contents (dry basis) of feedstock can produce 78.9% combustion efficiency while at 13% of moisture contents feedstock can produce up to 80.4% combustion efficiency (Black et al., 1977). By using a preheated air supply in gasification, the tar produced in the syngas was reported to be significantly low (Bhattacharya et. al). In a work by Doehearty et al. (2009), it was shown that the H_2 content in syngas composition also increased with the increase of preheated air temperature. At the gasifying air temperature of 25°C, the resulting H_2 composition in syngas was only 2.6%, while at 825°C the H_2 composition was increased to 17.5%.The gasifying air temperature and hydrogen content in the syngas is directly proportional to each other.

1.3 Objectives

During gasification, the temperature of waste heat produced at the gasifier is high and it can be used to reduce the moisture content of biomass feedstock (McKendry, 2001) and increase the gasifying air temperature before being fed into the gasification system (Ishii, 2003). Therefore, the objective of the project is to evaluate the effectiveness of utilizing waste heat from a gasification system for secondary drying of the biomass fuel and for heating of the gasifying air.

1.4 Scope of Study

The scope of study is outlined as follow:

1) To develop a heat exchanger system at the downdraft gasifier for utilization of the waste heat. A heat exchanger system was designed and constructed for secondary drying of biomass fuel and preheating of gasifying air before being fed into the gasifier.
2) To measure the effectiveness of the designed system through experiment. The experiment was performed to measure the temperature of pre-heated air and the biomass moisture content by using the waste heat captured from the gasification system.

CHAPTER 2

LITERATURE REVIEW AND THEORY

2.1 Theory

2.1.1 Gasification

Gasification is a thermal process that is performed at high temperatures in order to convert organic or fossil based carbonaceous materials into carbon monoxide, hydrogen and carbon dioxide. This is achieved by reacting the material at high temperatures (>700°C), without combustion, with a controlled amount of oxygen and/or steam. The resulting gas mixture is called syngas (from synthesis gas or synthetic gas) or producer gas and is itself a fuel. The power derived from gasification and combustion of the resultant gas is considered to be a source of renewable energy if the gasified compounds were obtained from biomass (Burgt et al., 2008).

The advantage of gasification is that using the syngas is potentially more efficient than direct combustion of the original fuel because it can be combusted at higher temperatures or even in fuel cells, so that the thermodynamic upper limit to the efficiency defined by Carnot's rule is higher (Burgt et al., 2008). Syngas may be burned directly in gas engines, used to produce methanol and hydrogen, or converted via the Fischer-Tropsch process into synthetic fuel. Gasification can also begin with material which would otherwise have been disposed of such as biodegradable waste. In addition, the high-temperature process refines out corrosive ash elements such as chloride and potassium, allowing clean gas production from otherwise problematic fuels.

The technology of gasification had existed for nearly two centuries, first originated in Europe sometime in early 1800s (Moni et al., 2012) . The term 'gasification' was coined from its process where solid and sometimes liquid fuels are converted to gaseous fuel via incomplete combustion. The concept can be explained from as simple as lighting a cigarette – the simplest application that works on the gasification principle. During the early days after the discovery of the technology, the gaseous fuel produced via gasification of coal was used for heat and home and street lighting in big cities. Today, the technology has revolved and implemented in more complex applications from small to large scales to generate heat and electrical power from coal, waste and biomass. Although gasification may be an old technology, it was a long way from discovery to its wide application today. Combustion technology preceded gasification at a faster rate due to high availability and low cost of petroleum fuels and natural gas. Only recently that gasification attracted a lot of attention mainly attributed to the growing interest in green technology and the quest for the alternatives to the depleting and costly hydrocarbon-based fuels.

The process of gasification is explained thoroughly by Moni and Sulaiman (2012) in his book "Downdraft gasification of oil palm frond: A practical approach". Gasification commonly has four common thermochemical stages for which the temperatures for each stage are different, as shown in Figure 2.1. The first stage – drying occurs at a temperature up to 200°C, where mostly water (H_2O) is driven off from the feedstock as steam that forms liquid condensates and corrosive organic acid compounds up to 10% of the feedstock weight or more, depending on feedstock's initial moisture content. This stage is essential to prepare the feedstock for pyrolysis.

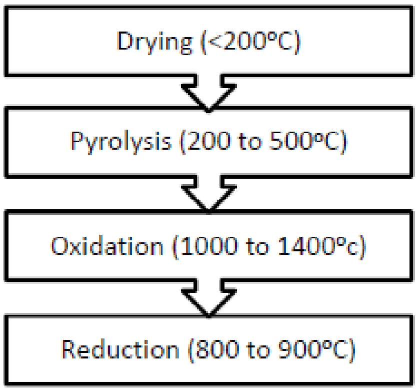

Figure 2.1: Thermochemical stages in gasification.

The second stage is pyrolysis process. Pyrolysis is a thermochemical decomposition of organic material at elevated temperatures in the absence of oxygen, occurs at temperatures exceeding 200°C and up to 500°C. At a temperature range of 200°C to 280°C known as the pre-pyrolysis temperature, CO_2, acetic acid and more H_2O are driven off due to the breaking of carbonyl and carboxyl functional groups. At pyrolysis temperature range of 280°C to 500°C, carbonic acids, methyl alcohol, tar, phenol, ether,

CO, CO_2 and other organic gases are formed in rich quantity due to the breaking of carbon aromatic rings. H_2 is highly formed at temperature around 400°C and maximum yield of oil is obtained as the temperature reaches 500°C. The third stage is oxidation via a typical combustion process, occurring at a temperature range of 1000 to 1400°C. This zone consumes the feedstock in combustion process, generating and supplying heat to the whole reactor to increase temperatures sufficiently for drying, pyrolysis and reduction processes to take place. When volatile gases travel through the charcoal bed where oxidation process normally takes place, the high temperature zone thermally-cracks heavy hydrocarbon, tar, watery condensates and pyrolysis oil into simpler organic chemical components. Also it promotes large quantity of H_2 to be produced and further converterd into producing hydrogen-rich gas mixtures. The final stage is reduction process, where high temperature chemical reactions occur with absence of oxygen. Main principal chemical reactions that take place during this stage, namely Boudouard Reaction and Water-Gas Shift Reaction, are endothermic. Hence the temperature of gas reduces at this stage and is lower than oxidation stage temperature, usually of 800°C to 900°C. After this stage only char, ash and sometimes slag are left out of the initial biomass without further reacting and are considered as gasification slid by-products. No reaction takes places beyond this point as temperature drops below 700°C.

2.1.2 Waste Heat

Waste heat is a heat which is generated in a process by way of fuel combustion or chemical reaction, and then “dumped” into the environment even though it could still be reused for some useful and economic purpose. The essential quality of heat is not the amount, but rather its “value”. The strategy of how to recover this heat depends in part on the temperature of the waste heat gases and the economics involved (Reay et al., 1979). If some of the waste heat from large quantity of hot flue gas generated from thermochemical process device could be recovered, a considerable amount of primary fuel could be saved. The energy lost in waste gases cannot be fully recovered. However, much of the heat could be recovered and loss minimized by adopting a proper measurement and technique. Usually higher the temperature, higher the quality and more cost effective is the heat recovery. In any study of waste heat recovery, it is absolutely necessary that there should be some use for the recovered heat. Typical examples of use would be preheating of combustion air, space heating, or pre-heating boiler feed water or process water. With high temperature heat recovery, a cascade system of waste heat recovery may be practiced to ensure that the maximum amount of heat is recovered at the highest potential. An example of this technique of waste heat recovery would be where the high temperature stage was used for air pre-heating and the low temperature stage used for process feed water heating or steam raising.

Recovery of waste heat has direct and indirect effects on the efficiency of the process. The direct benefits are reflected by reduction in the utility consumption & costs, and process cost. Meanwhile the indirect benefits are reflected in reduction in pollution, equipment sizes and auxiliary energy consumption (Zhang et al., 2009).

2.2 Related Work

2.2.1 Heat Exchanger System

Brammar and Bridgwater (2001) conducted modelling study on types of biomass dryer by using heat recovered from hot engine exhaust gas, engine coolant circuits and gasifier exhaust gas. They used spreadsheet package Microsoft Excel together with the programming code Microsoft Visual basic to conduct the study. It compromised sub-models of each system element, each on a separate worksheet, with an inputs and results worksheet in addition. Anyhow, they did not focus on the temperatures during gasification operation. They assumed the temperatures captured from the three locations to be 100°C before entering the dryers. They focused on how efficient are the dryers on reducing the moisture content of biomass with the variable of its feeding rate.

There are 3 types of dryers that have been developed by the authors.

1) Rotary cascade dryer, using engine exhaust gas and ambient air (Figure 2.2),
2) Rotary cascade dryer with integral burner, using engine exhaust gas, burner exhaust gas and ambient air (Figure 2.2),
3) Deep-bed band conveyor dryer, using warm air heated from the engine coolant system (Figure 2.3)

The result gained for the simulation study of all three types of dryers is shown as per graph in Figure 2.4.

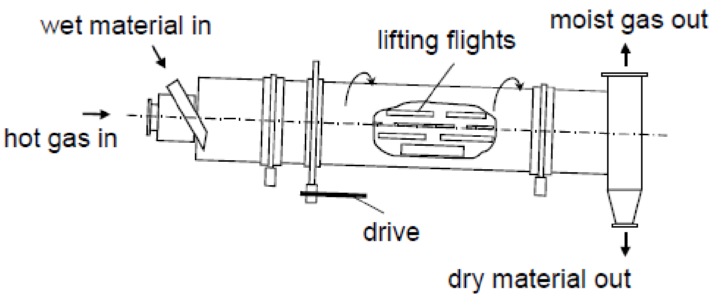

Figure 2.2: Rotary cascade dryer by Brammar and Bridgwater (2001)

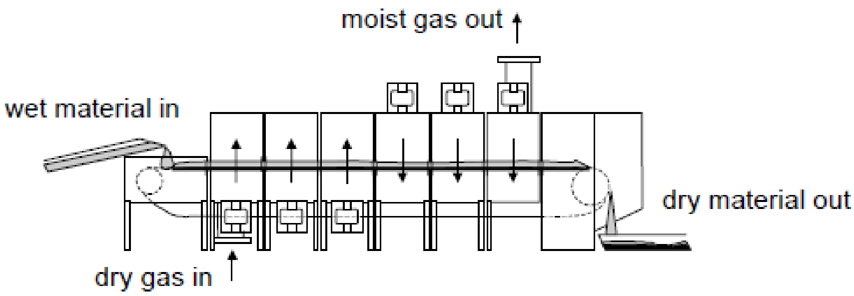

Figure 2.3: Bed band dryer by Brammar and Bridgwater (2001)

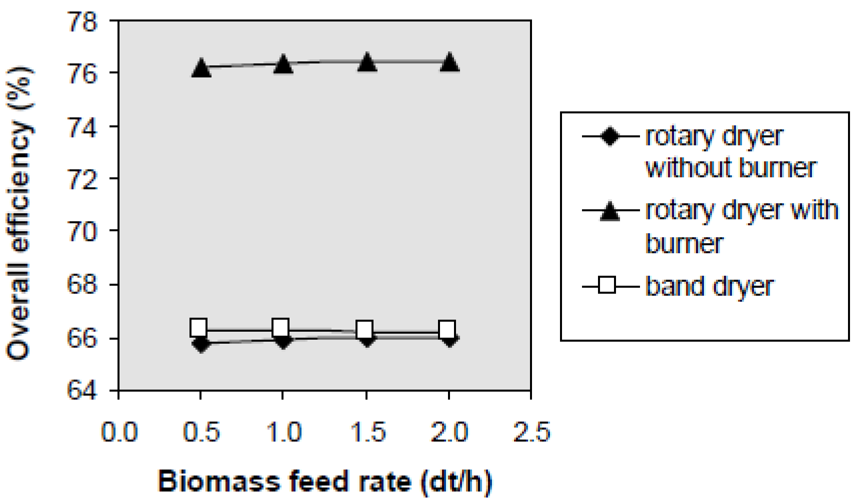

Figure 2.4: Result of overall efficiency against biomass feed rate of three dryers type gained by Brammar and Bridgwater (2001)

The result shown by the Brammar and Bridgwater prove that rotary dryer with integrated burner is much more efficient at any biomass feed rate, compared with the other two dryers. The use of integrated burner managed to get additional heat to dry the biomass. However, the integrated burner requires high electricity consumption to work, which adds to high capital and utility cost. They concluded that the bed bend dryer is the best dryer to be used as it has the lowest electrical power requirements, capital cost and utility cost but provided a good overall efficiency.

In the article "High-temperature, air-blown gasification of dairy-farm wastes for energy production" written by Young and Pian (2002), they conducted an experiment of preheating air by using heat recovery. The heat recovery system that they used was Multistage Enthalphy Extraction Technology (MEET). The system was able to recover the waste heat produced by the fuel gas and added extra heat to supply as gasifying air. The same MEET system was used by Ishii et. all (2003) in "Gasification Performance of Coals Using High Temperature Air" to increase the temperature of preheated air. Both studies showed that they managed to recover the waste heat and generate extra air temperature prior to entering the gasifier. The systems used by both studies are illustrated in the Figures 2.5 and 2.6

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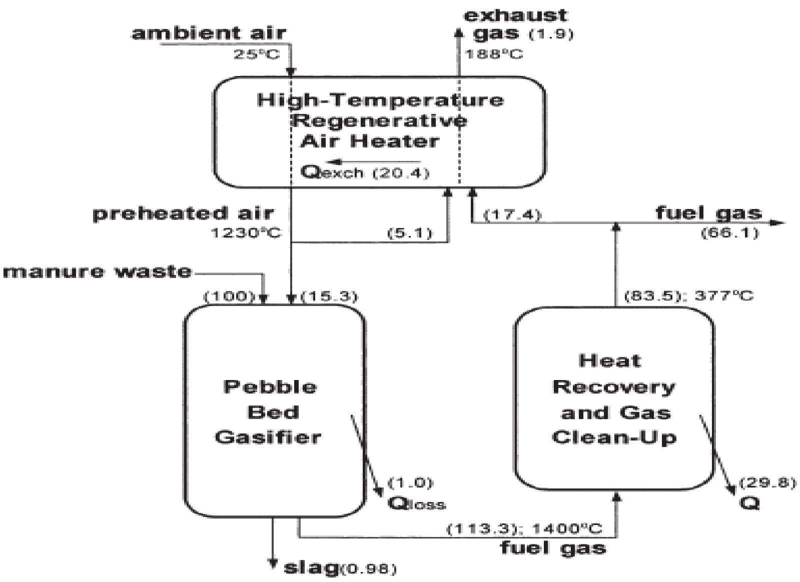

Figure 2.5: MEET system implemented by Pian et. all (2003)

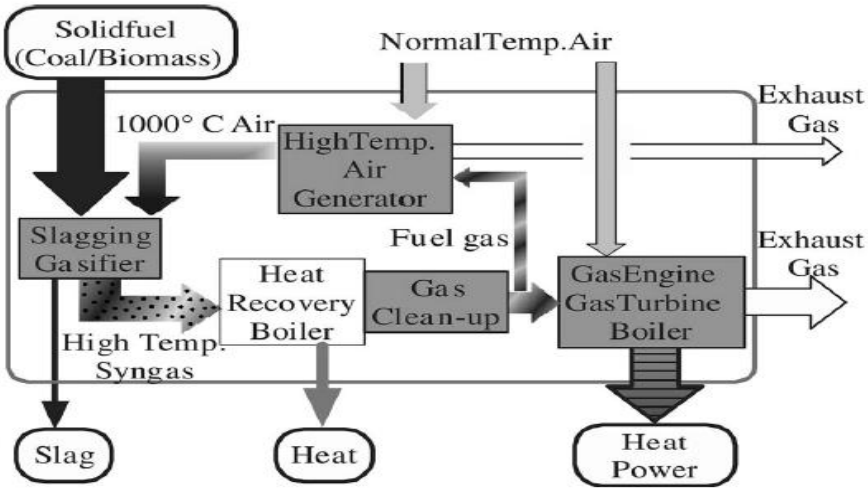

Figure 2.6: MEET system implemented by Ishii et. all (2003)

Although both Pian (2003) and Ishii (2003) experiments managed to capture the waste heat from gasification system. They also used the syngas produced by gasifier to be the fuel for high temperature air generator to increase the gasifying air up to 1200°C. The disadvantage of the MEET system used by both studies is that they have to use part of the syngas produced from gasification to generate the air heating generator.

A research by Roesch (2011) used spiral plate counter flow heat exchanger to convert waste exhaust heat into useable heated water. The entire heat exchanger was covered in silica based insulation to prevent heat loss to environment. The experiment was conducted at different water flow rate in the heat exchanger. The heat exchanger constructed and experiment result is shown in Figures 2.7 and 2.8.

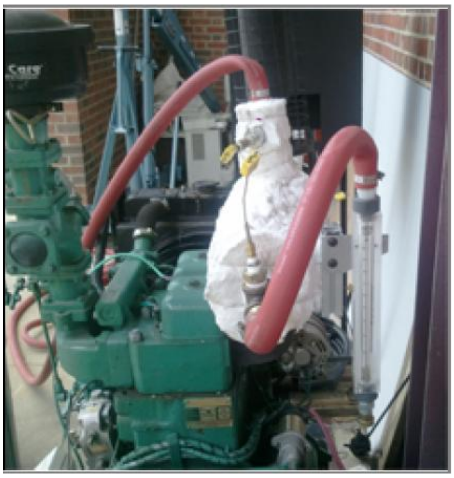

Figure 2.7: Heat exchanger constructed by Roesch (2011)

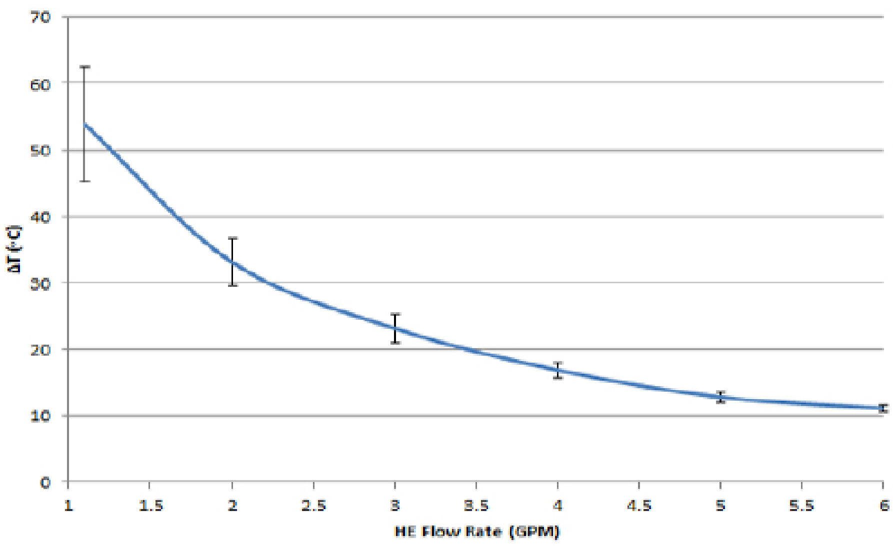

Figure 2.8: The result of heat exchanger experiment conducted by Roesch (2011)

Based on the graph shown in Figure 2.8, the waste heat captured in the heat exchanger is higher when the water flowrate in heat exchanger is low. As comparison, at 1.1 gallon per minute (GPM), the waste heat manage to increase the temperature of water up to 54°C from original temperature, while at 6 GPM water flow rate the captured waste heat only manage to increase the temperature by 11°C. This experiment shows that by having a lower water flowrate travelling in heat exchanger, the waste heat captured is much higher.

2.2.2 Biomass Moisture Content

In “Biomass Downdraft Gasifier Engine Systems Handbook” written by Agualas and Reed (1988), they found that combustion efficiency and recoverable heat drops dramatically with the increased moisture. As comparison, biomass at 0% of moisture content, the recoverable heat and combustion efficiency produced by the gasification is 7097 Btu/lb and 82.5% respectively, while at 50% moisture content biomass, the recoverable heat and combustion efficiency is only 5868 Btu/lb and 68.2% respectively. The result of their study is shown in Figure 2.9.

Effect of Moisture Content on Heat Recovery and Combustion Efficiency[a]

Moisture (wt %) Dry Basis	Moisture (wt %) Wet Basis	Recoverable Heat[b] (Btu/lb)	Combustion Efficiency (%)
0.00	0.00	7097	82.5
4.76	4.54	7036	81.8
9.09	8.33	6975	81.1
13.04	11.54	6912	80.4
16.67	14.29	6853	79.7
20.00	16.67	6791	78.9
23.08	18.75	6730	78.3
28.57	22.22	6604	76.8
33.33	25.00	6482	75.4
42.86	30.00	6178	71.8
50.00	33.33	5868	68.2
60.00	37.50	5252	61.1
66.67	40.00	4639	53.9
71.43	41.67	4019	46.7

Figure 2.9: The effect of moisture content on recoverable heat and combustion efficiency by Agualas and Reed (1988)

The result gained by Agualas and Reed (1988) was clearly explained by McKendry (2002) in his article "Energy production from biomass (part 1): Gasification techonologies". The relationship between biomass moisture content and appropriate bio-conversion technology is essentially straight forward. According to McKendry, thermal conversion requires low moisture content feedstock, while bio-conversion can utilise high moisture content feedstocks. Thermal conversion technologies can also use feedstocks with high moisture content but the overall energy balance for the conversion process is adversely impacted. On this basis, woody and low moisture content herbaceous plant species are the most efficient biomass sources for thermal conversion to liquid fuels, such as methanol. For the production of ethanol by biochemical (fermentation) conversion, high moisture herbaceous plant species, such as sugarcane, are more suited: such species can also be fermented via another biochemical process, anaerobic digestion (AD), to produce methane.

This effect of biomass content in gasification was explained more by McKendry in another article ("Energy production from biomass (part 3): Gasification Technologies"). Fuel with moisture content above about 30% makes ignition difficult and reduces the Calorific Values of the product gas due to the need to evaporate the additional moisture before combustion/gasification can occur. High moisture content reduces the temperature achieved in the oxidation zone, resulting in the incomplete cracking of the hydrocarbons released from the pyrolysis zone. Increased levels of moisture and the presence of CO produce H_2 by the water gas shift reaction and in turn the increased H_2 content of the gas produces more CH_4 by direct hydrogenation. The gain in H_2 and CH_4 of the product gas does not however compensate for the loss of energy due to the reduced CO content of the gas and therefore gives a product gas with lower Calorific Values.

The effect of moisture content in the feedstock on the quality of the gas was agreed by Moni et al. (2012). The authors claimed that the biomass feedstock with a moisture content range of lower than 15% were found to be the most suitable fuel for the production of syngas. Fuel with moisture content of higher than 15% was found to cause several gasifier operation breakdowns due to excessive water production and has to be avoided.

2.2.3 Preheating of Gasifying Air

Air preheating was found to increase the production of combustible gases, H_2 and CO, which increases the product gas heating value (Doherty et al., 2009). The effect of gasifying air temperature on gas compositions was clearly stated in the graph in Figure 2.10.

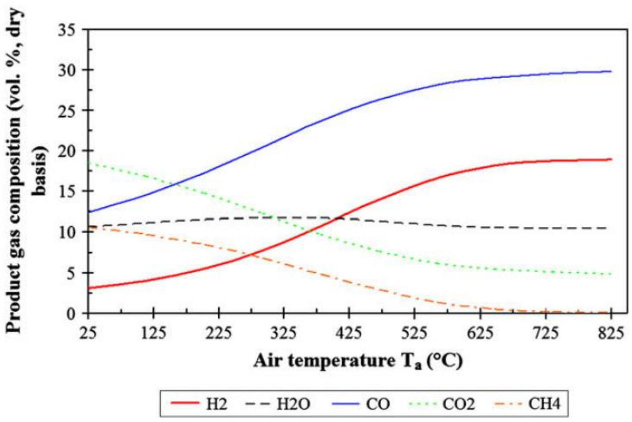

Figure 2.10: Effect of gasifying air temperature on product gas composition

(Doherty et al., 2009)

Although the methods are different, the same graph pattern was shown by Blasiak et al. (2005) in his article "Performance analysis of a fixed-bed biomass gasifier using high-temperature air". Blasiak et all used a calculation method while Doherty et. all used a software simulation method. Nevertheless, the result gained from the two researchers proved that increasing the gasifying air provides a better production gas.

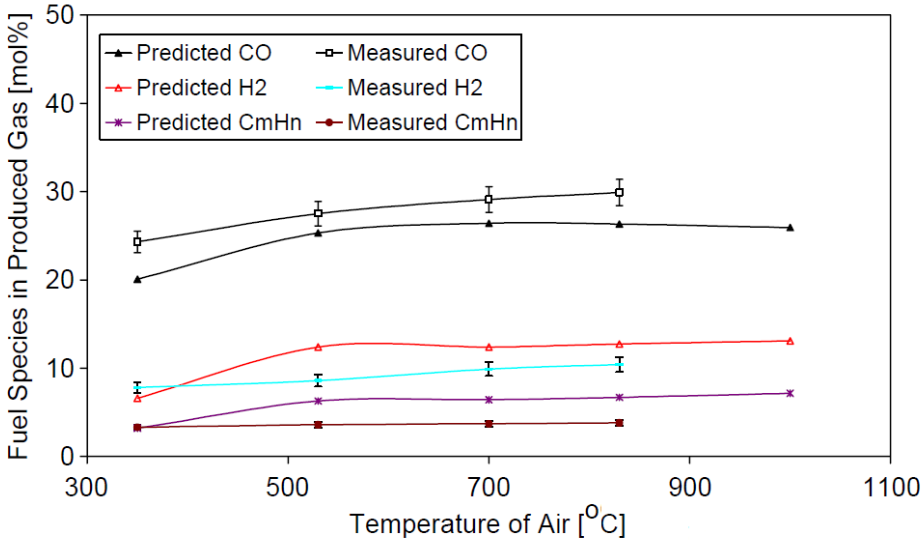

Figure 2.11: Effect of intake air temperature on product gas compositions

(Blasiak et al., 2005)

Air preheating is a means of increasing the conversion efficiency of the gasification process (Doherty et al., 2009). The sensible heat in the air caused a rise in the gasification temperature, which in turn influenced the product gas composition, causing an increase in the production of combustible gases, H_2 and CO. Air preheating offers an alternative and more economical approach than oxygen blown system. The overall efficiency of the process on a thermal basis would be increased if the heat required for air preheating was recovered from the gas cooling section of the plant. Use of high temperature air as an oxidant achieves downsizing of the plant. Downsizing is achieved because a smaller volume of air is needed to bring the gasifier to the required operating temperature, which in turn reduces the size of the reactor and gas cleanup system needed.

CHAPTER 3

METHODOLOGY

In this chapter, the methodology is explained on how the project is executed; the process of the project and the scheduling of activities performed which include flow chart, and project gantt chart.

3.1 Flow Chart

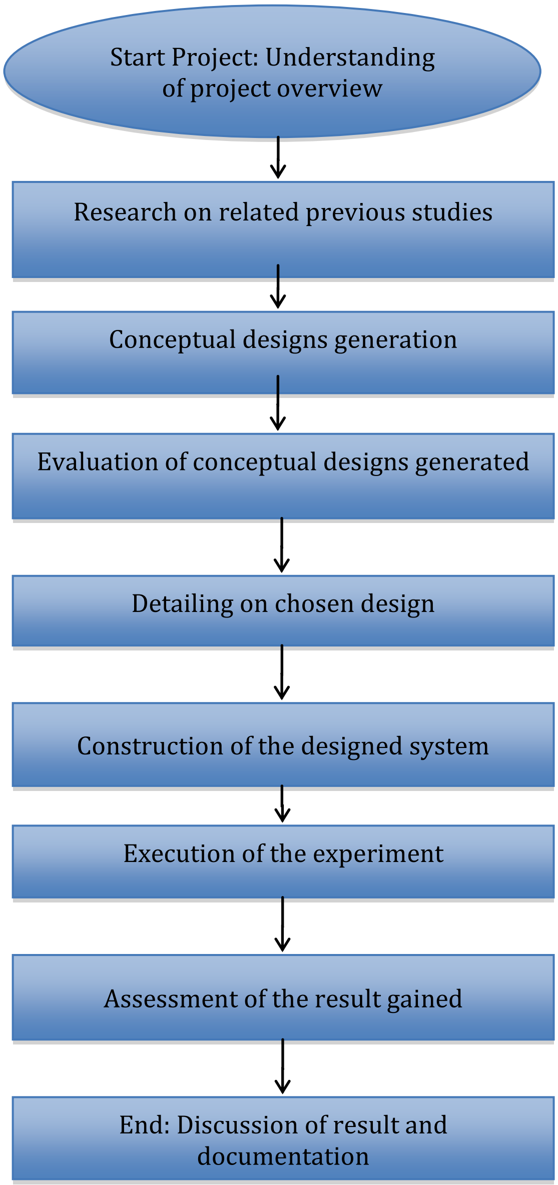

Figure 3.1: The process flow of the project

Figure 3.1 shows the process flow of the project that had been done during FYP 1 and FYP 2. The project commenced with the understanding the overview basic of the project. The background, problem statement, and objective of the study were explored in detail. The project then was initiated with the study on previous researches to gain all necessary information related to the study. After that, the generation of conceptual designs took place. The design was evaluated to choose the best design, and it was based on few criteria, namely; reliability, safety, flexibility and cost. The best design that was chosen from the evaluation was detailed in the next stage. The size, shape, materials and functionality of the design are determined thoroughly. The design then was sent for construction by a fabrication company, RNR Tools Sdn. Bhd in Falim, Ipoh, Perak. However, only heat exchanger was constructed by fabricator while the drying box was fabricated in UTP. Once all the system has been constructed, the experiment was executed with few variables were tried to find the effectiveness of the system designed. The result gained was assessed and discussed, before it is written in this report.

3.2 Project Work

The main steps in the methodology are as follows:

1. Research and studying concept.

   Subsequent to decide the topic for the study work, the author did the research on different journals to have better understanding about the concept of gasification operation and furthermore related to the objectives of the study.
2. Conceptual designs.

   Few conceptual designs were generated based on author’s basic knowledge especially in heat transfer. All the designs were evaluated to choose the best design and it was based on few criteria, namely; reliability, safety, flexibility and cost.
3. Detailed design.

   The best design that has been chosen from evaluation will be detailed in terms of sizing, shape, materials and functionality. The detailed drawings of system designed were produced at this stage.

4. Construction of design.

   The designed system was constructed by a fabrication company in Falim, Ipoh, Perak. Only heat exchanger was constructed by the fabricator while the drying box was fabricated in house.

5. Execution and assessment of experiment

   When both heat exchanger and drying box had been fabricated, the system was performed on functional test to see if the constructed item is working well. The whole system also was assembled before the real experiment is being executed. The result of the experiment was assessed and discussed in this report.

3.3 Gantt Chart

Activity (FYP 1)	**Week of January 2013 semester**													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Overview Basic of the Project														
Conceptual Design Generation														
Evaluation of Conceptual Design														
Study on Literature, Technical Paper & Extended Proposal														
Design Detailing														
Interim Report Preparation														

Figure 3.2 Gantt chart for FYP 1

Activity (FYP 2)	**Week of May 2013 semester**													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Design Detailing														
Construction of the Heat Exchanging System														
Functional Test For Constructed System														
Execution of the Experiment														
Assessment of the Experiment														
Final Report Preparation														

Figure 3.3 Gantt chart for FYP 2

The project commenced in FYP 1 with the understanding the overview basic of the project once the project was confirmed to be undertaken by the author in week 3. The generation of conceptual design and its evaluation were taken place in week 3 and 4 of

January 2013 semester. At the same week 3 of the semester, the study on literatures, technical papers and preparation for extended proposal were initiated for 3 weeks long. After that, the activity of detailing the design and preparation for interim report took place starting from week 6 and 13 until last week of the semester. The interim report was submitted at week 14, and the detailed design work had to continue in the next semester.

The FYP 2 in May 2013 semester started with the continuation of design detailing. The detailing took a time before the construction is performed by fabricator once the design is confirmed at week 12. Due to time constraint, the system functional test, experiment execution and its assessment were performed in only a week at week 13 before the preparation for final report and viva took place at the end of the week.

CHAPTER 4
DESIGN AND CALCULATIONS

In chapter elaborates the conceptual designs, design evaluations, calculations, detailed designs and the parameters that have been generated for the execution of the experiment.

4.1 Conceptual Design

This part in the chapter will be explaining all conceptual designs that have been generated by author before being evaluated to pick the best design to be constructed. There are three conceptual designs generated by author. Design 1 and 2 use air as a heat transfer medium while Design 3 uses water. The details of each conceptual design generated are further explained in Section 4.1.1.

4.1.1 Conceptual Design Details

Design 1

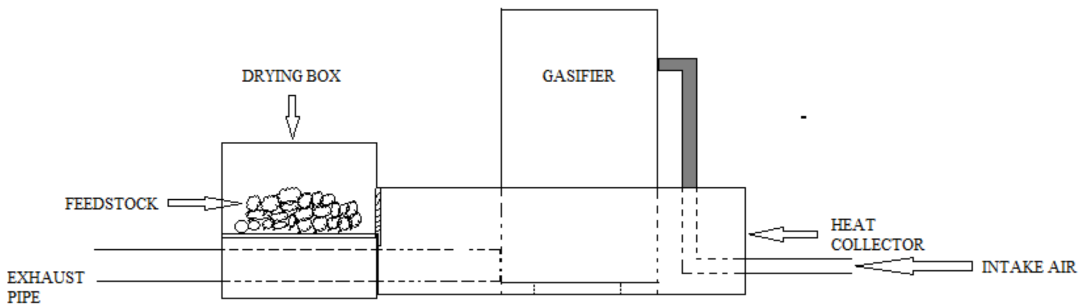

Figure 4.1: Conceptual Design 1

This designed system only use air as a heat transfer medium. The wall of gasifier and its exhaust pipe are jacketed to trap the waste heat released from the components. The heat trapped will increase the temperature inside drying box which is installed directly on top of the exhaust pipe to avoid heat loss to surrounding. Meanwhile for preheating of gasifying air, air pipe is installed near the gasifier wall, going through the heat collector before entering the gasifier.

Design 2

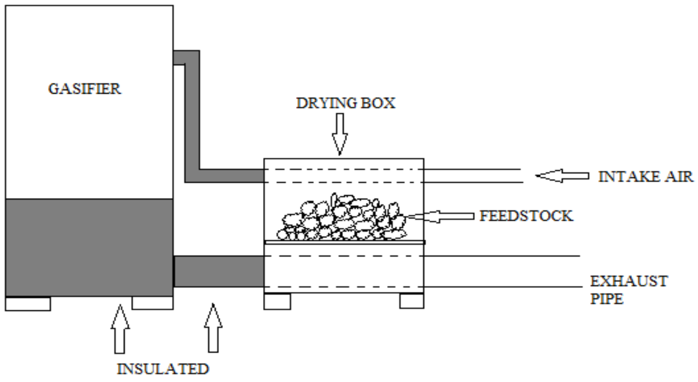

Figure 4.2: Conceptual Design 2

The wall and exhaust pipe of the gasifier are insulated to keep the temperature from released to surrounding. The drying box is installed at the exhaust pipe, where the exhaust pipe in the drying box is not insulated. This resulted the drying box is heated to its maximum temperature. For preheating of gasifying air, an air pipe is located at the top of drying box to heat the gasifying air by using the same heat released by exhaust pipe inside the drying box.

Design 3

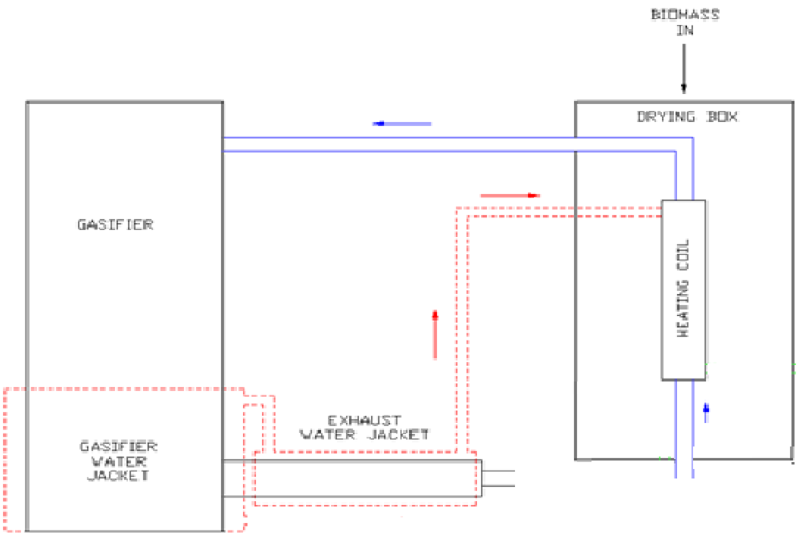

Figure 4.3 Conceptual Design 3

The wall and exhaust pipe of gasifier are jacketed with water jacket. Water will be pumped in to go through to the water jackets to be heated. The heated water enters the heat exchanger inside drying box to dissipate the heat and increase the temperature inside drying box to dry the biomass. The heat exchanger also is designed to circulate air pipe to heat the intake air heading to gasifier.

4.1.2 Comparison Table

Table 4.1 shows the evaluation that had been made to find the best design to be constructed. Each conceptual design was evaluated, and the highest mark was found to be Design 3.

Table 4.1 Comparison table for conceptual designs

Criteria	**Weightage**	**Design 1**	**Design 2**	**Design 3**
Reliability	5	6	6	8
Safety	2	8	9	9
Flexibility (Fabrication)	2	8	9	7
Cost	1	8	9	7
Total	**10**	**70**	**75**	**79**

The conceptual designs were evaluated based on 4 criteria; reliability, safety, flexibility in fabrication and cost. Each evaluation criteria has its own weightage. They are weighted based on the explanation below:

Reliability – Can the system perform and maintain the functions in routine circumstances?
(1 – Not reliable, 10 – Very reliable)

Safety – Is the heat exchanging system safe to operate? Is it flexible for user to do the modification or adjustment during gasification operation without getting exposed to the heat?
(1 – Dangerous, 10 – Very safe)

Flexibility (Fabrication) – Is the system easy to fabricate and construct? *(1 – Hard to fabricate, 10 – Easy to fabricate)*

Cost – How high the cost required to fabricate and operate the system? *(1 – Very expensive, 10 – Cheap)*

4.2 Theoretical Calculations

Calculations were made theoretically during the design detailing to find out the best parameters to be used during the execution of experiment. It is summarized in the Section 4.2.1 and 4.2.2. The detailed calculations can be found in Appendix A.

4.2.1 Heat Loss

<u>Reactor Wall</u>

The downdraft gasifier normally works at a reactor temperature of 700^{o}C and above. Its wall, at the most minimum thickness is composed of 4 mm carbon steel sheet (k=47 W/mK), 21 mm refractory cement layer (k=1.01 W/mK) and another 4 mm carbon steel sheet, in that order. Only the bottom one-third area (450 mm (L) x 450 mm (W) x 400 mm (H)) of each of the gasifier wall experiences high temperature exposure due to its location that is nearer to the reactor core. The average outer surface temperature of this area is 200^{o}C, giving an average temperature drop of 500^{o}C through the gasifier wall. The heat loss from the gasifier wall was found to be 19,320 W.

<u>Exhaust Pipe</u>

Hot gases from the downdraft gasifier travel out of the reactor via the 500 mm long, 3 mm thick and 100 mm in diameter galvanized iron pipe (k = 30 W/mK) with an average temperature of around 250^{o}C. The pipe outer surface temperature averages at 200^{o}C. The heat loss through the pipe is calculated using the conductive heat loss formula through a cylindrical system. The heat loss at the exhaust pipe was found to be 15, 232 W.

<u>Total Heat Loss</u>

The total heat loss from the gasifier system is combination of heat loss from gasifier wall and exhaust pipe. The total heat loss through conduction from the system is 34,463 W or

34.5 kW. Assuming that 70% of the heat is recoverable, the total recoverable heat from the system, Q_{rec} will be 24.2 kW or rounded to 24 kW.

4.2.2 Heat Carrier

The heat carrier used for the heat capturing system will be treated water with 1000 kg/m^3 density and 4,181.3 J/kgK specific heat capacity value at a standard temperature of 20^{o}C. The heat carrier is expected to experience an increase of 70^{o}C in temperature after heating. The final heat carrier temperature will be 90^{o}C.

Flow Rate

The volume flow rate of heat carrier was found to be 0.000082 m^3/s or 0.3 m^3/hour. This is equivalent to 300 liter per hour or 5 liter per minute (LPM).

Heating Time

The heating time required was found to be 549 seconds (9 min 9 sec). This is equivalent to the traveling time of the heat carrier through the water jackets. To compensate, the heat carrier flow rate needs to be adjusted accordingly. However, the flow rate must not be low enough to increase the heat carrier retention time in tubing that enables the carrier to change state to steam at 100^{o}C, which is calculated to be 0.26 m^3 / hour.

4.3 Detailed Design

<u>Design Summary</u>

The parameters of the design are summarized in the Table 4.2 while the CAD drawing of the design is shown in the Figure 4.4.

Table 4.2: Design parameters summary

Water Jacket	
Gasifier water jacket	
Dimension, m	0.55 (L) x 0.55 (W) x o.4 (H)
Volume, m^3	0.04
Heat carrier capacity, liter	40
Exhaust pipe jacket	
Dimension, m	0.15 (D) x 0.5 (L)
Volume, m^3	0.005
Heat carrier capacity, liter	5
Heat Carrier	
Flowrate	0.26 m^3 / hour.
Drying Box	
Dimension, m	0.39 (L) x 0.39 (W) x 0.5 (H)
Volume, m^3	0.77

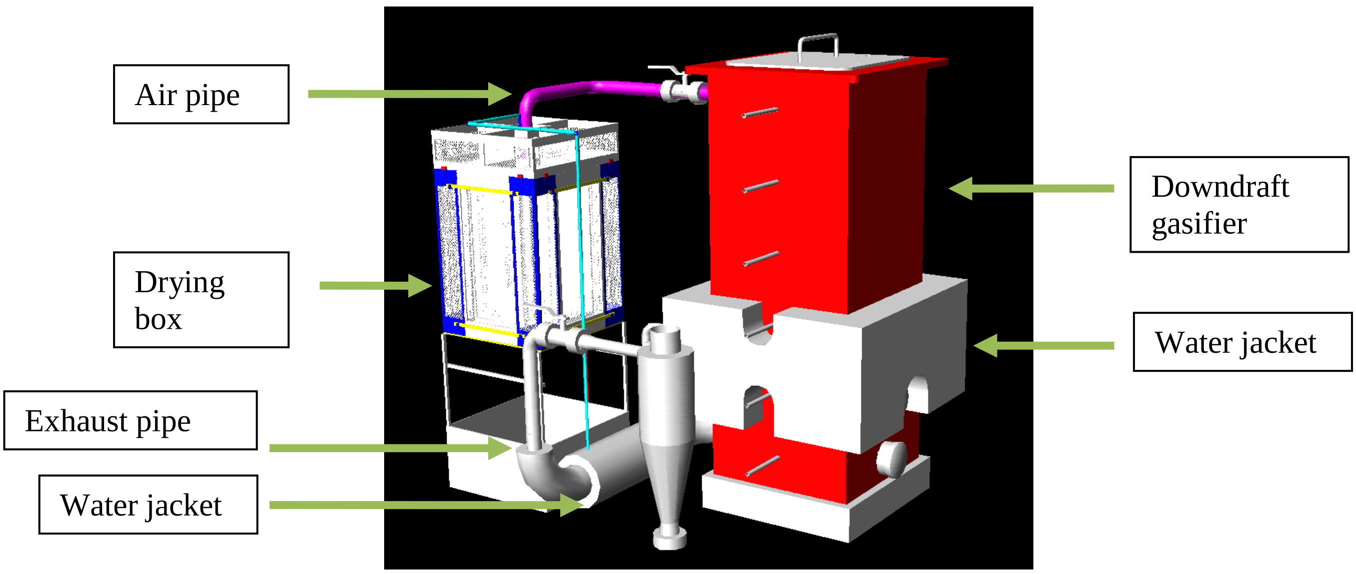

Figure 4.4: CAD drawing of heat exchanger system designed

4.3.1 Water Jackets

Gasifier Water Jacket

A rectangular water jacket heat exchanger will be attached to the gasifier to cover a heating area of 450 mm (L) x 450 mm (W) x 400 mm (H) on the gasifier wall. The dimension of the water jacket is 550 mm (L) x 550 mm (W) x 400 mm (H), giving a total volume, V_{gasjac} of 0.04 m^3, equivalent to 40 liters of water.

Exhaust Pipe Water jacket

A tubular water jacket heat exchange will be attached to the exhaust pipe in the form of twin-tube heat exchanger. The exhaust pipe has a dimension of 100 mm (D) x 500 mm (L) while the water jacket has a dimension of 150 mm (D) x 500 mm (L). The volume of the water jacket, V_{exhjac} is 0.005 m3, equivalent to 5 liters of water.

Total Volume of Water Jacket

The total volume of water jackets, $V_{jackets}$ is the summation of volume of the gasifier water jacket, V_{gasjac} and exhaust water jacket, V_{exhjac} which is 0.045 m^3 and is able to house 45 liters of water at full capacity.

4.3.2 Drying Box

The drying box designed consists of 4 main boxes which can be assembled into one. The boxes are differentiated by its location towards heat exchanger which is located at the middle of the box. Each box has been divided into minor parts, so that the minor parts in all boxes are identical in volume (with the tolerance of 5%). Figure 4.5 shows the assembly drawing of all the boxes combined into 1 box. Figure 4.6 shows the drawing of Box A and C which will be placed on top and bottom of the drying box. Figure 4.7 shows the central dryer which to be located in the center of the drying box and Figure 4.8 shows the Box B which to be placed to fit the void space at central dryer. Details of all the drying boxes (dimensions and materials) can be seen in the Appendix B.

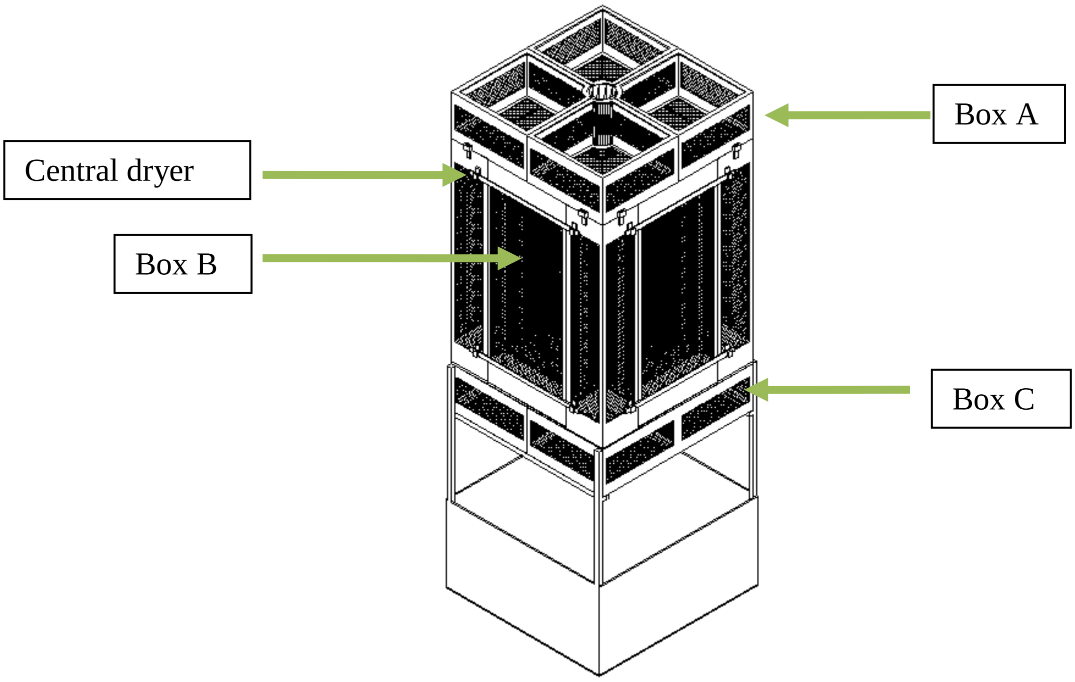

Figure 4.5: The assembly drawing of the drying box

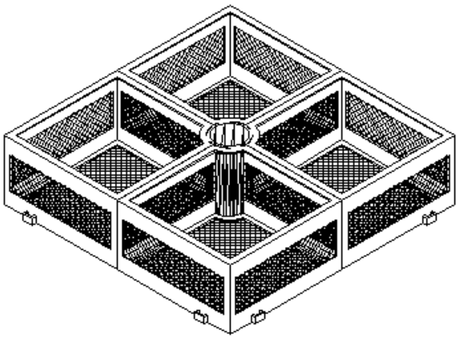

Figure 4.6: Box A and C (Placed at the top and bottom of the drying box)

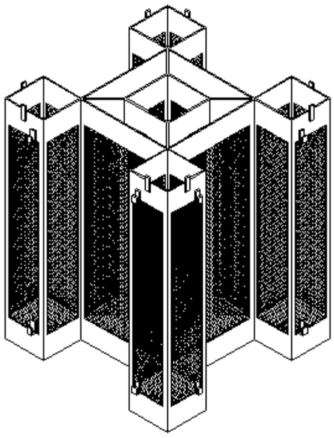

Figure 4.7: Central Dryer (Placed at the center of the drying box)

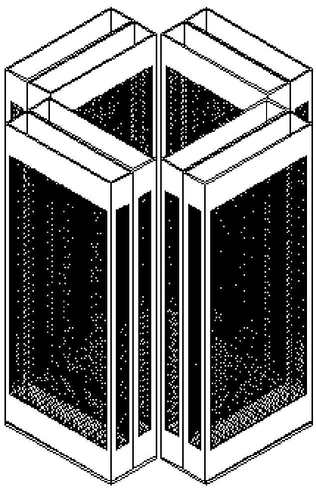

Figure 4.8: Box B (Placed to fit the void space at central dryer)

4.3.3 Heat Exchanger

Heat exchanger which is located inside the drying box was designed to let the hot water flow through the copper coil to dissipate the heat to the air tube (inside the heat exchanger) and/or to the surrounding. Details of the heat exchanger (dimensions and materials) can be seen in the Appendix B.

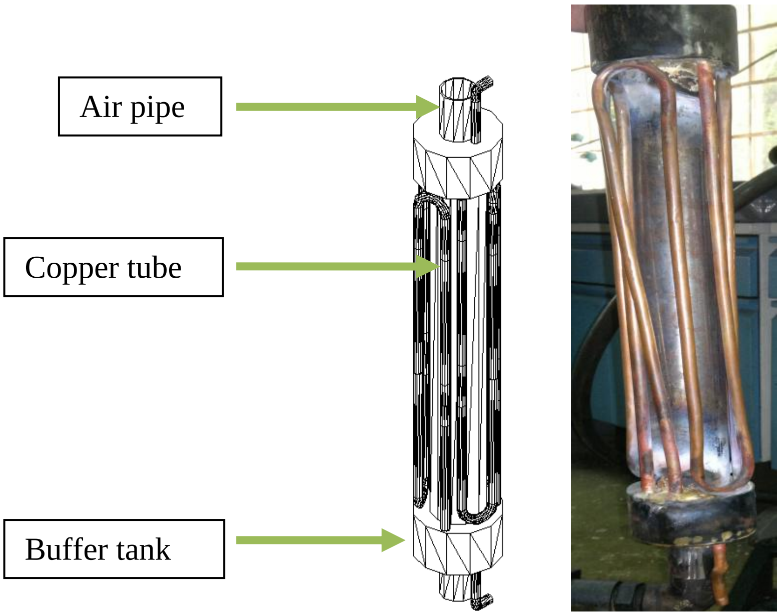

Figure 4.9: Heat exchanger in the drying box

CHAPTER 5

RESULT AND DISCUSSION

Due to time constrain in academic calendar to fabricate the whole designed system, the experiment was simplified by only simulating the heat exchanging process in the drying box. The reservoir tank was placed on top of the drying box to let the hot water from reservoir tank flow inside the heat exchange. The hot water flowrate was suppose to be as what had been calculated which is 0.26 m^3 / per hour or 260 liter per hour or 4.3 LPM. However, the author only managed to get the hot water to flow at the rate of 3.5 LPM. This shall not be a problem as by using a lower flowrate of heat carrier, more heat can be dissipated to the drying box and gasifying air. The air flowrate used is as same as standard gasifying air flowrate for the downdraft gasifier which is 150 LPM. The experiment arrangement is shown in the Figure 5.1.

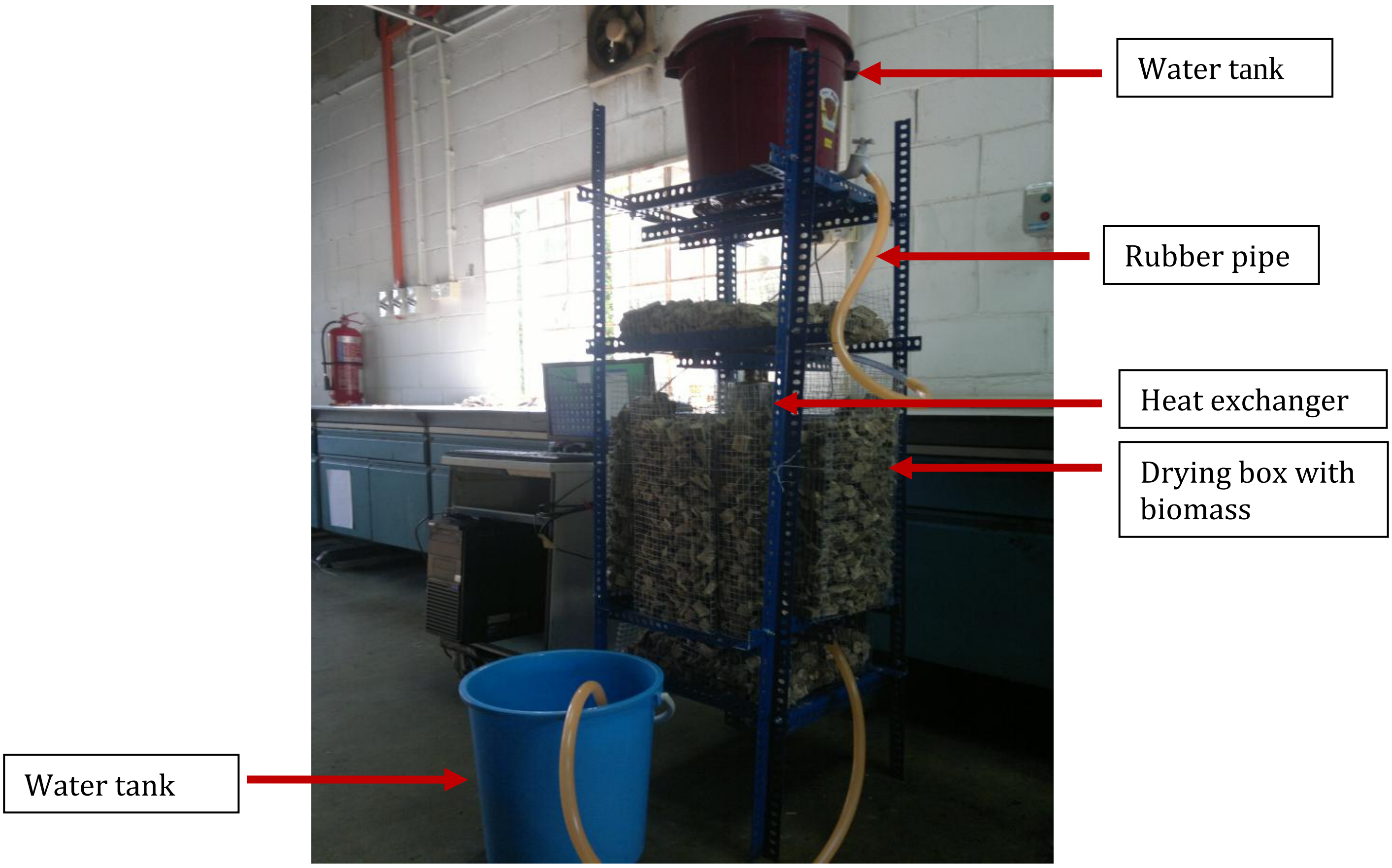

Figure 5.1: The experiment arrangement

Each zone in the drying box was fully filled with the 55% moisture content (dry basis) of OPF that had been cut into block shape (Length: 250 mm, cross section length: as grown). The weight of OPF in each zone is taken before and after experiment for moisture content reduction assessment. Each experiment was performed at approximately 20 minutes.

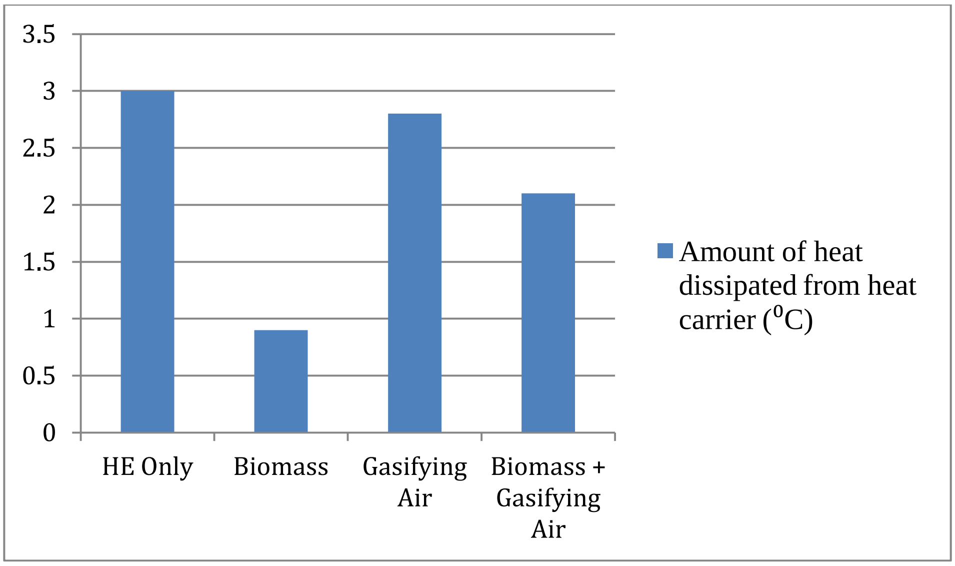

Figure 5.2: Amount of heat dissipated in heat exchanger through different approach

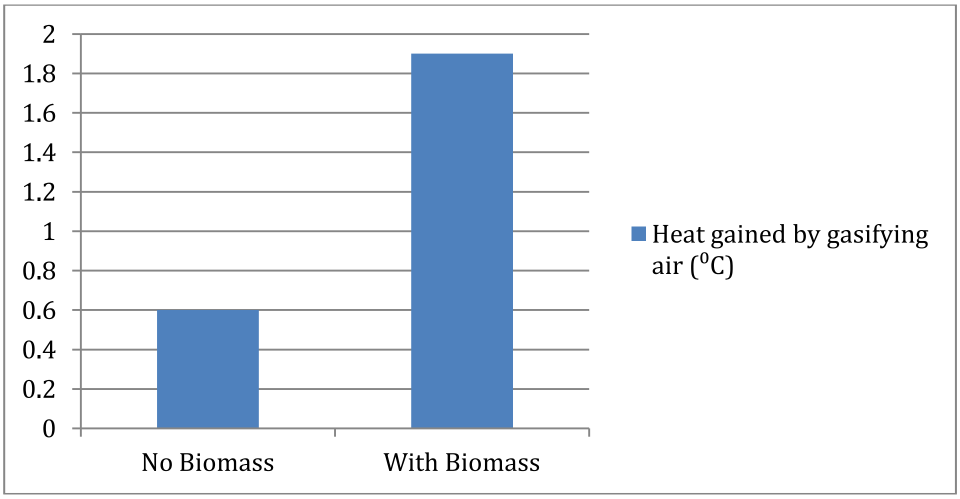

Figure 5.3: Amount of heat gained by gasifying air through different approach

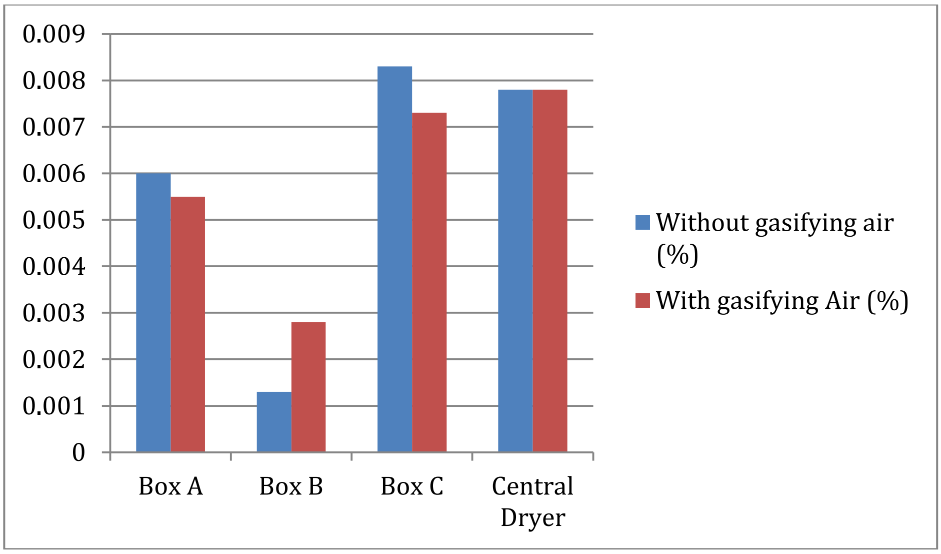

Figure 5.4: Reduction of biomass moisture content in each box.

The experiment first was conducted by letting only the hot water flow in the heat exchanger at the drying box to see how much temperature is dissipated from it. Then, gasifying air was blown at 150 LPM flowrate in the heat exchanger (HE) when the hot water is flowing. The result shown at Figure 5.2 where without gasifying air blow in the HE, the temperature dissipated from the HE is 3^{o}C while when there is a gasifying air blown in the HE, the heat dissipated from water is only 2.8^{o}C. However, the gasifying air only manages to have 0.6^{o}C increase in temperature (as per Figure 5.3).

The result gained from the biomass drying experiment as in Figure 5.4 is unexpected. The system designed cannot really reduce the moisture content of the OPF. By having low heat carrier temperature difference as shown in Figure 5.2, the system shows that the heat from HE cannot be dissipated to the drying box due to compactness of OPF in the drying box which act like an insulation barrier around the HE.

The experiment performed with gasifying air blown in the HE during biomass drying has no big different on result of reducing the OPF moisture content. However, with the OPF in the drying box acted as insulation barrier around the HE, more heat was found to increase the temperature of gasifying air in the HE. As comparison, the temperature rise when there is a biomass drying process is higher than when there is no biomass drying process happening.

CHAPTER 6
CONCLUSION

Based on the experiments conducted, it can be concluded that:

i. The simplified experiment fails to reduce the moisture content of OPF with or without gasifying air flowing in the heat exchanger at around $60^{o}C$ heat carrier temperature.
ii. The compactness of OPF in drying box will act as an insulation barrier surrounding the heat exchanger, in which it helps to increase the gasifying air temperature.

In the time ahead, based on experience and knowledge gained from this project, the author recommends several points to improve this experimental study:

i. To design a drying box where the OPF feedstock is not compacted inside as it will prevent it to form insulation-like barrier.
ii. If the same experiment is going to be conducted in future, use a higher heat carrier (water) temperature to be fed in the heat exchanger with a longer experiment time.
iii. Every OPF crumbs is considered as important contribution to the moisture content calculation. The loss of OPF crumbs to the ground can be calculated as the loss of moisture content in OPF and it will bring to the inaccurate result.

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