Application of Swirling fluidized bed in Converting Bio oil to Gasoline

by

Chin Xi Yi

Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

MAY 2010

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

Application of Swirling fluidized bed in Converting Bio oil to Gasoline

by

Chin Xi Yi

A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(MECHANICAL ENGINEERING)

Approved by,

(Prof. Dr. Vijay R Raghavan)

Vijay R. Raghavan
Professor
Mechanical Engineering Department
Universiti Teknologi PETRONAS

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
May 2010

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

CHIN XI YI

ABSTRACT

Swirling fluidized bed is proposed to be the reactor in the process of changing the bio-oil into gasoline. Hydrodexoygenation is the main process in changing the bio-oil into gasoline. It is the reaction that happens inside the reactor (swirling fluidized bed). During the reaction inside the reactor, large amount hydrogen gas is needed. This is due to the reaction require long residence time in the reactor. The excessive hydrogen gas must constantly supply to the reactor in order for the bio-oil to react with it. This will result many unreacted hydrogen gas coming out from the reactor. A hydrogen recycle system is developed conceptually to recycle back the hydrogen gas to the reactor. The process flow diagram and the plant flow sheet are determined and parts of the system are identified from the plant flow sheet and process flow diagram. There is 4 parts in the system which is the blower, heater, make-up hydrogen supply system and the piping system. The dimensioning of the parts will be further discussed in this report.

ACKNOWLEDGEMENT

For this project, I would like to reserve the highest appreciation to Prof. Dr. Vijay R Raghavan for his supervision, advice, and guidance during the project period. I also owe my deepest gratitude to Mr Vinod for giving me guidance in this project. Also thanks to Mr. Ahmmad Shukrie Bin Md Yudin for providing useful information and data for the completion of this project. Alongside, I would like to thanks all those involved directly and indirectly in assisting me through this FYP.

TABLE OF CONTENT

LIST OF FIGURE

LIST OF TABLE

CHAPTER 1

INTRODUCTION

1.1 Project Background

The researches of changing bio oil liquid fuel (gasoline) are one of the important topics now day. This is because it is one of the renewable energy.

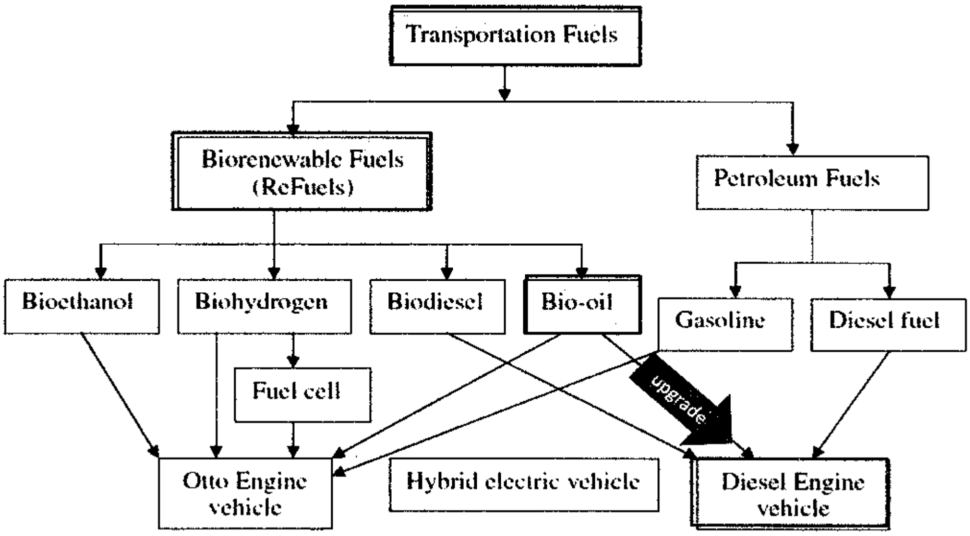

Figure 1: Alternative of Transportation Fuels

There are two routes to change the biomass to gasoline: (i) pyrolysis, whose products when cooled give a liquid, (ii) gasification process followed by gas-to-liquid process (GTL). Gasification is a process that converts carbonaceous materials into carbon monoxide and hydrogen by reacting the raw material, at high temperatures with a controlled amount of oxygen and/or steam. After the process, the biomass will turn into bio oil. The oxygenate compound from the bio-oil must be removed in order to become gasoline. Figure 1 shows the oxygenated compound in the bio-oil.

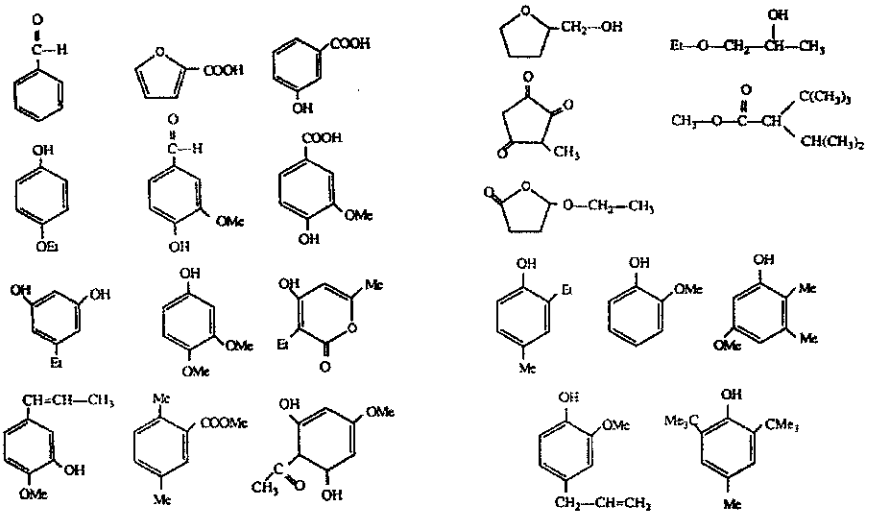

Figure 2: Typical structures of O-compounds in bio-oils.

Hydrogen must be added in to serve this purpose. This process is named Hydrodeoxygenation (HDO). HDO is the chemical reaction that results from the addition of hydrogen (H_2) to remove the oxygenated compound in the bio-oil. The oxygen will combine with the hydrogen and convert into water (H_2O). The process is usually employed to reduce or saturate organic compounds. Non-catalytic hydrodeoxygenation takes place only at very high temperatures. Catalysts are required to reduce the for the activation energy needed for the reaction. With the right proportions of these three substances an effective product (gasoline) that could sell just as the current gasoline can be produces.

Figure 3: Process of Changing Biomass to Gasoline

But the challenge is to bring those 3 substances in contact and way to lower the pressure and temperature of the reaction. Those challenges can be counter by using the swirling fluidized bed. The swirling fluidized bed used the cylindrical distribution plate to rotate the bed of rigid particles about its axis. It used the fluidization to operate the processes.

Fluidization is the operation by which fine solid are transformed into a fluid like state through contact with a gas or liquid (Dr. K. Sasi, 2006).

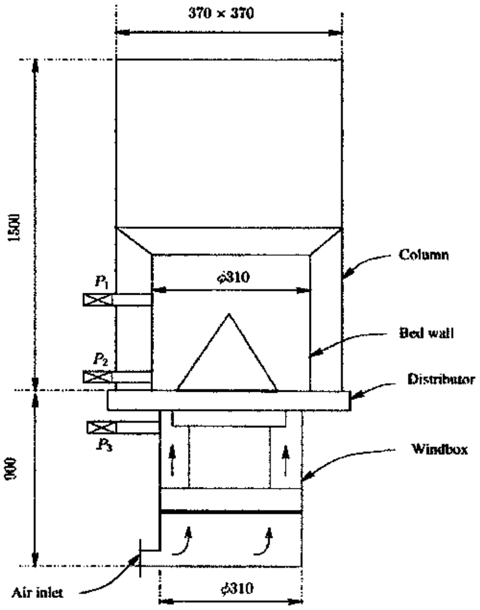

Figure 4: Schematic diagram of the Swirling Fluidized Bed (Sreenivasan & Raghavan, 2002)

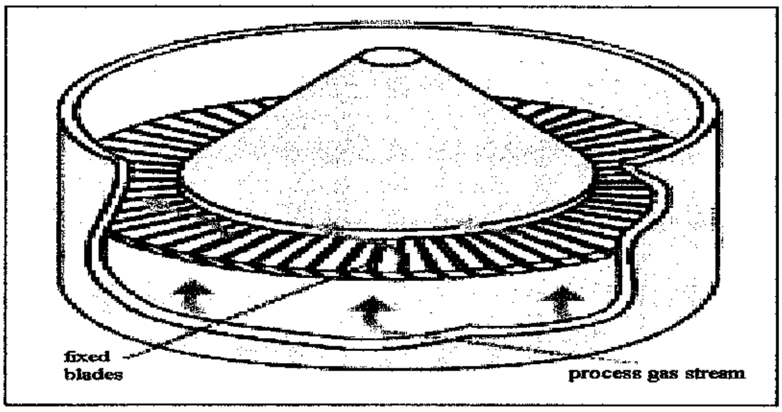

Figure 5: Swirling Fludized Bed

1.2 Problem Statement

In order to make the process of changing the bio oil to gasoline in the swirling fluidized bed certain problem have arise. Firstly, the reaction requires very long residence time in order to reach equilibrium state. Below is the chemical formula for the hydrodeoxygenation process.

$$C_6H_8O_4 + 4H_2 \leftrightharpoons C_6H_8 + 4H_2O$$

$C_6H_8O_4$ is the conceptual stoichiometric composition of bio-oil. Equilibrium state of the reaction requires that more than 8 mol of hydrogen to be supplied to the reaction. Non-equilibrium state (due to limited residence time requires) even more hydrogen to be supplied. So, excessive hydrogen gas must constantly supply to the system to make sure all the bio-oil reacted with the hydrogen. After the process, there are many exceeded hydrogen gases. Those hydrogen gases need to recycle back to the system so that no wastage happens during the process. Second, precaution must be taken while handling hydrogen gases. Hydrogen gases are flammable gases and hazard will happen if handling not well. Besides that, hydrogen will cause hydrogen embrittlement to various materials especially high strength steel. So, it is important to determine which material to be used in the system.

1.3 Objective of Study and Scope of Study

The objective of the project is to conceptually develop hydrogen gas recycle system in the conversion of bio-oil to gasoline process for a particular demand. Hydrogen gas needs to be recycled back to the reactor because there are many exceeded hydrogen gas after the process. A system must be developed in order to surf this purpose. Parts of the system must then be determined. Besides that, Specification of the system must also be determined. Plus, suitable matter while installing the system and choosing the material of the piping system must also must be determined.

Study on the safety of hydrogen gases must also been focus since the hydrogen gases is a flammable gases. It will cause problem if precaution doesn't taken. Study on the standard that need to be used in the piping system also needed because maybe there is some standard in handling the hydrogen gas. Apart from that, Study on how to determine the size of the equipment also needed to developed the system.

CHAPTER 2

LITERATURE REVIEW

2. LITERATURE REVIEW

Review for the study was taken abundantly from journals, books and the internet.

2.1 Biofuel

Renewable liquid biofuels for transportation have recently attracted huge attention all over the world.

Accoding to Stöcker (2008)

> Alternatives to fossil-based energy resources are nuclear power (5%), hydropower (6%), and biomass (13%), representing currently about one quarter of the world's primary energy consumption.

Other issue like decreasing of crude-oil reserves, enhanced demand for fuels worldwide, increased climate concerns about the use of fossil based energy transportation and political commitment improved the needed of alternatives energy.

Biofuel is the liquid or condensable gaseous fuels made from biomass materials. It can substitute conventional fuels in engine vehicles by upgrading the biofuels.

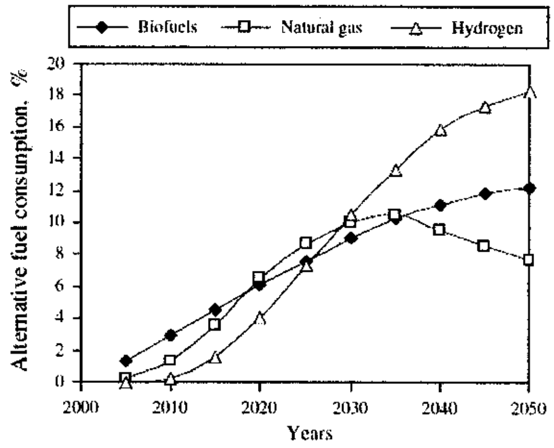

Figure 6: Shares of alternative fuels compared to the total automotive (S. Zhang, 2004)

Figure 6 shows the prediction of the demand of alternative fuel consumption of the biofuels in the future. It shows that that is an increasing trend in the consumption biofuel.

Stöcker (2008) says that biomass is an abundant and carbon-neutral renewable energy resource for the production of biofuels and valuable chemicals. Energy produced from biomass is carbon dioxide free compared to the conventional fossil fuels. The carbon dioxide generated during the energy conversion is consumed during subsequent biomass regrowth (Figure 7).

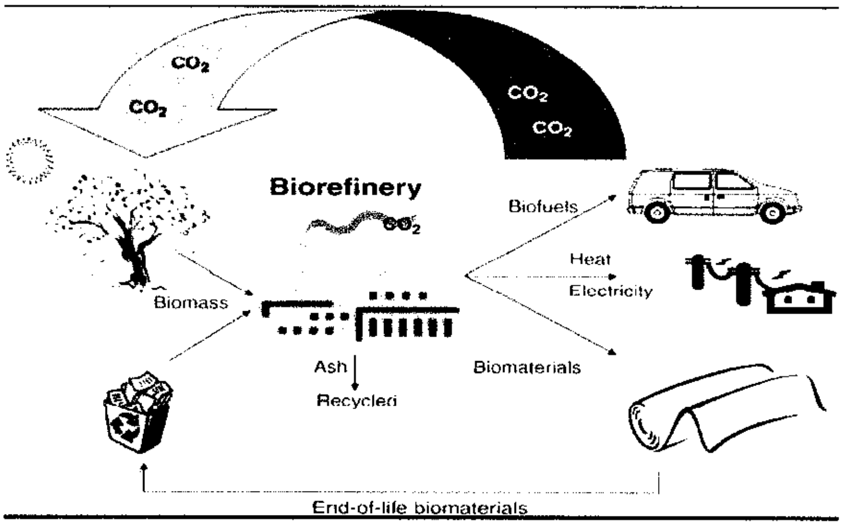

Figure 7: Sustainable technology in an integrated biorefinery. (Stöcker, 2008)

2.2 Improvement of Bio-oil

Improvement of bio-oil is needed in order to produce the biofuel. This is due to the some characteristic of bio-oil for example high water and oxygen content, corrosiveness, lower stability, immiscibility with crude-oil-based fuels, high acidity, high viscosity, and low calorific value, which cause disadvantages for the bio-oil.

Four main approaches to improve the quality of bio-oil:

a) Fluidized catalytic cracking (FCC): $C_6H_8O_4 \rightarrow C_{4.5}H_6 + H_2O + 1.5CO_2$
b) Decarboxylation (DCO): $C_6H_8O_4 \rightarrow C_4H_8 + 2CO_2$
c) Hydrodeoxygenation (HDO): $C_6H_8O_4 + 4H_2 \rightarrow C_6H_8 + 4H_2O$
d) Hydrotreating (HT): $C_6H_8O_4 + 7H_2 \rightarrow C_6H_{14} + 4H_2O$

According to Stöcker (2008),

> $C_6H_8O_4$ refers here to the conceptual stoichiometric composition of bio-oil. The preferred catalysts for FCC are based on ZSM-5 (structure code: MFI) and zeolite Y (structure code: FAU), with the microactivity test (MAT) as reactor equipment. To date, upgrading of bio-oil by FCC has been investigated only using fixed-bed equipment within the temperature range of 340–500°C. Hydrodeoxygenation (HDO) is based on hydrotreating (HT) using sulfur-containing NiMo and CoMo catalysts processed at about 400°C and under hydrogen at high pressures. Complete decarboxylation (DCO) may be the best upgrading route for bio-oil, as hydrocarbons are produced and hydrogen is not required. ZSM-5 and USY zeolites have been used for this process.

2.1 Hazards Associated with Hydrogen

According to F. Rigas and S. Sklavounos (2005), safety of using hydrogen gases have became a concern to everybody because hydrogen may cause a series of accidental events like jet fire, flash fire, detonation, fireball and confined vapor cloud explosion. Knowing the cause of each accident is very important because it will help to prevent the accident mention above happen.

When there is a hydrogen leakage and immediate ignition occurs, the mixing of gas cloud and atmospheric oxygen is limited. The ignition only takes place on the outer layer between the flammable limited. The burning cloud rises and become more spherical in shape forming a ball in flames when buoyancy forces of the hot gases begin to dominate. If delayed ignition occurs, the fuel cloud has been adequately mixed with air so it flashes back after ignition. It differs from fireball because it proceeds faster and can burn from inner to outer flammable layers if a proper ignition source is there.

The fast burning occurs initially with a medium increase of pressure if sufficiently mixed with air. This is known as deflagration. If considerable confinement exists, the flame propagation speed increase rapidly and blast wave is produce. The general term for this explosions in which a shockwave develops is called detonation. For the gaseous mixtures exploding in confined space, the term Confined Vapor Cloud Explosion (CVCE) is used in which either a detonation or a deflagration takes place.

The flash fire is a phenomenon that happens in a very poor or very rich in fuel mixture, but still within flammability limits and the flame front travels the cloud in low velocity and insignificant pressure increase.

F. Rigas and S. Sklavounos also done some analysis using Event Tree Analysis regarding the accidental hydrogen release displayed in figure 4. It shows that, there is some time of dispersion that intervenes between release and ignition unless an immediate ignition takes place. Furthermore, even if no ignition takes place, escaping hydrogen may accumulate into closed space adjacent to the source posing asphyxiation hazard for the people being there. So, if there is no ignition occurs and no space confinement exists the hydrogen is considered safe.

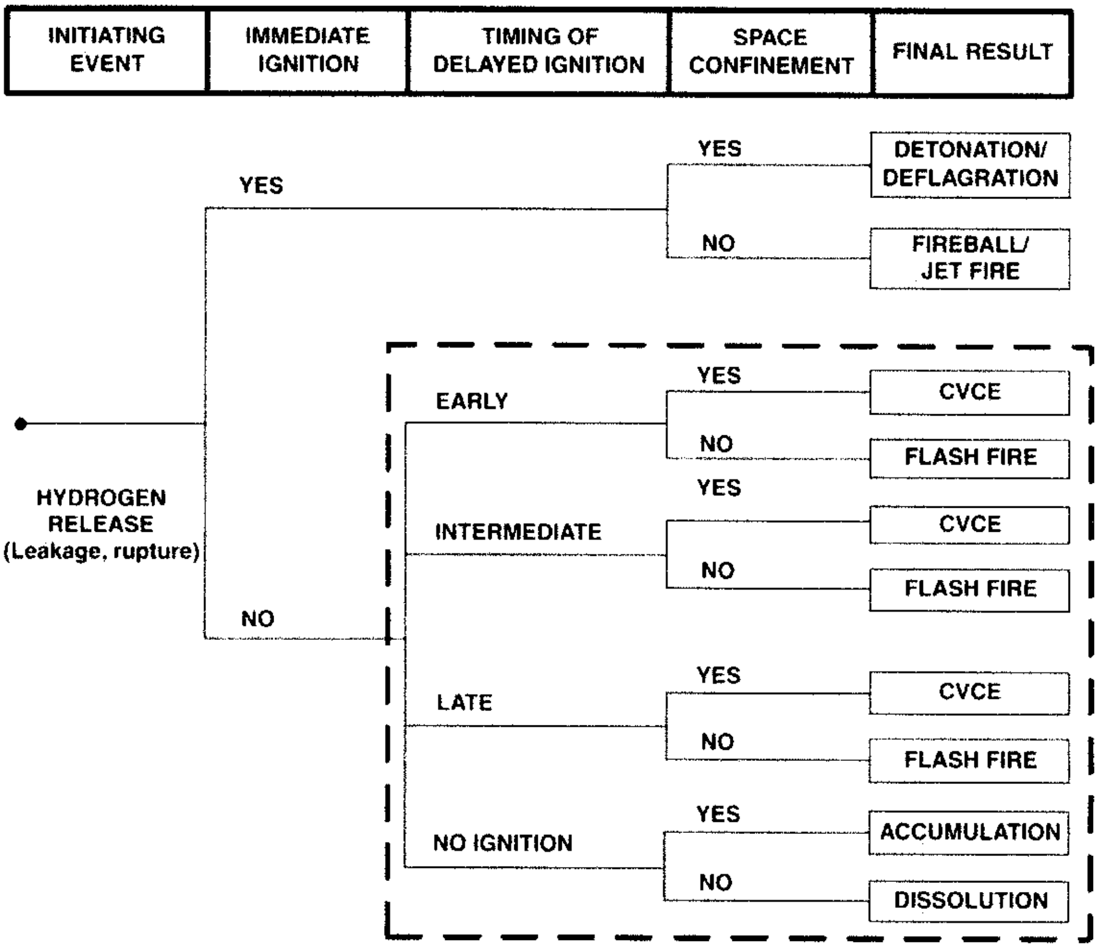

Figure 8: Event Tree Analysis adapted to accidental hydrogen releases. (Rigas & Sklavounos, 2005)

Table 1: Hydrogen Fire hazard Characteristics

Property	
Density (kg/m^3)	0.084
Diffusion coefficient in Air (cm^2/sec)	0.610
Specific heat at constant pressure (J/Gk)	14.89
Ignition limits in air (vol %)	4.0-75.0
Ignition energy in air (Mj)	0.02
Ignition temperature (^{o}C)	585
Flame temperature in air (^{o}C)	2045
Explosion energy (G TNT/kj)	0.17
Flame Emissivity 1%	17-25

2.2 Pipelining Hydrogen

It is not realistic to direct utilization of the existing natural gas infrastructure for hydrogen delivery due to limitations of engineering created by hydrogen gas physical peculiarities. To cover the safety, energy loses and material science, the land transmission system for hydrogen should be very specific in design. Compressor station must be included in the pipelines for hydrogen to compensate for the transmission pressure losses. Utilizing 5000 psig pipeline pressure will partially improve the energy per unit volume ratio. However additional engineering and fabrication costs will be charge if the pipeline's diameter increases.

High pressure hydrogen will easily leak through the smallest holes and even straight through a lot of materials that would be impervious to natural gas. Plus, the hydrogen gas is capable of the metal embrittlement, especially in the mild steel used for pipeline construction. (Press, Santhanam, Miri, Bailey, & Takacs, 2008). Different welding procedures, piping and equipment materials, gaskets, seals, and many other components widely used in the natural gas delivery to a user will require to the pipelines for transporting the hydrogen gases.

CHAPTER 3

METHODOLOGY

3.1 Part Determination

Researches have been done by journal reviewing and cooperation with master student. The process flow of the system must be determined before the system is being developed.

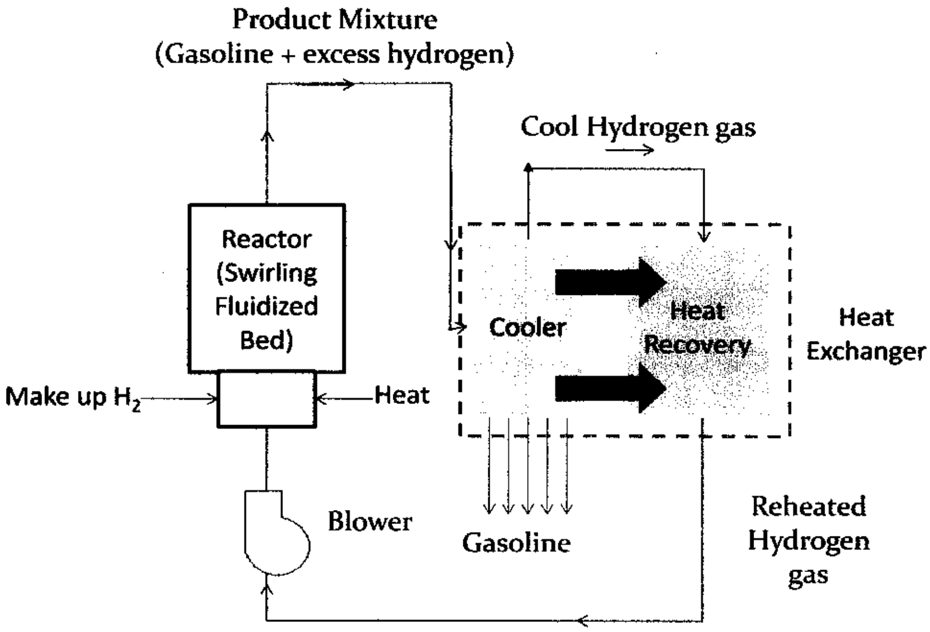

Figure 9: Process Flow Diagram

Figure 9 shows the process flow diagram of the system. The hydrodeoxygenation process happens inside the reactor. The bio-oil will react with the hydrogen and the product mixture of gasoline and excess hydrogen will come out from the reactor. The product mixture will then enter the heat exchanger and being cooled down. Gasoline will separate from the mixture due to condensation and the cooled hydrogen gas will come out from the cooler and reheated by the heat recovery from the heat exchanger. The reheated hydrogen gas will recycle back to the reactor by the blower. Addition heat will be added to the hydrogen gas before it enters the reactor. This is to make sure the hydrogen gas reaches the reaction temperature before enter the reactor.

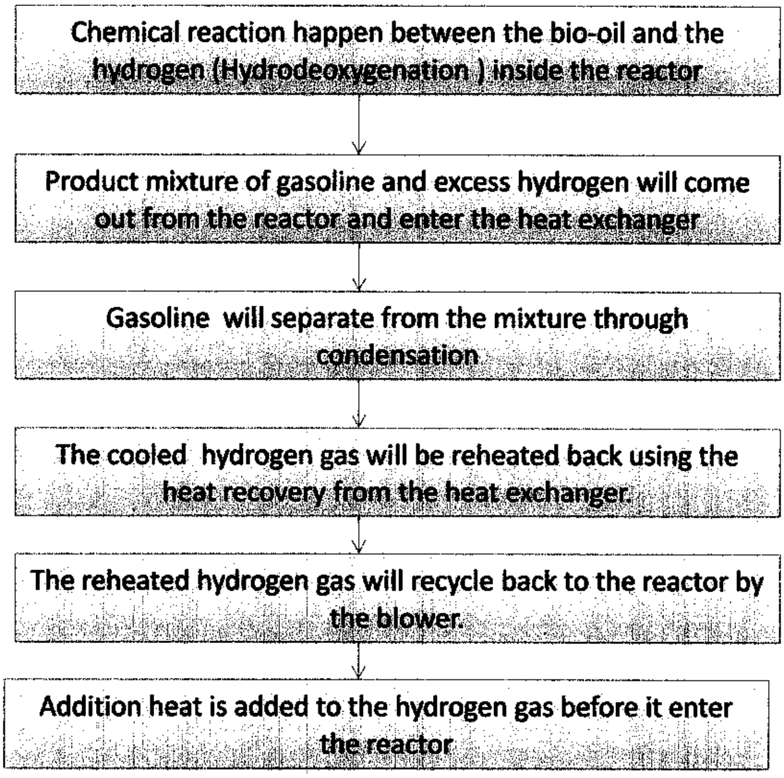

Figure 10: Plant Flow Sheet

From the process flow diagram, the parts of the system can be determined. The main part of the system consists of:

a) Blower
b) Make-up hydrogen supply system
c) Heater
d) Piping system

3.2 Amount of Hydrogen Gas needed

The hydrodeoxygenation process was given a chemical formula of:-

$$C_6H_8O_4 + 4H_2 \leftrightharpoons C_6H_8 + 4H_2O$$

In order to convert 1 ton/hr of bio-oil into gasoline, the amount of the hydrogen gas needed can be calculated out.

Bio-oil: $C_6H_8O_4$

Atomic mass for carbon =12

Atomic mass for hydrogen = 1

Atomic mass of oxygen = 16

So the atomic mass of the $C_6H_8O_4$ can be calculated out,

$$(12 \times 6) + (8 \times 1) + (4 \times 16)$$

=144 g/mol

To convert 1 ton/hr bio-oil,

$$\frac{1 \times 10^6\ g/hr}{144\ g/mol} = 6.944\ kmol/h$$

The hydrogen gas needed to be supplied,

$$H_2\ needed = 6.944\ kmol/hr \times 8\ g/mol$$

$$= 55.56\ kg/hr$$

The calculation above shows that minimum of 55.56 kg/hr of hydrogen gas must be supplied to the system in order for to bio-oil to react completely.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Operating Condition

The reactor of the system is run at temperature of 400 °C and 50 bar of pressure. High temperature and high pressure is used in reactor. This is to drive the reaction forward when it is in equilibrium state. Besides that, the high pressure is used to keep the size of the equipment down. This is because hydrogen has the low density but high specific volume. Apart from that, high temperature is used to supply the heat to the reaction. Energy is needed to break the oxygen bond inside the bio-oil in the hydrodexoygenation process.

4.2 Blower

There will be pressure drop happen in the hydrogen gas when it travels through the pipe and the equipment. This is due to the following reason:

- Friction between the gas and the pipe
- Vertical pipe difference or elevation
- Change of kinetic energy

In order to circulate and recycle the hydrogen gas back to the reactor, a blower is installed to supply back the pressure drop to the hydrogen gas. To determine the size of the blower that needed, volume flow rate (Q) and the pressure difference (ΔP) of the system must be known.

To calculate to volume flow rate, the formula is shown below:

$$Q = Av$$

The diameter of the reactor (swirling fluidized bed) is define as *d* and the velocity of the flow is defined as *v*.

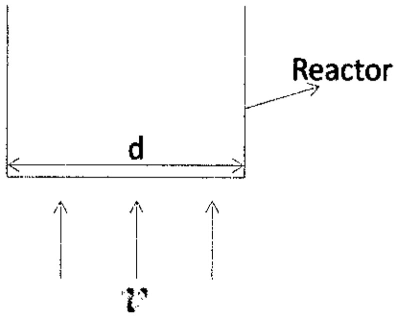

Figure 11: Dimension of the Reactor

The volume flow rate of the blower is calculated using the equation below.

$$Q = \frac{\pi}{4} \times (d)^2 \times v$$

Pressure drop will happen when the hydrogen gas passes through the equipment of the system. So the pressure difference of the blower is actually the summation of all of pressure drop happen in the system.

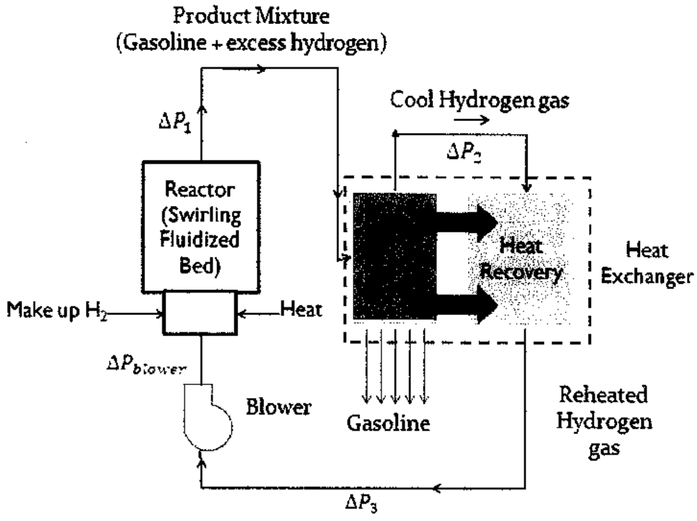

Figure 12: Pressure Drop of the System

The pressure difference of the blower is:

$$\Delta P_{blower} = \Delta P_1 + \Delta P_2 + \Delta P_3$$

4.2.1 Type of Blower

There are many types of blower available in the market. In order to choose which blower is suitable for the system, the volume flow rate and the pressure difference that calculated out earlier is used to compare the performance in the fan performance curve (figure 13).

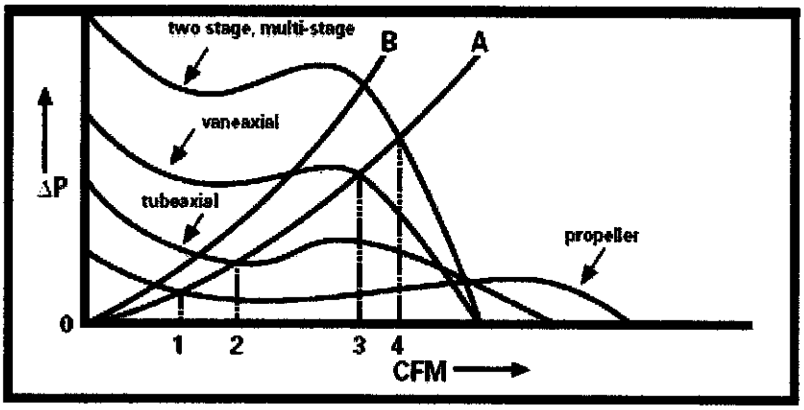

Figure 13: Fan Performance Curve

Axial Blower

Axial blower is chosen when large quantity up to 1000 cfm of air at low pressure is needed. The air flows parallel to the axis of the rotating drum or hub. Axial blower has two set of aerofoil blades, one set is called "stator blades" which the blades being fixed on casing. The other is rotor blades which the other blade row being fixed on the rotating drum. Axial blower has several stages.

The enthalpy and pressure of air will increases as it passes through the rotating blades. The rotating blade rotor rotated by an electric motor will also increases the air velocity. The air pressure increases as the air enter the divergent end of aerofoil blades. The fixed blades will guide the air to flow to the next stage of rotating blades.

The used of aerofoil blades is to reduce the turbulence and boundary separation. The pressure ratio of the axial blower is 1.2 to 1.3 per stage and a maximum achievable pressure ration is 10. Normally 4 to 16 stages are used to achieve the required pressure.

Type of Axial Blower

Propeller fan

Propeller fan consists of a propeller rotating within a mounting ring or orifice and includes provision for motor supports. Propeller fans are the simplest, most economical and least efficient axial flow devices.

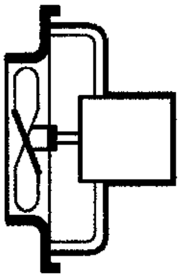

Figure 14: Propeller Fan

Tubeaxial fan

Tubeaxial fan consists of an impeller rotating within a full cylindrical housing, which also provides motor support struts. The term tubeaxial implies more efficient airfoil blades, closer tip clearance and generally cleaner flow patterns than the propeller fan. Greater pressure capability and higher efficiency can be archived by this.

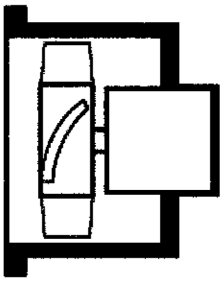

Figure 15: Tubeaxial Fan

Vaneaxial Blower

Vanexial blower is the sophisticated brother of the tubeaxial, it also improve the propeller fan. Guide vanes are inclined on either the inlet or outlet side of the propeller. The function of the vanes is to reduce the rotational or “whirl” pattern of the air stream and results in higher pressure before stall and increased of efficiency.

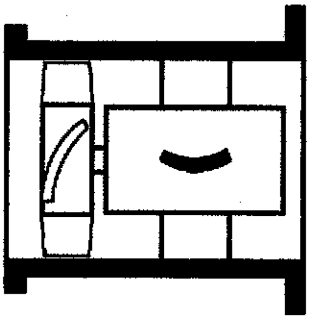

Figure 16: Vaneaxial Blower

Multi-Stage Axial Blower

Multi- Stage Axial Blower is essentially two or more vaneaxial fans mounted in a common shaft and housing in series. The first vaneaxial fan, or the first stage, feeds the second stage with axial flow at the design point. The product of the number of stages and stall pressure of a single stage represent the static pressure available. Multi-stage units are capable of the highest pressures attainable nu an axial device for given size and speed. The multi-stage units are heavier and more expensive than the other axial units.

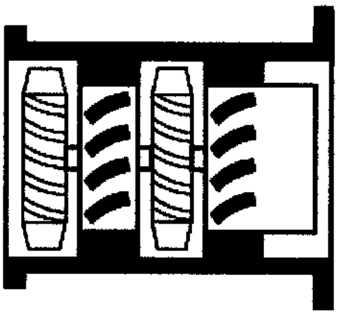

Figure 17: Multi-Stage Axial Blower

Centrifugal Blower

A centrifugal blower is a mechanical device for moving air or gases. It has a fan wheel composed of a number of fan blades, or ribs. The fan blade of the centrifugal blower is mounted around a hub. The hub turns on a driveshaft that passes through the fan housing. The gas enters from the side of the fan wheel, turns 90 degrees and accelerates due to centrifugal force as it flows over the fan blades and exits the fan housing. Centrifugal fans can generate pressure rises in the gas stream.

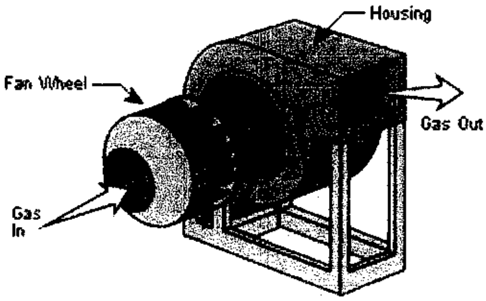

Figure 18: Centrifugal Blower

4.3 Make-up Hydrogen Supply System

The hydrogen gas is constantly used by the reaction during the process. In order to make sure there is continuous supply of hydrogen gas, make up hydrogen should be supplied to the system to cover back the amount of hydrogen gas that used in the system.

The amount of the hydrogen that needs to supply back to the system is same as the amount of hydrogen that reacted in the reaction. As calculated early, to convert 1 ton/hr of bio-oil, 55.56 kg/hr of hydrogen is used. So, 55.56 kg/hr of hydrogen gas must be supplied to the system by the hydrogen gas make-up system.

4.4 Heater

Hydrogen gas must reaches the reacting temperature which is 400 °C before it enter the reactor. Although it is reheated by the heat recovery system, but it is not enough for it to reaches the reacting temperature. Plus, make-up hydrogen is added in to the system. The make-up hydrogen that enters the system is not yet heated. It will further bring down the temperature of the recycle hydrogen gas. Besides that heat loss will be happen to the hydrogen gas when it transport throughout the piping system. Additional heat must be added to the hydrogen gas before it enters the reactor.

To calculate the heat needed to be added to the system, the below equation is used:-

$$Q = \dot{m}C_p(\Delta T)$$

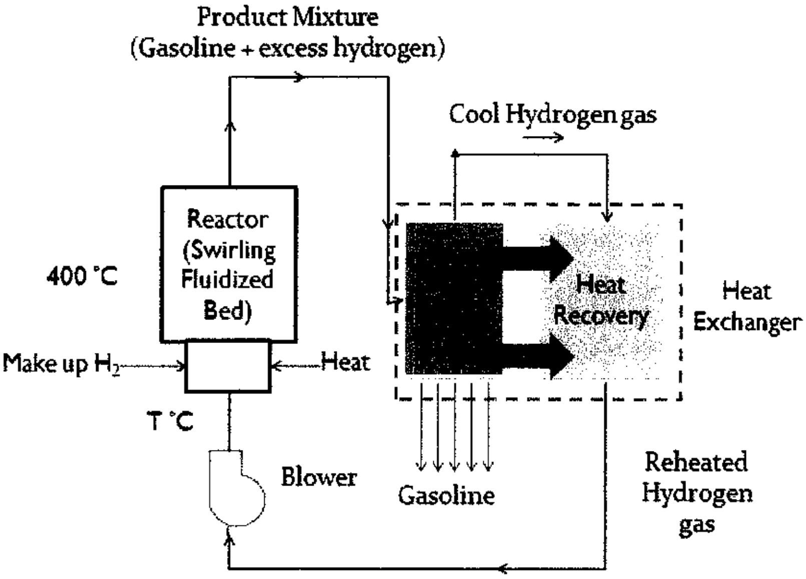

Figure 19: Temperature of the System

Refer to figure 19, the reactor temperature is 400 °C, hydrogen gas has to reach that temperature before it enter the reactor.

To find the heat that need to the recycle hydrogen gas,

$$Q_1 = \dot{m}C_p(400 - T)$$

Where $\dot{m}$ is the mass flow rate of the hydrogen gas in the system and C_p is the specific heat of the hydrogen. T is the temperature of the hydrogen after the blower.

To calculate the heat that needs to add into the make-up hydrogen, the same equation is used. The amount of make-up hydrogen added to the system is same with the amount of hydrogen gas that used in the reaction. As mention early, to convert 1 ton/hr of bio-oil, 55.56 kg/hr of hydrogen is used. So the heat that needed to add in is:-

$$Q_2 = 55.56 \times C_p \times (400 - T_{hydrogen})$$

Where $T_{hydroge\ n}$ is the temperature make-up hydrogen gas and C_p is specific heat of the hydrogen.

So, the total heat Q_{total} that added into the system is:-

$$Q_{total} = Q_1 + Q_2$$

4.5 Piping System

Piping system is used to convey the hydrogen gas throughout the system. As the hydrogen gas passing through the system, head loss will be happen inside the pipe. The head loss is the main contributor for the pressure drop inside the pipe system.

To calculate the pressure drop of the hydrogen along a pipe and pipe component, the Reynolds number must be first calculate to determine whether the flow is laminar or turbulent.

$$Re = \frac{\bar{W} \times D}{v}$$

Where,

Re = Reynolds Number

$\bar{W}$ =Velocity of flow

D = Diameter of Pipe

v= Kinematics Viscosity

If the Reynolds number <2320, the flow is laminar flow. The pressure drop caused by the friction of the laminar flow does not depend on the roughness of pipe. Whereas if the Reynolds number >2320, the flow is turbulent flow. The pressure drops due to friction of the turbulent flow are depending on the roughness of the pipe.

The pipe friction coefficient is than calculate according to the type of low.

For the pipe friction coefficient of the laminar flow, it can be calculated using the below formula:

$$f = \frac{64}{Re}$$

Where,

f = pipe friction coefficient

Re = Reynolds number

For the pipe friction coefficient of the turbulent flow, it can be determined using the Moody Diagram.

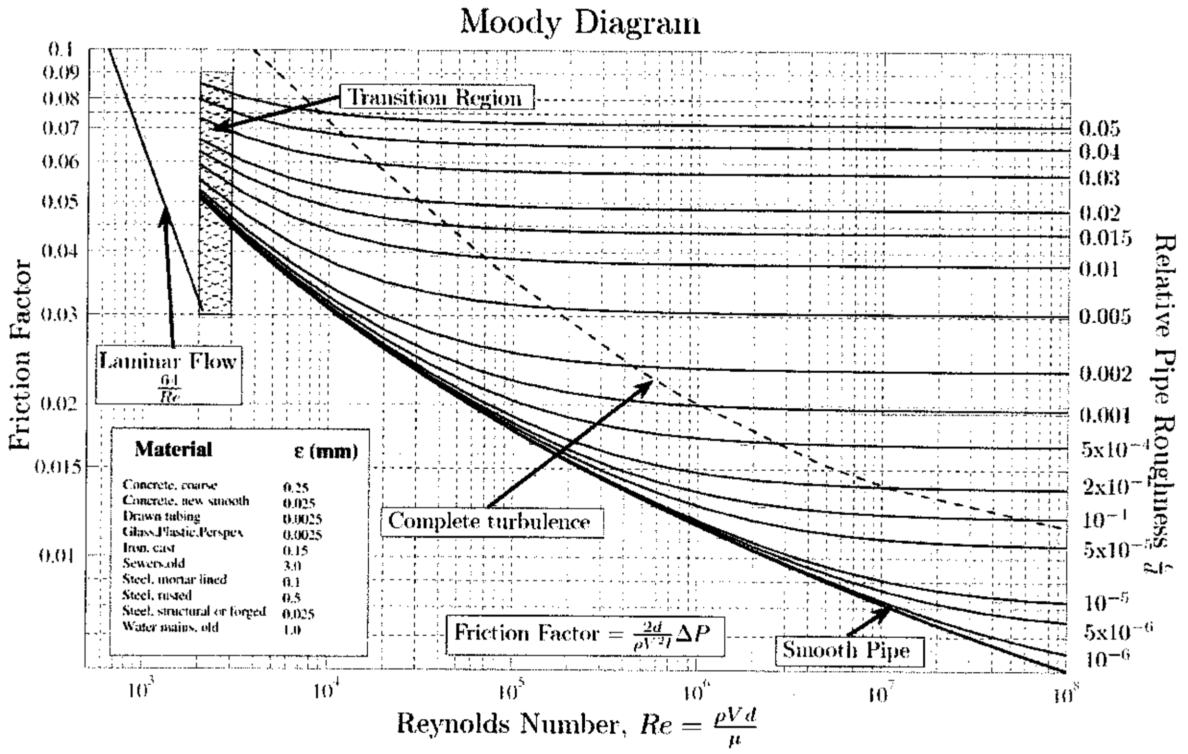

Figure 20: Moody Diagram

After the pipe friction coefficient (*f*) has been calculated out, the head loss (h_L) in the piping system can be determined using the follow equation.

$$h_L = f\frac{L}{D}\frac{V_{avg}^{\ 2}}{2g}$$

Where,

f = pipe friction coefficient

L = Length of the pipe

D = pipe diameter

g = gravity acceleration

V_{avg}= average flow velocity

If there are valves, elbows and other elements along the pipe, it will interrupt the smooth flow of the fluid and case additional losses to the piping system. This is the minor loses happen in the piping system. Minor loses can be calculated with resistance coefficients (K_L) specifically for the element included in the calculation.

—

Table 2: Table of resistance coefficient (K_L) of the pipe in various conditions (Cengel & Cimbala, 2006)

Condition of the pipe	**K_L**
Reentrant	0.80
Sharp Edge	0.50
Well rounded	0.03
Slightly rounded	0.12
Sudden Expansion	$\left(1-\frac{d^2}{D^2}\right)^2$
90° smooth bend (flanged)	0.3
90° miter bend (without vanes)	1.1
45° threaded elbow	0.4
180° return bend (flanged)	0.2
Tee (Branch flow) (Threaded)	2.0
Ball valve (fully open)	0.05
Ball valve (1/2 open)	2.1
Angle valve (fully open)	5
Angle valve (1/4 closed)	0.3
Globe valve (fully open)	10
Gate valve (fully open)	0.2

The total head loses happen in the pipe are:

$$h_{L,total} = h_{L,major} + h_{L,minor}$$

$$h_{L,total} = \left(f\frac{L}{D} + \sum K_L\right)\frac{V^2}{2g}$$

4.5.1 Suitable Matter for Piping System

As mention earlier, hydrogen embrittlement will happen to the piping system when the pipe is exposed to the hydrogen. Special material has to be used to prevent the hydrogen embrittlement to happen. Stainless steel (304 & 316) tubing, piping, fittings, and components are preferred. 304 and 316 are the stainless steel annealed seamless pipe which will lower down the chance of hydrogen embrittlement to be happened. The maximum composite hardness of pores and solid materials is 80 rb. Piping systems should be designed and built to meet ANSI/ASME B31.3 for process piping and specifications for the tubing are ASTM A269 TP 304 and 316.

Joining Technique

Welded joints are preferable in the high pressure hydrogen systems instead of threaded or brazed connection. But threaded connection cannot be fully eliminated. Many components are available only in thread connections. So, threaded connections should be kept to minimum. Socket welds or butt welds are used in the weld joint and should be accomplished using GTAW (TIG) welding techniques for either manual or automated (orbital welding).

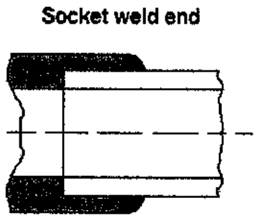

Figure 21: Socket Weld

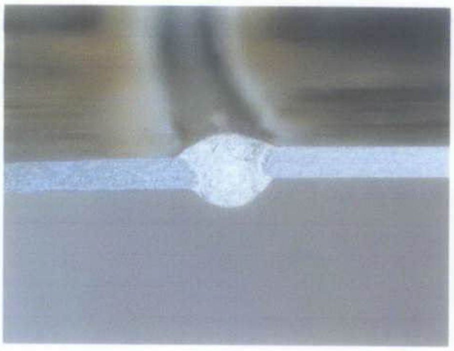

Figure 22: Butt Weld

Purging is required to minimize oxidation and contamination in the weld zone. It also helps to control the weld bead profile. A liquid source of argon gas should be used for purging system ID and for shielding on the OD of the weld area.

The maximum allowable diameter misalignment for butt weld should be less than 0.005in. The pipe/tube ends should have no nicks, burrs, chamfers or sharp edges and no reduction in diameter or wall thickness. So, it should be cut and prepped very carefully. The ends should be square and perpendicular within 0.003in. The weld must have 100% penetration and show no points of discontinuity. The weld may have no undercut that will render the weld wall thickness. The weld bead should not be 10% thicker than the nominal wall thickness and should be 2-5% thicker than the nominal wall thickness. When inspected under magnification and under white light, the welds should have no porosity or inclusions. The weld bead should have uniform width and should not be more than three times the nominal wall thickness. Discoloration of the weld should be kept to a minimum through proper purging with argon. Between the pipe end and the socket bottom, all socket weld joints must have a 1/16-in, gap.

Bending

Tubing may be bent in the system. The minimum mandrel bend radius must be equal to or greater than five times the OD of the tubing.

Testing

Leak test should be conducted on all circuits of the piping system before putting the system into operation. Clean dry nitrogen should be used for the test gas for the leak test. The test must be done in a ventilated area because leakage of nitrogen into the atmosphere may create an oxygen-deficient atmosphere that can asphyxiate personnel in the area. Slowly pressurize the circuit and increases the pressure in stages.

Pressurize the system to 1.1 times the maximum allowable working pressure from a remote location, using an approved pressure testing control system. The pressure is hold for 15 minutes in the system. If the pressure declines more than a few psig, it means that there is a leakage in the section of pipe/tube. Depressurize the circuit to about 150 psig and locate the leak using soap water. The soap water is applied to each joint and look for the formation of bubbles. If no bubbles form within 30-60s, the joint is acceptable. If bubbles are forms on the joint, the joint must be repaired and retested.

Figure 23: Example of Bubble Form in the Leak Test

After the system passes the 15 minute pressure retention test at 1.1 times maximum allowable working pressure, reduce the pressure to 90% of maximum allowable working pressure. Record the pressure and the temperature. Hold this pressure for 24 hours and then observe the test pressure gauge for any loss of pressure. If the loss of pressure that cannot be attributed to a change in temperature, it is an indication of a leak. Locate the leak point with the previous matter and repair the leak.

CHAPTER 5

CONCLUSION

5.1 Conclusion

High temperature and high pressure is used in the reactor to drive the reaction forward. The reactor of the system run at temperature of 400 °C and 50 bar of pressure. High pressure is used to keep the size of the equipment down while high temperature is used to supply the heat to the reaction to break the oxygen bond.

There is 4 main parts in the hydrogen recycle system which is:-

a) Blower
b) Make-up hydrogen supply system
c) Heater
d) Piping system

The blower is used to supply back the pressure drop to the hydrogen gas in order for it to be circulated in the system and recycle back to the reactor. In order to determine the size of the blower and the type of the blower, pressure difference (ΔP) and volume flow rate (Q) of the system must be known. The pressure drops happen in the hydrogen gas when the hydrogen gas passing through the equipment or when the hydrogen gas transports throughout the piping system. The pressure difference of the blower can be found by the summation of the entire pressure drop happen in the system. The volume flow rate can be determined by using the formula below:

$$Q = \frac{\pi}{4} \times (d)^2 \times v$$

Where d is the diameter of the reactor and v is the velocity of flow.

There are many types of blower in the market:

a. Propeller fan
b. Tubeaxial fan
c. Vaneaxial Blower
d. Multi-Stage Axial Blower
e. Centrifugal Blower

Fan performance curve (figure 13) is used to determine which type of blower to be used.

The hydrogen gas of the system is constantly used by the reaction. So, make-up hydrogen needs to be supplied back to the system. The make-up hydrogen gas supply system is used to supply back the hydrogen gas to the system.To convert 1 ton/hr of bio-oil, 55.56 kg/hr of hydrogen gases is used. So, 55.56 kg/hr of hydrogen gas must be supply back to the system.

The heater is used to supply heat to the hydrogen gas in order for it to reach the reactor temperature before it enters the reactor. Heat need to be added to both recycle hydrogen and make up hydrogen. The heat that needs to be added in to the recycle hydrogen is calculated as:

$$Q_1 = \dot{m}C_p(400 - T)$$

The heat that needs to add to the make-up hydrogen gas is calculated as:-

$$Q_2 = 55.56 \times C_p \times (400 - T_{hydrogen})$$

The total heat Q_{total}that added into the system is:-

$$\boldsymbol{Q_{total} = Q_1 + Q_2}$$

Piping system is used to convey the hydrogen gas throughout the system. As the hydrogen gas passing through the system, head loss will be happen inside the pipe. The head loss is the main contributor for the pressure drop in the system. The total head loss of the piping system is calculated using the equation of:-

$$h_{L,total} = \left(f\frac{L}{D} + \sum K_L\right)\frac{V^2}{2g}$$

The material of the piping system is suggested to use Stainless steel (304 & 316) annealed seamless pipe to prevent hydrogen embrittlement. Piping systems should be designed and built to meet ANSI/ASME B31.3 for process piping. Weld joint using GTAW (TIG) welding technique is preferable to join the pipe. In order to bend the tube, the minimum mandrel bend radius must be equal to or greater than five times the OD of the tubing. Leak test must be conducted to all the circuit of the pipe.

5.2 Recommendation

This project is a concept development project; it is just study the concept of the hydrogen recycle system. The concept of the system included all the theory part and how to determine the size of the equipment of the system. So the exact value of all the specification is unknown. For the future, the exact value of the specification can be known through the plant design. The value can be plugged in the equation showed in this project and the hydrogen recycle system can be designed. All the specification of the parts in the system can be determined based on the concept developed in this project.

REFERENCES

C.G.Lee, Cho, Y. J., Song, P. S., Kang, Y., Kim, J. S., & Cho, M. J. (2003). Effects of temperature distribuition on catalytic pyrolysis of polystyrene waste in swirling fluidized bed reactor. *Catalysis Today. Catalysis in Multiphase Reactors*, 453-464.

Cengel, Y. A., & Boles, M. A. (2006). *Thermodynamics.* New York: Mc Graw Hill.

Cengel, Y. A., & Cimbala, J. M. (2006). *Fluid Mechanics.* New York: McGraw-Hill Education (Asia).

Didwania, A., & Tsimiring, L. (2002, December 24). *Swirling air fluidized bed fot microgravity applications.* Retrieved October 28, 2009, from http://inls.ucsd.edu/~volfson/cur_research/node5.html

Incropera, F. P., Dewitt, D. P., Bergman, T. L., & Lavine, A. S. (2007). *Introduction to Heat Transfer.* Danvers: John Wiley & Sons.

Press, R., Santhanam, K. S., Miri, M. J., Bailey, A. V., & Takacs, G. A. (2008). *Introduction to Hydrogen Technology.* New Jersey: John Wiley & Sons, Inc.

Rigas, F., & Sklavounos, S. (2005). Evaluation of hazards associated with hydrogen storage facilities. *International Journal of Hydrogen Energy*, 1501-1510.

S. Zhang, Y. Y. (2004). Upgrading of Liquid fuel from the pyrolysis of biomass. *Bioresource Technology*, 545-550.

Sreenivasan, B., & Raghavan, V. R. (2002). Hydrodynamics of Swirling Fluidized Bed. *Chemical Engineering and Processing*, 19-26.

Stöcker, M. (2008). Biofuels and Biomass-To-Liquid Fuels in the Biorefinery: Catalytic Conversion of Lignocellulosic Biomass using Porous Materials. *Angewandte Chemie International Edition*, *47* (48), 9200-9211.

Zenz, F., & Othmer, D. (1960). Fluidisation and Fluid Particle Systems. In Reinhold. London: Chapman and Hall.