PEMBANGUNAN PENGGAS SIKLON UNTUK HABUK KAYU

(DEVELOPMENT OF CYCLONE GASIFIER FOR SAWDUST)

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NOMENCLATURE

a	Cyclone inlet width, m
A/F	Air-fuel ratio
b	Cyclone inlet height, m
B	Cyclone lower outlet diameter, m
C.I	Combustion Intensity, kW/m^3 atm
D	Diameter, Cyclone diameter, m
D	Dry mass of biomass, kg
G_ϕ	Flux of angular momentum, kgm^2/s^2
G_x	Flux of linear momentum, kgm/s^2
h	Height of the cylindrical section of cyclone, m
H	Cyclone height, m
K	Equilibrium constant
n	vortex exponent
p	Pressure, Pa
P	Drive power of screw feeder, W
r	radius, m
Re	Reynolds number
S	Swirl number
S	Cyclone outlet pipe length, m
T	Temperature
TR	Turn down ratio
v	Velocity, m/s
W	Wet mass of biomass, kg
Φ	Equivalent ratio
ζ	Pressure drop coefficient
ρ	Density, kg/m^3
η	Efficiency of cyclone, %
ϕ	Trough filling coefficient

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CHAPTER 1

INTRODUCTION

1.1 Overview

Malaysia has recently adopted a five fuel diversification policy, identifying oil, natural gas, coal, large hydro, and renewable energy as key fuels. A mandate has been established by the Malaysian government that 5% of its energy basket should come from renewable energy by the year 2006. Priority technology areas have been identified to be mini-hydro, biomass, landfill gas, solar, and wind. The government also offered a kick-start package for the first 20 MW of renewable energy from biomass, as well as various tax credits and incentives [New and Renewable Energy Technologies 18th Meeting Report].

Meanwhile, reserves of carbon and fossil fuels are ever decreasing and demand for energy is ever increasing due to technological advancement of the world. Biomass can be one of the forms of energy resources that have to be explored to offset the future shortage of such fuels. One of the options is to utilize agricultural waste as nature energy resource such as sawdust since there are only a few usage of sawdust, whereas lot of tons of sawdust produced everyday. Furthermore, unmanaged sawdust also can contribute to air pollution that can cause to uncomfortable life.

In Malaysia, sawdust can be found easily since there are many sawmills operate in all states in Peninsular Malaysia and East Malaysia. Table below shows the top five sawn timber producing states in Peninsular Malaysia for year 1998. Then the following table is the top five species of logs being consumed by the sawmill industry, also in Peninsular Malaysia [www.forestry.gov.my].

Table 1.1 Top five sawn timber producing states in Peninsular Malaysia for year 1998.

TOP 5 SAWN TIMBER PRODUCING STATES, PENINSULAR MALAYSIA, 1998		
States	Volumes (m^3)	% of total production
1. Pahang	721,762	25.8
2. Terengganu	451,251	16.2
3. Kelantan	425,955	15.2
4. Johor	342,083	12.2
5. Perak	279,553	10.0

Table 1.2 Top five species of saw logs being consumed by the sawmill industry

TOP 5 SPECIES OF SAWLOGS BEING CONSUMED BY THE SAWMILL INDUSTRY, PENINSULAR MALAYSIA, 1998*		
Species	Volume (m^3)	% of total input
1. Red Meranti	979,787	21.7
2. Kelat	342,172	7.6
3. Heveawood (Kayu Getah)	291,345	6.5
4. Kedondong	243,483	5.4
5. Keruing	228,537	5.1

* = excludes species like Other MHW and Other LHW

Generally, sawmills process two main types of wood; Heveawoods and forest-woods. Sawdust that generated from forest-woods are used as raw material to make rod charcoal and also being used as extra fuel in brick-manufacturing process. Meanwhile, sawdust that generated from Heveawoods is considered as permanent waste so that it is burnt to be eliminated.

Theoretically, every 1 m^3 of saw log gives 11.9% of sawdust. This means that from 291345 m^3 of Heveawood, 34670 m^3 are sawdust. And by taking wood's density as 210 kg/m^3, about 20 tons of sawdust is produced everyday.

One of the ways to process the biomass is by using gasification process. In gasification, biomass is subjected to partial pyrolysis under sub-stoichiometric conditions with the air quantity being limited to suitable kg of air per kg of biomass. The resultant mixture of gases generated during the gasification process is called producer gas, contains CO and H_2 and is combustible. The raw producer gas contains tar and particulate matter which have to be removed as they are harmful to the engine.

Normally, conventional gasifiers are based on gasification of biomass in size of 10mm to 100mm. Those gasifiers include fixed bed gasifiers such as up-drought, down-drought, cross-drought and devolatilisation. Although there is one type of gasifier that gasify smaller particle of biomass – fluidised bed gasifier, using 1mm to 10mm biomass particles, it is still not enough to accommodate today's energy needs.

For a few decades, cyclones were studied to be an alternative to gasify smaller particle like sawdust. Since its original function is to separate solid particles from clean gas/air, it can increase the efficiency of gasification process if used as a gasifier where cyclone gasifier can be dual-functional gasifier – gasify the sawdust and separate the harmful particles from the producer gas.

Works on cyclone combustors were done as early as 1920 in the United Kingdom [Syred et al., 1987]. But only a few studies including practical work on gasification of wood fuels in cyclones have been reported in literature.

The possibility of using commercial fluid dynamics codes to obtain knowledge about straw behavior in cyclone gasifiers was investigated by Astrup [1995] by using CFDS-FLOW3D and FLUENT software. Experimental results from studies of the velocity field and pressure drop have been presented for example by Shepherd and Lapple [1939] and Boysan et. al [1983]. Fredriksson [1999] also had made an experimental and theory studies of cyclone gasification of wood powder which shows that it was possible to generate a combustible gas when injecting the wood powder with steam. In his thesis is also found several parameters that affect the cyclone gasifier efficiency.

1.2 Objective

The objective of this project is to design a cyclone gasifier for sawdust as the fuel. Air at atmospheric pressure will be used as the gasification agent. A cyclone gasifier will further be developed with the objective to convert sawdust as solid waste into usable gas via gasification process as well as separating the sawdust from the clean air. The cyclone gasifier is designed to drive the sawdust that enter the cyclone tangentially through the chamber in spiraling motion and partially burn the sawdust particle that drift at the side wall before its collected at the bottom of the cyclone. Sawdust is fed through screw feeder with the help of a hopper. The development of this cyclone will be based on previous experiments done on several types of cyclone separator and cyclone gasifier. The result of this development will be compared to the previous project as the output of the studies.

1.3 Scope of project

The scopes of the project are:

1. Literature study on fundamental concept of solid waste combustion and principle of cyclone separator.
2. Computer simulation of cyclone gasifier.
3. Detail design of the component making up the cyclone gasifier system.

In the first part of this project, literature study will be carried out to understand the fundamental concepts behind solid waste combustion. The main focus will be on gasification process of solid waste. As an addition, literature study on cyclone separator also will be carried out.

In the second part, computer simulation will be done base on some modification of existing cyclone gasifier specification. The main purpose of the simulation is to ensure that the dimension of the cyclone can cause the air-fuel flow entering the cyclone chamber in spiraling motion to allow the gasification process to be done with the help of heat produced by burner.

In the third part, detail design of every component that making up the system will be done by using the information and results of calculations that have been made in first part. These detail design will be shown in technical drawings.

1.4 Methodology

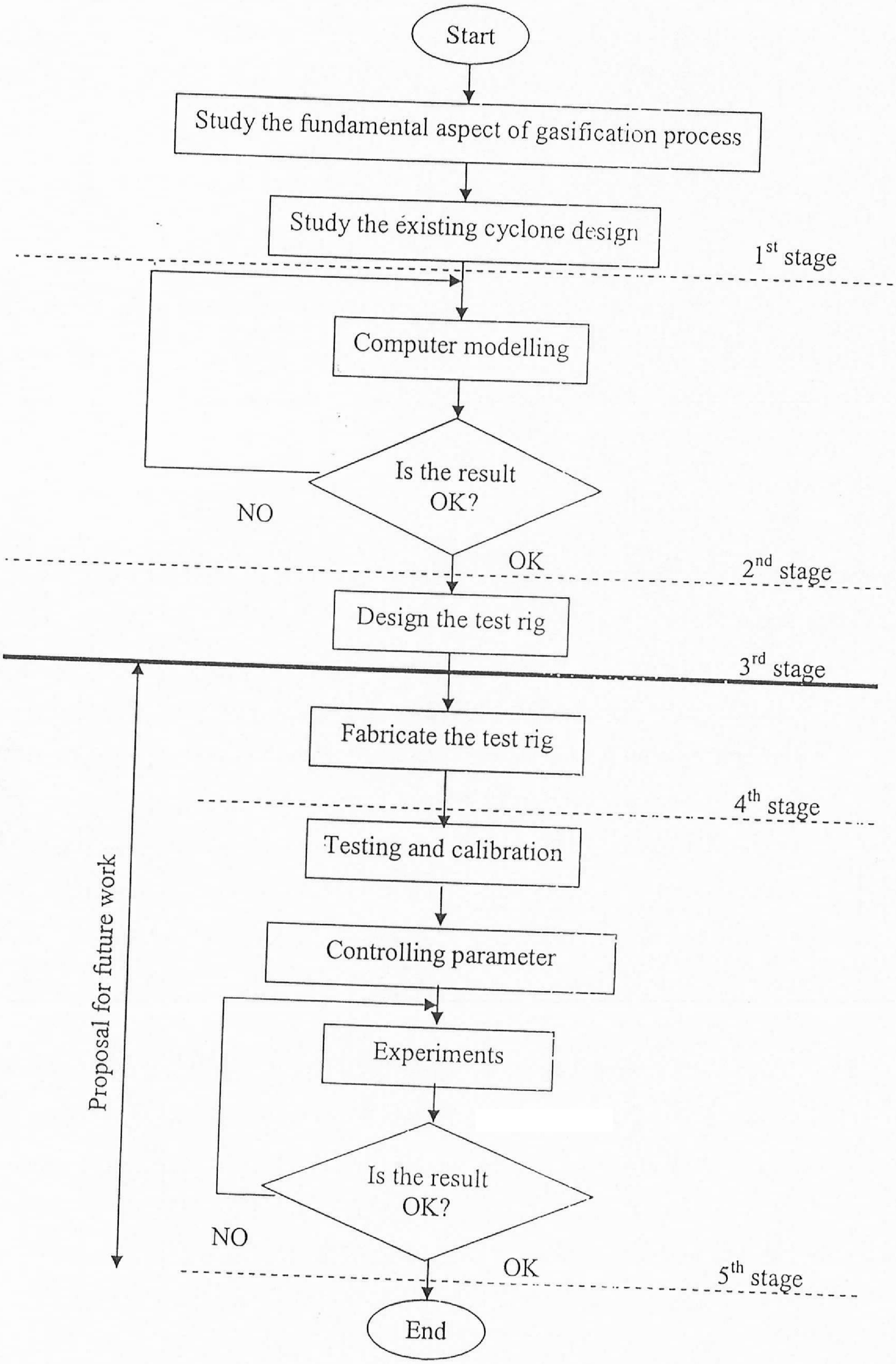


Figure 1.1Methodology Flow Chart

CHAPTER 2

BIOMASS GASIFICATION

2.1 Overview

This chapter gives an introduction to renewable energy, some characteristics of fuel (sawdust) and biomass gasification. It is hoped that with this chapter, readers will be provided with short but precise information on what biomass gasification is all about.

2.2 Renewable energy

Referring to the Texas Renewable Energy Industries Association (TREIA), renewable energy is defined as follows:

> " Renewable energy: Any energy resource that is naturally regenerate over a short time scale and derived directly from the sun (such as thermal, photochemical and photoelectric), indirectly from the sun (such as wind, hydropower, and photosynthetic energy stored in biomass), or from other natural movement, and mechanism of the environment (such as geothermal and tidal energy). Renewable energy does not include energy resources derived from fossil fuels, waste products from fossil sources, or waste products from inorganic sources." [www.treia.org]

Biomass is a renewable energy source because the energy it contains comes from the sun. Through the process of photosynthesis, chlorophyll in plants captures the sun's energy by converting carbon dioxide from the air and water from the ground into carbohydrates, complex compounds composed of carbon, hydrogen, and oxygen. When these carbohydrates are burnt, they turn back into carbon dioxide and water and release the sun's energy they contain. In this way, biomass functions as a sort of natural battery for storing solar energy. As long as biomass is produced sustainably, the battery will last indefinitely [http://www.ucsusa.org/energy/brief.biomass.html].

Photosynthesis process can be represented by the equation:

Carbon Dioxide + Water + Energy (solar radiation) = Biomass + Oxygen 1

$$CO_2 + H_2O + Light \ldots\ldots\ldots \underrightarrow{chlorophyll} \ldots\ldots (CH_2O) + O_2$$

If the biomass is combustible, the process is reversed and energy is released.

Biomass + Oxygen = Carbon Dioxide + Water + Heat Energy 2

As harvested, biomass will usually have high water content and this will affect the available energy. A typical figure of heating value for air-dried wood (20% water content, wet basis) is 15 MJ/kg.

Biomass gives a lot of advantages if used as fuel to convert the energy into a useful energy forms, whether electricity or combustible gasses. Since there are many types of biomass energy sources, the advantages of the biomass energy depends on the use of the biomass in it particular usage. Some of the advantages of biomass energy are:

- It is renewable, abundant and a natural energy source.
- It can be found easily in most of places. Energy plantation also can be made for some biomass plantation such as willow, miscanthus, switch grass, prairie bluestern, poplar and rubber wood.
- Although biomass combustion produces CO_2, it is consumed by plants, thus result in zero net emissions of greenhouse gases, enabling both industry and government to work towards meeting a quality environment.
- It is suitable for electricity supply, process heat, low temperature heat and fuels.
- It can be in solid, liquid or gaseous form.
- It is a storable form of renewable energy, capable of being transported and utilized 24 hours a day, 7 days a week.
- It is capable of providing energy on a small-scale through to large-scale, centralized production.
- It will create localized employment opportunities for rural communities.
- It enables a reduction in the volumes of waste to landfill, thus helping councils to meet their zero-waste commitments.

2.3 Gasification

Gasification of biomass is a relatively recent innovation or technology. Work really only started in the 1930's. Interest in biomass gasification began as a cheaper alternative to coal gasification and was driven by World War II fuel shortages as an alternative fuel for vehicles.

The complete definition of gasification is the conversion of solid fuel into combustible gases at elevated temperature with limited quantities of gasifying agents such as oxygen, hydrogen or steam. Gasification technologies differ in many aspects but rely on four key engineering factors:

1. Gasification reactor atmosphere (level of oxygen or air content).
2. Reactor design.
3. Internal and external heating.
4. Operating temperature.

Typical raw materials used in gasification are coal, petroleum-based materials, and organic materials. The feedstock is prepared and fed, in either dry or slurries form, into a sealed reactor chamber called a gasifier. The feedstock is subjected to high heat, pressure, and either an oxygen-rich or oxygen-starved environment within the gasifier. Most commercial gasification technologies do not use oxygen. All require an energy source to generate heat and begin processing.

There are three primary products from gasification:

1. Hydrocarbon gases (also called syngas).
2. Hydrocarbon liquids (oils).
3. Char (carbon black and ash).

Syngas is primarily carbon monoxide and hydrogen (more than 85 percent by volume) and smaller quantities of carbon dioxide and methane. Syngas can be used as a fuel to generate electricity or steam, or as a basic chemical building block for a multitude of uses. When mixed with air, syngas can be used in gasoline or diesel engines with few modifications to the engine.

2.3.1 Types of gasification process

The types of gasification process are determined by the types of gasifying agents. The gasifying agents provide a suitable temperature and condition to promote gasification process. There are five main gasification processes:

1. Pyrolysis gasification
2. Air gasification
3. Oxygen gasification
4. Hydrogasification
5. Steam gasification

2.3.1.1 Pyrolysis gasification

Heat is the only gasifying agent in this process. Pyrolysis processes is primarily used to produce char and oil products, with some of the gas produced being burnt to provide the heat for the process. However some processes burn the oil and the char to recover their heat in the form of higher yields of medium energy gas

2.3.1.2 Air gasification

Air gasification is the most common, simplest and the cheapest type of gasification process. Air contains 79 % by volume of nitrogen which does not react with the biomass. Thus when using air as the gasifying agent, the nitrogen dilutes the gas produced and hence lowers its heating value to about 4-5 MJ/m^3. However the gas produced is suitable for operation of boilers or engines but is too diluted to be efficiently transported in pipelines over long distances.

2.3.1.3 Oxygen gasification

A medium energy gas of about 8 MJ/m^3 will be produced if using oxygen as gasifying agent suitable for limited pipeline distribution. This gas can be used for industrial process heat or as synthesis gas to make methanol, gasoline, ammonia, methane or hydrogen.

2.3.1.4 Hydrogasification

This process is also called methanation. Hydrogen is used as the gasifying agent producing methane as the product. Hydrogen can be added to the system or generated in the reaction by the shift reaction between carbon monoxide and steam.

2.3.1.5 Steam gasification

Steam is sometimes added with air as gasifying agent to increase the quality of the gas produced and to reduce the high heat of reaction. The presence of small quantity of steam helps in the production of methane. The steam is also generated from the drying process of biomass.

2.3.2 Types of gasifier

The main type gasifiers are:

a) Fixed bed
   a. Up-drought
   b. Down-drought
   c. Cross drought
   d. Devolatilisation
b) Fluidized bed

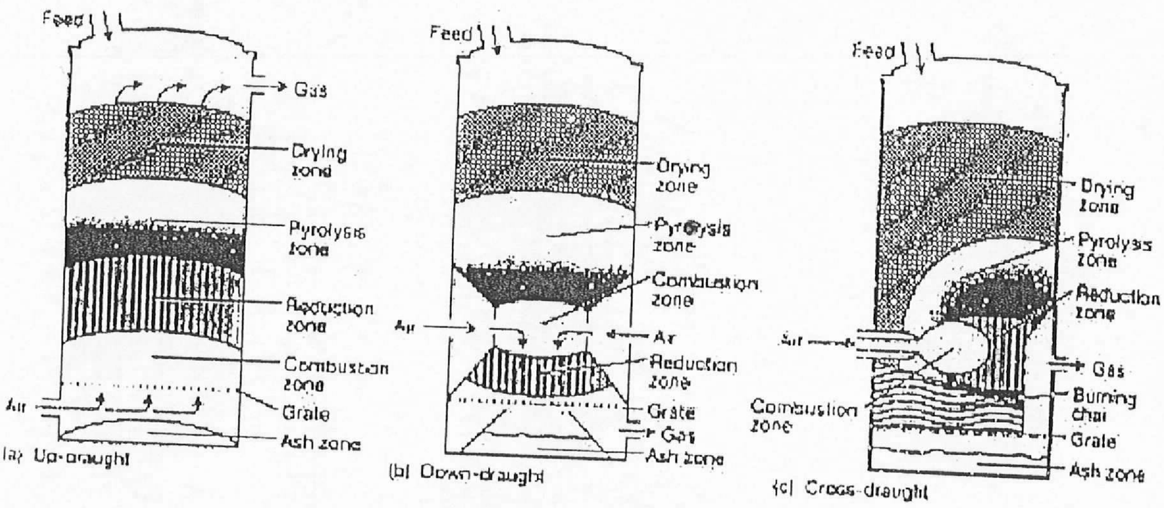


Figure 2.1 Types of fixed-bed gasifiers

Table 2.1 Gasifiers' characteristics

Types of gasifiers		Characteristics
Fixed-bed gasifier (10-100 mm fuel size)	Up-drought	• Simplest and oldest type • Relatively insensitive to size and moisture content (< 60% wb) • Produces oils, tars etc which contaminate gas • also disposal problem
	Down-drought	• Sensitive to fuel type, size, moisture content (<25% wb), density, • ash content, and load fluctuation • Some tar in gas plus ash and dust
	Cross-drought	• Small sizes <10 kW(e) • Charcoal fuel • High operating Temp ~1500°C • Reduced tar/oil in gas
	Devolatilisation	• Larger sizes • Burns oils, tars, etc in separate chamber
Fluidized bed (1-10 mm fuel size)	Bubbling bed	• Basically same form of up-draught gasifier with reaction zone and air velocity sufficient to fluidize particles in bed. • Special case of fluidised bed combustor with sub stoichiometric air • Bed fine grained or pulverized fuel • High tar content • Poor response to load change • Control equipment required

2.3.3 Producer gas cleaning system

If the gas is to be used with an internal combustion engine it is essential to clean the gas to remove tar and solid particles. Quite complex clean up systems are required. Nevertheless, gasifier/internal engine combustion systems are found to have problems with sustained use. Environmental factors such as noise, emissions may also be of importance. Figure 2.2 below shows an example of clean-up arrangement in gas producer system.

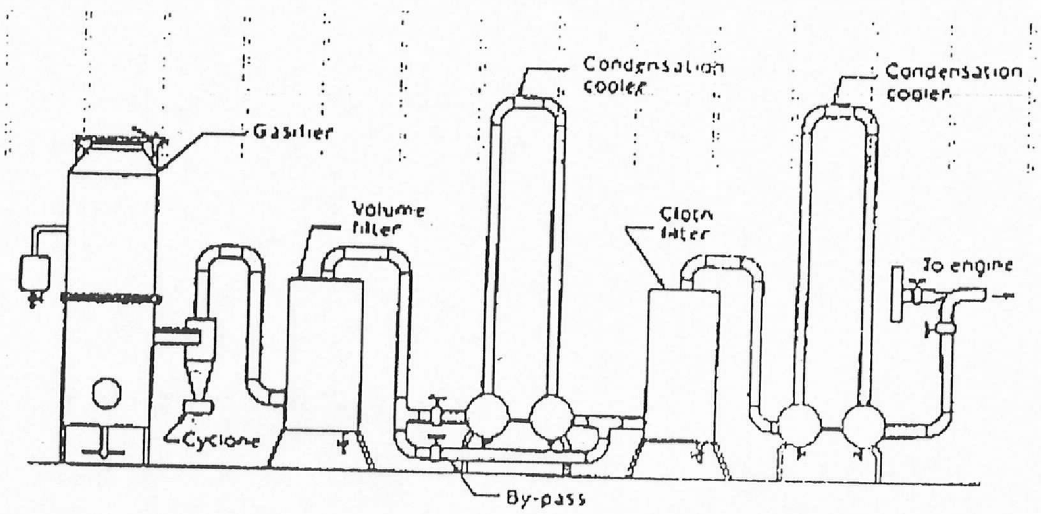


Figure 2.2 Example of clean-up arrangement in gas producer system.

2.4 Energy heating value

Sawdust is the main biomass energy source in this study where it will be used as a fuel in cyclone gasifier. This part will discuss the characteristic of sawdust to give further understanding of its characteristics so that can be used as a fuel in cyclone gasifier.

The main constituents of dry wood are:

- Cellulose, $CH_{1.66}O_{0.83}$
- Hemicelluloses
- Lignin, $CH_{1.23}O_{0.38}$
- Some resin and mineral

From ultimate analysis, the chemical compositions of wood, by mass basis (dry and ash-free) are:

- Carbon, C = 47.3%
- Hydrogen, H = 5.8 %
- Oxygen, O = 45%
- Nitrogen, N = 0.8%
- Sulfur, S = 0%
- Ash = 1.1%

This chemical composition varies very little in different species.

From the ultimate analysis above, calorific value for sawdust is calculated as:

$$HHV = 0.341C + 1.323H - 0.12O - 0.00153A + 0.0685 \text{ MJ/kg} \quad 3$$

The energy content of dry wood (oven dry) is remarkably constant at around 20 MJ/kg or 20 GJ/tone. When dry wood is combusted, 20MJ/kg of heat is released partly as hot gas (CO_2, N_2 and excess O_2) and partly as steam [Harker, A.P; Sandels A; Burley J, 1982].

1 kg wood → 0.540 kg water

If the steam is condensed, the latent heat is recovered (gross calorific value). If lost, the useful heat is reduced (net calorific value) by 1.38 MJ/kg to give a net value of 18.6 MJ/kg.

The moisture content of wood Mw is normally given on a wet basis where

$$Mw = (W - D) / W \times 100 \quad 4$$

and W = Wet mass, D = Dry mass

As harvested, wood has a moisture content of 50%. Since half the 1 kg of harvested mass is water, the 9.3 MJ net energy from the half kilogram of wood will be further reduced by the energy required to evaporate the excess half kilogram of water to give a net energy of only 8.03 MJ/kg. Normally the 'harvested' wood is dried to a moisture content of around 20% before the energy conversion stage. The net energy per kg of wood at 20% moisture is around 14.4 MJ/kg. (In calculations a figure of 15 MJ/kg or 15 GJ/tone is often used).

As the biomass fuels are gasified, the general compositions of product gas for sawdust are: CO 20%, H_2 15%, CO_2 15%, CH_4 2%, N_2 45%, and O_2 3%.

So, the calorific value of product gas can be determined as:

$$(LHV)_{co}.x_{co} + (LHV)_{H2}.x_{H2} + (LHV)_{CH4}.x_{CH4} \quad 5$$

It is found that heating value for biomass producer gas usually 4 MJ/m^3 to 5 MJ/m^3. It seems to be that low calorific value compared with raw sawdust because of presence of N_2.

Table 2.2 shows the comparison of heating value of various materials (biomass and fossil fuels).

Table 2.2 Heating value for various materials

Material	LHV (MJ/kg)
Shell	17.3
Fibre	10.9
Oil palm empty fruit branch	7.2
Husk	13.2
Wood	11.4
Baggase	7.8
MSW	10
Chicken dung	14
Diesel	40.9
Coal	29.5
Crude oil	42.1
Natural gas	14

2.5 Chemistry of biomass gasification

Biomass gasification can be shown as a global reaction between the biomass and the gasifying agent. The ideal gasification reaction with oxygen can be written as follow:

$$\mathbf{CH_{1.4}\,O_{0.6} + 0.2\,O_2 \rightarrow CO + 0.7\,H_2} \qquad 6$$

where $CH_{1.4}\,O_{0.6}$ is chemical formula for wood which is seem to be closed to chemical formulae for Cellulose and Lignin.

Heat is required to convert the solid wood into carbon monoxide and hydrogen. This reaction is an endorthermic reaction. An additional amount of oxygen has to be supplied to provide the combustion heat for the gasification reaction. The excess oxygen reacts with about a third of the carbon monoxide and hydrogen ideally produced. The above reaction becomes the theoretical global gasification reaction given by

$$CH_{1.4}O_{0.6} + 0.45O_2 \rightarrow 0.7CO + 0.3CO_2 + 0.55H_2 + 0.2H_2O \qquad 7$$

The above gasification reaction can be partly represented by a homogeneous gasification reaction with the shift reaction being considered to be at equilibrium. The equilibrium constant of the shift reaction can be written as follows:

$$K = \frac{P_{H_2}.P_{CO_2}}{P_{CO}.P_{H_2O}} = \frac{0.55 \times 0.3}{0.7 \times 0.2} = \frac{0.165}{0.14} = 1.1786 \qquad 8$$

$$= 1.1786$$

where P_{H2}, P_{CO2}, P_{CO} and P_{H2O} are the mole fractions for hydrogen, carbon dioxide, carbon monoxide and water vapour respectively obtained from equation 4.

From the table of equilibrium constants, the equilibrium temperature is 768.28°C. This indicates that the theoretical gasification temperature is

$$T|_{(gasification)} = 768.28\ °C$$

The temperature obtained is based on dry biomass material. Normally biomass material is characterised by its moisture content. The higher the moisture content the more the water-gas reaction occurs. The limit is about 36 % whereby the equivalent saturation reaches 100 % and thereby reduces the reduction temperature to about 500°C. This reduces the combustible gases concentration and the hence the calorific value. This is true for certain gasifiers in particular the downdraft type. However fluidised gasifiers or updraft gasifiers can gasify biomass material having moisture content up to about 60%.

2.5.1 Air-fuel ratio for theoretical gasification processes

In order to determine the amount of air required to gasify a quantity of biomass material, air-fuel ratio is necessary to be known. By using the Global Chemical Reaction as mentioned before (**Equation** 7), air-fuel ratio can be calculated. The global reaction can be written in mass form by multiplying the molar fractions of the biomass and the gases by their molecular masses.

The above equation becomes,

$$(23kg)\ CH_{1.4}O_{0.6} + 0.45(32kg)O_2 \rightarrow 0.7(28kg)CO$$
$$+0.3(44kg)CO_2 + 0.6(2kg)H_2 + (18kg)H_2O \qquad 9$$

This becomes

$$23CH_{1.4}O_{0.6} + 14.4O_2 \rightarrow 19.6CO + 13.2CO_2 + 1.2H_2 + 18H_2O \qquad 10$$

For 1 kg of $CH_{1.4}\ O_{0.6}$, the amount of O_2 required is 0.626 kg. Therefore the amount of air which is used as the gasifying agent per kg of biomass is given by

$$0.626\ kg/0.233 = 2.687\ kg$$

Therefore the gravimetric air-fuel ratio for theoretical gasification process is given by

$$(A/F)_{theoretical} = 2.69$$

The volume of air required for theoretical gasification will be about

$$2.69/1.2 = 2.24\ m^3/kg\ of\ biomass$$

It shows that 2.24 m^3 of air is required for 1 kg of biomass material. However, biomass rate and air supply flow rate is not considered to obtain this value. The higher the flow rate of air supplied, the higher is the rate of biomass consumed and the higher is the rate of gasification and hence the higher the flow rate and the rate of energy output of the producer gas.

2.5.2 Equivalence ratio

The amount of air required for complete combustion of the biomass material to form carbon dioxide and water vapour can be represented by

$$CH_{1.4}O_{0.6} + 1.05\ O_2 \rightarrow CO_2 + 0.7\ H_2O \qquad 11$$

In mass form,

$$(23)\ CH_{1.4}O_{0.6} + (32)1.05\ O_2 \rightarrow (44)\ CO2 + 0.7\ (18)\ H2O \qquad 12$$

The amount of oxygen required per kg of biomass material is 1.46 kg

Therefore the air -fuel ratio becomes 6.27 kg of air/ kg of biomass or in terms of volume, 5.22 m^3/ kg of biomass

Hence for equivalent ratio (ϕ) of unity, the air-fuel ratio is 5.22 m^3/kg of biomass. The equivalent ratio of a gasification process can therefore be determined from the air-fuel ratio of the gasifier.

Similarly the equivalent ratio can also be determined from the number of moles of oxygen used in the reaction. For equivalent ratio of unity the number of mole of oxygen is 1.05. Hence for ideal gasification where the number of moles of oxygen used is 0.2, the equivalent ratio is 0.19. Likewise for theoretical gasification where the number of moles of oxygen is 0.45, the equivalent ratio is 0.43. Therefore the equivalent ratio for gasification is 0.19-0.43 ranging between the ideal gasification and the theoretical gasification

CHAPTER 3

DESIGN BASIS FOR CYCLONE GASIFIER

3.1 Overview

This chapter will discuss the basic theory of cyclone gasifier and its characteristic in isothermal condition in order to understand the capability of cyclone separator to be used as cyclone gasifier as well as a separator. It is all about the flow field in cyclone, particle separation, pressure drop, and effects on cyclone efficiency. This chapter also will explain the design basis for the cyclone gasifier system.

3.2 Cyclone Separator

Cyclone is widely used as a dust separator where the air that contains dust enters the inlet of the cyclone then will be cleaned by separating the dust from the clean air. The cyclone is used to separate solids from air stream because it is simple, economical and reliable. There are many size of cyclones based on requirement. Basically cyclone has one or two inlets and one outlet at the top of it to drive out the separated gas or air. At the bottom of the cyclone separator is usually attached with a dust collecting system – can be as simple as a rectangle box to collect the dust or separated product. The following figure shows the basic concept of air-dust movement in a cyclone separator.

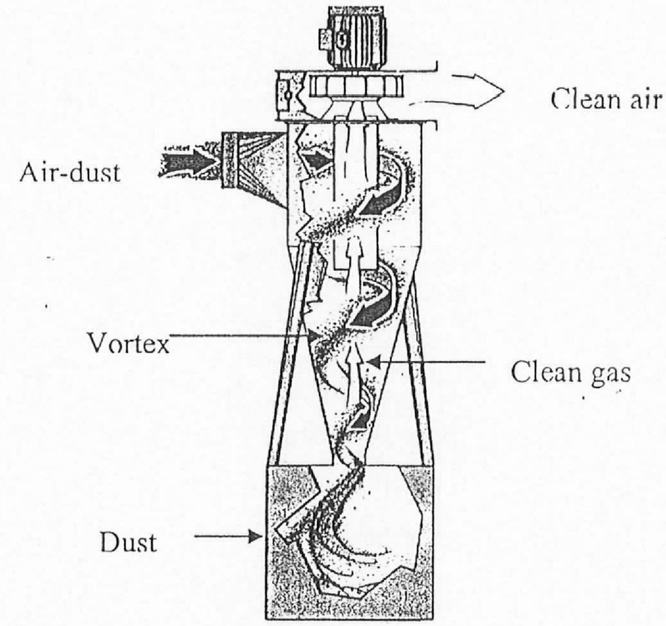


Figure 3.1 Basic concept of dust separating system in a cyclone separator [www.uniwashinc.com]

The uses of the cyclone have fallen into four categories:

1. *Pollution control* where high efficiencies are required to meet stringent regulation.
2. *Precleaner* plays upstream of pollution control equipment that maybe sensitive to high loadings to particulate matter such as scrubbers. Cyclone protects these devises and allows them to operate more efficiently.
3. *Product recoveries* where the valuable product can be remove from the gas stream.
4. *Particulate size classifiers* where aerodynamic classification of particle size plays a vital role in the production process.

3.2.1 General description of isothermal flow field in a cyclone

In cyclone separator, the polluted air will enter the cyclone inlet tangentially with suitable velocity so that the swirl motion will occurs along the inside space of the cyclone. It has been observed that the gas flow is more spiraling downward from the inlet close to the wall of the cyclone until it reaches the bottom of the cyclone. At the bottom, the gas spiral changes direction and spirals upwards, towards the outlet, in the centre of the cyclone. At the same time while the gas flows as mentioned before, the heavier particle such as sawdust will swirl together with the gas but will drop at the bottom of the cyclone when the gas spiral upwards [Fredriksson,.1999].

The gas velocity is however well inside the turbulent flow region which leads to a redistribution of the velocity between the spirals. Any particular distinct spirals are therefore not present. The turbulence will also lead to a transfer of gas between the outer and inner flow which is important for particle separation applications [Alexander, 1949].

The isothermal tangential velocity distribution can be described as a Rankine's combined vortex model which is composed of a forced vortex (solid body rotation) and a free vortex [Ogawa, 1984].

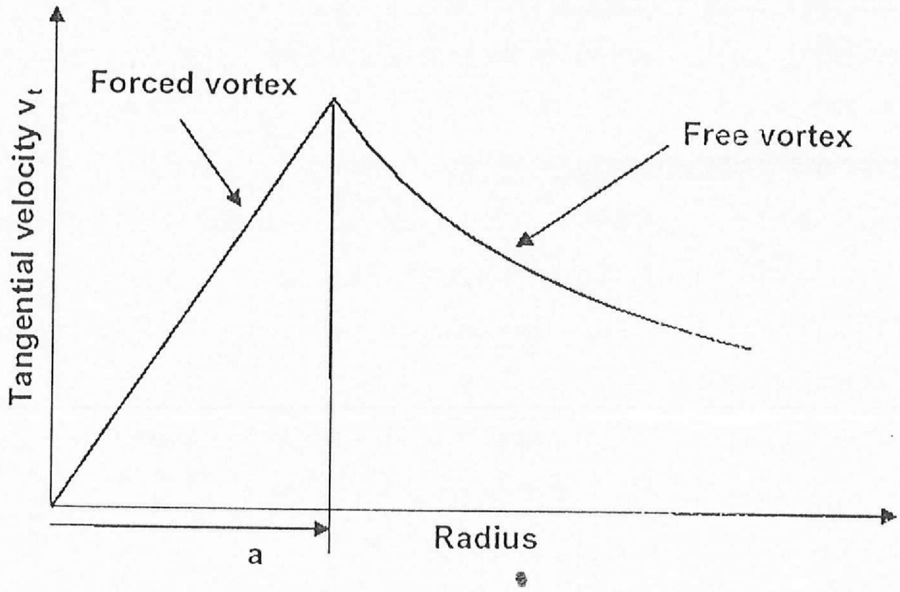


Figure 3.2 Tangential velocity distributions [Ogawa, 1984]

The tangential velocity can be described as:

$V_t \longrightarrow$	V_t = constant X r	for 0 < r < a	D – Diameter of cyclone body
	V_t X r^n = constant	for a < r < D/2	r – Radius of cyclone body
			n – Vortex exponent

Value of vortex exponent, n has a great effect on particle separation efficiency and pressure drop for the cyclone. It is basically a measure of the conservation at angular momentum and in an ideal free vortex with zero viscosity and no frictional effect, n is equal to 1. It has been found experimentally to be between 0.5 and 0.9 [Leith and Licht, 1972].

Empirical expression for n [Alexander, 1949] is given as

$$n = 1 - \{[1-0.67\,(D^{0.14})]\,(T/283)^{0.3}\} \qquad 13$$

- Where T is temperature in a cyclone [K].

The radial position **a**, of the maximum tangential velocity can be found somewhere between half the outlet pipe radius and equal to the outlet pipe radius depending on the gas flow rate and cyclone geometry. Maximum tangential velocity may be several times the average inlet gas velocity. It is normally found to be between 1.5 and 2.5 times the inlet velocity [Perry and Green, 1984].

The axial flow is directed downwards in the outer region of the cyclone and upwards in the centre. The radial position where the axial flow changes direction is a distance from the cyclone wall approximately to the width of the inlet pipe. However, the flow in the centre of the cyclone is not always only directed upwards. If the diameter of the outlet pipe is small, the flow will normally upward and have a positive velocity profile with a maximum on the cyclone axis. But if the outlet pipe is large, the flow in the core of the central region may have a velocity minimum on the axis. In some cases of this condition, it results in a reversed flow and entrainment of the outside fluid [Griffiths and Boysan, 1996].

In central region of the solid body rotation, the radial velocities are directed outwards. Radial velocity measurements at different tangential positions show that the cyclone flow is not rotational symmetric [Fredriksson, 1999].

Double vortex flow can be explained as the flow that is spiraling down at the outer region of the cyclone and upwards in the centre. A model of the main flow but generally considered to be in simplification can describe the flow where superimposed on this main flow has been shown to exist a double vortex or double eddy [Ogawa, 1984].

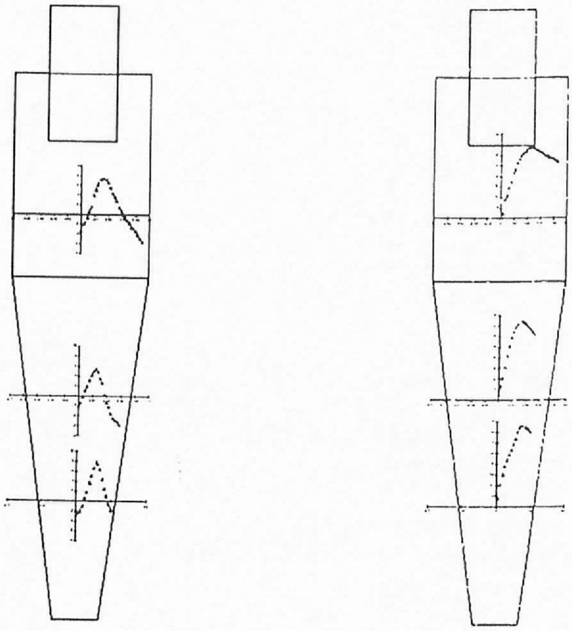


Figure 3.3 Axial (left) and tangential gas velocities (right) in a typical cyclone [Boysan, 1983]

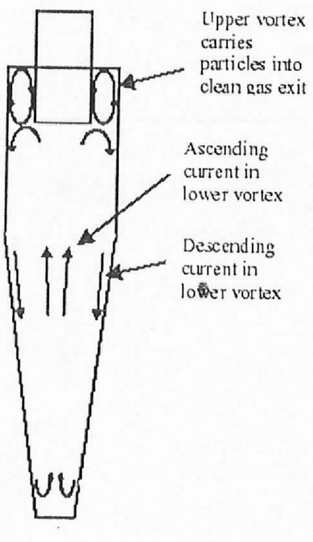


Figure 3.4 Secondary flows in cyclone [Ogawa, 1984]

The double vortex leads to a short-circuiting of the cyclone as incoming gas flow escapes directly to the outlet pipe via the upper part of the double vortex. A rule of thumb is that 10% of the incoming flow rate escapes this way [Muschelknautz, 1993].

The appearance of the double vortex is caused by the radial static pressure gradient that increases with increasing radius. Near the top and bottom walls the tangential velocity is damped within the boundary layer and cannot uphold the same pressure gradient generated in the main flow field. This will result in a radial inward secondary flow in the boundary layer at the roof which drives the upper vortex [Fredriksson, 1999].

Alexander [1949] has done experiments that show that the axial position of the turning point of the cyclone vortex is not determined by the length of the cyclone. It is on the other hand suggested that there exist a 'natural length' of the vortex that varies with cyclone proportions. The turning point of the vortex has been observed to oscillate around a fixed position and it has also been shown that the position of the turning point has a considerable effect on the separation efficiency. The oscillation was found to oscillate with a random frequency around the mean position. The mean position could however change abruptly to another position where the oscillations would continue [Hoffman et al., 1995].

3.2.2 Particle Separation

The idea behind cyclone separator is to generate a centrifugal force field, which make it possible to separate small dust particle - below 10 micrometer in diameter, from a turbulent gas flow. The centrifugal force field is established by a swirling flow inside the entire cyclone. The ratio between the centrifugal force and gravity force ranges from 100 to 2000, thus the gravity force has a minor influence [Fredriksson, 1999].

The particle that follows the main path of the gas spiral is primarily affected by two radial forces in its way down through the cyclone - centrifugal force due to the curved path and the drag force caused by the inward radial flow. If the centrifugal force is larger than the inward drag force, the particles move towards the wall and are swept towards the lower cyclone outlet by the main gas flow. For small particles, the drag force maybe sufficient to move the particle towards the center of the cyclone. If the inward drag force is strong enough, and particles reach the central flow region where the flow is ascending, they will most likely to escape together with the outgoing gas. However, the centrifugal force will increase as the particle is moving towards the radius of the outlet pipe due to the increased tangential velocity. Thus, the force on a particle may balance at some radius where the particle theoretically stops its radial movement and rotates in an orbit with a constant radius. In practice, the radial velocity is not constant in the tangential direction and the particle will consequently move. The particle can also change path caused by secondary effect such as turbulent eddies or collisions with other particles [Stairmand, 1951].

As mentioned before, double vortex is a secondary flow that has a large effect on particle separation. The upper part of the vortex is effectively short-cutting the flow, this mean that the particles following this flow will be carried to the gas exit and will most likely not be separated. Re-entrainment or base pick-up of particles from the dust bunker to the ascending vortex has also been identified as a major cause of poor cyclone performance. Lower part of the vortex also can reach down into the dust bunker and pick up already separated particles. If the sealing between cyclone and dust bunker is leaking, the vacuum pressure in the core region which extends down into the bunker will cause a leakage flow into the bunker. The leakage-flow picks up particles on its way to the upward vortex flow which reduces the separation efficiency [ter Linden, 1949].

3.2.3 Pressure drop

Pressure drop over the cyclone is an important variable when evaluating performance of a cyclone. It is a measure of the amount of work that is required to operate the cyclone at the given condition, which is important for operational and economical reasons [Fredriksson, 1999].

The pressure drop can be defined as the difference in mean total pressure at the inlet and the outlet. Normally, it is the static pressure difference that is measured which is reasonable assumption if the area of the inlet and outlet are similar. The total pressure drop over a cyclone consists of losses at the inlet, outlet and within the cyclone body. The main part of the pressure drop (about 80%) is considered to be pressure losses inside the cyclone due to the energy dissipation by the viscous stress of the turbulent rotational flow. The remaining 20% of the total pressure drop are caused by contraction of the fluid flow at the outlet, expansion at the inlet and fluid friction on the cyclone wall surface [Ogawa, 1984].

When cyclones are used as particle separators, the desire to minimize the pressure drop is unfortunately in conflict with the wish to maximize the separation efficiency. Any measure to increase the separation efficiency is normally coupled with considerable increases in pressure drop [Mothes at el., 1984].

A general empirical equation of the pressure drop over the cyclone, Δp_c has been defined as [Ogawa, 1984]:

$$\Delta p_c = \zeta_c.\rho.\frac{v_i^2}{2} \qquad 14$$

υ_i is the mean inlet velocity at inlet pipe, ζ_c is the pressure drop coefficient. ζ_c is defined as:

$$\zeta_c = X.\left(\frac{A_i}{D_e^2}\right)^z \qquad 15$$

X and z are function of the cyclone geometry, A_i is the inlet pipe area and D_e is the outlet pipe diameter.

The above expression for the pressure drop is validated for an isothermal flow without particles. Pressure drop will change due to the influence of the particles. The pressure drop will decrease with an increase in particle concentration. This phenomenon has been said to be caused by the particles, which tends to equalize the gas momentum in adjacent layers in the radial direction. This will lower the exponent n in **Equation 13** and consequently lower the tangential velocity. A lower tangential velocity will lower the total pressure loss due to decreasing losses connected to turbulence and friction losses at the wall. However, at a certain level of particle concentration, the pressure drop will start to increase as the particle concentration is further increased. That is when particles will start to collide each other and with the cyclone wall which increases the frictional pressure losses [Fredriksson, 1999; Ogawa, 1984; Shepherd and Lapple, 1939].

3.2.4 Various effects to cyclone efficiency

There are many parameters that affect the cyclone efficiency. One of the most important characters that influence in cyclone efficiency and friction losses is the surface area in contact with the fluid flowing inside the cyclone. This area is affected by many geometrical parameters. High collection efficiency in a cyclone requires high residence time and mean velocity of the flow inside the cyclone. Therefore it is needed to define the optimum cyclone height to obtain higher efficiency. Cyclone efficiency will increase with the increase of height and this statement is proven by experiments done by Avci and Karagov (2000). But the height is limited due to friction and separation from the surfaces.

In cyclones, the second phase is separated mainly during the flow from the inlet to the cone apex and is less affected by the reverse flow to the exit. Nevertheless, the dimension of the exit channel is important, and therefore it will be appropriate to consider the effects of the reverse flow together with the dimensions of the exit channel. Increasing the exit channel diameter, D_1 may decrease the width and increase the height of the flow cross section. This may lead to an increase in efficiency and pressure losses [Avci and Karagoz, 2000]

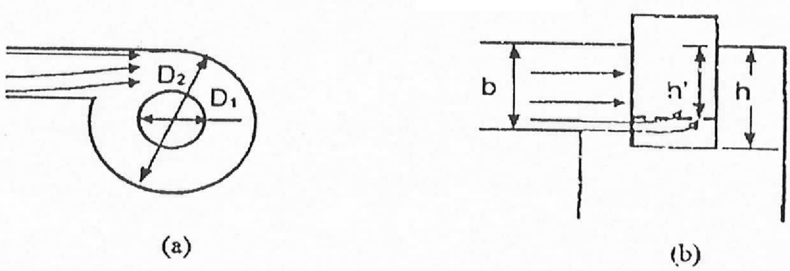


Figure 3.5 Effect of the exit channel on the flow

3.2.5 Cyclone performance at high temperature

Influence of temperature as parameter on separation efficiency and pressure drop is needed to be investigated since the cyclone in this study was designed to operate at high temperature. Results from experiments by Bohnet and Lorenz [1983] and Parker et al [1981] show that the separation efficiency is significantly influenced by temperature and the separation efficiency has been shown to decrease with increasing temperature. Oppositely the pressure drop will decrease with increase in temperature. These effects have been explained by the decreased density, increased wall friction and increased viscosity due to the increased temperature. All three variables have the effect of lowering the tangential velocity that accordingly lowers the pressure drop and separation efficiency. All these results were based on conditions where the inlet velocity was constant between the different experiments [Fredriksson, 1999].

3.3 General operating parameter for gasifier

The operating parameters inside the gasifier which will govern the biomass gasification are as follows;

i) Turndown ratio

ii) Efficiency

iii) Conversion rate

Turndown ratio (TR) is defined as follows:

$$TR = \frac{\text{Designed thermal output}}{\text{Min. thermal output}} \qquad 16$$

This ratio is claimed to vary between about 3- 20 and must be specified in terms of the gas quality required. Too low a value generates a very dirty gas and a too high a value yields low energy gas. TR is also important for load varying applications. Typically TR for fixed bed gasifier is about 5 and that for fluidized bed is 3. Turndown ratio is primarily affected by the fuel moisture content; combustor size and insulation are also important.

The efficiency of a gasifier is also an important parameter which is defined as follows:

$$\eta = \frac{\textbf{Energy in the cold gas}}{\textbf{Energy in the biomass feed}} \qquad 17$$

The efficiency of a gasifier normally ranges from 70-90 %. Most of the losses are associated with sensible heat loss of the gas, loss in the heat transferred to the skin of the gasifier, tar loss and char carryover. Fredriksson (1999) have also shown that the gasification efficiency (as expected) reduces as the moisture content increases. This is due to the energy loss in evaporating the water present in the solid fuel.

Finally the conversion rate which is the rate, at which gas is produced from the solid feed, is also an important parameter. The conversion rate is defined either as energy per area which is approximately 630-9450 kW/m^2 or as energy per volume which is approximately 1030-5150 kW/m^3. The area refers to the cross-sectional area of the gasifier throat and the volume refers to the volume of the reduction zone. These values are convenient for comparing gasifiers of different sizes and estimating gasifier size requirement.

3.4 Cyclone as a gasifier as well as a separator

3.4.1 Gasification in cyclone

The parameters which determine the gas quality are important because it will determine the application of the gas. The heating value of the gas for example affects the ease of combustion. Tar and particulate level of the gas produced are required to estimate cleanup problems and to determine the use of suitable burners, engines, etc. The temperature of the raw gas dictates the degree of cooling required for use in engines or the sensible heat that may be recovered. The moisture content of the gas determines, in part, the cooling load.

Related to this study, cyclone gasifier will be developed using sawdust as the fuel. Cyclones commonly used as a solid separator but for decades, researches and studies had been done on cyclone as a gasifier. The significant limitation when using cyclone is the fuel size must not be too large. So, sawdust is used as the fuel because of the size and its calorific value. Sawdust as fuel requires relatively long residence time and good mixing with the oxidant to be completely burnt. This can be achieved in a cyclone where burning fuel particles can be suspended, according to their size, in the cyclone chamber thanks to the centrifugal forces.

Experiment with cyclone combustion of gas oil, which is expected to imitate solid fuel combustion fairly well, show that the velocities in the outer region of the cyclone are more or less of the same magnitude as in the isothermal case [Mohammed Ali and Syred, 1987].

Compared to pulverized coal, wood powder contains high fraction volatiles. A higher fraction of the fuel will be converted to gas immediately upon rapid heating. The released volatile gas reacts instantaneously with the oxygen present. In this sense a wood fuel behave more like a gaseous fuel [Najim et al., 1981].

Depending on fuel type and combustion conditions, the behavior of the reacting flow will be different. The volatile part of a solid fuel will behave similar to gaseous fuel and react immediately at the entrance region of the cyclone. The decrease in density due to the temperature rise will force the products towards the center and outlet pipe as a result of the centrifugal force field. This buoyancy effects will in a similar way transport partially burned products and air, with a lower temperature and higher density, towards the wall. Particle also will move outwards due to the centrifugal forces. This stratification of the flow is beneficial from the point of view of that the unburned material can be suspended in the cyclone long enough to be completely burned [Fredriksson, 1999].

Swirl number S is normally used to characterize the swirling flow in swirl burner (similar kind of combustion device as the cyclone combustor). For cyclone, swirl number S is defined as:

$$S = \frac{2.G_\phi}{D_e.G_x} \qquad 18$$

where G_ϕ is the axial flux of angular momentum and G_x is the axial flux of linear momentum.

Simpler variant is usually calculated based on the geometry of the cyclone since the swirl number calculation is not straightforward without detailed information on the flow. So that geometric swirl number S_g is referred for isothermal operation.

$$S_g = \frac{\pi.D_e.D}{4.a.b} \qquad 19$$

For non-isothermal operation, where inlet and outlet gas temperatures are known, non-isothermal geometric swirl number is used as follows:

$$S_{gT} = S_g \times \frac{T_{inlet}[K]}{T_{outlet}[K]} \qquad 20$$

This equation shows that the swirl number decreases when the gas temperature increases due to combustion reaction. If the gas from the cyclone is discharged into open air, a toroidial recirculation zone will form if the swirl number is higher than 0.6 and if the exit Reynolds number is above 18000.

The exit Reynolds number was defined as $Re = U^*D_e/v$ where U is the average exit velocity based on the total mass flow rate, the exit area and the exit gas temperature. D_e is the exit diameter and v is kinematics viscosity of the gases at the exit based on the exit temperature. The swirl number for cyclone combustor was recommended to be typically at $8 < S < 20$ [Syred and Beer, 1974].

CHAPTER 4

DESIGN REQUIREMENTS

4.1 Overview

This chapter discusses the performance requirements of the system, geometrical basis, and auxiliary system requirements. It is hoped that with this chapter, reader will understand clearly on what will be calculated in Chapter 5.

4.2 Performance requirements.

The cyclone gasifier was designed to gasify sawdust to obtain an output of 200 kW_T at thermal power input of 286 kW_T with assumption that the cyclone efficiency is at 70%. This requires input mass flow rate of the raw material (sawdust) at 0.0159kg/s of sawdust. Since air is used as injection media, the minimum air flow rate needed for this gasification system corresponding to sawdust flow rate is 1709 liter/minute or 60.35 cfm. Calculation for these values is mentioned in detail in the next chapter.

This cyclone gasifier will operate at atmospheric pressure and using a propane burner or LPG to provide the heat to start the gasification process at temperature of 800°C– 850°C. The operation should be stable and the gas produced must be combustible. The pressure loss over the cyclone shall be as small as possible and the separation efficiency as high as possible.

4.3 Design basis

The cyclone gasifier in this study will be based on the design of cyclones used as combustor that has been studied by Syred and Beer [1974] then evaluated by Fredriksson [1999] shown in his thesis. Since the objective of this study is to design cyclone gasifier;

data and information that shown in the Doctoral Thesis: Exploratory Experimental and Theoretical Studies of Cyclone Gasification of Wood Powder, 1999 by Fredriksson were used as the main reference and guidance for the development of the cyclone gasifier.

4.3.1 Cyclone chamber volume

The size of cyclone chamber is determined by the rate of heat release. Combustion intensity C.I can be used to scale the combustor volume when the heat release rate and the pressure are given.

$$C.I. = \frac{heat \quad release \quad rate}{combustor \quad volume \times pressure} \; kW / m^3.atm \qquad (21)$$

The following table (Table 3.1) shows the result of comparison between some references. It is found that C.I values range between 2 and 23 MW/m^{3}atm with different fuels. According to Fredriksson report, design with combustion intensity C.I of 5 MW/m^{3}atm gave good performance. So, for this study also, value of 5 MW/m^{3}atm was used as the testing parameter.

Table 4.1 Combustion intensity achieved in different kinds of cyclone gasifiers

Reference	Fuel	Fuel flow [kg/h]	Fuel power [kW]	Cyclone dim. D*H [mm]	Combustion intensity [MW/m^{3}bar]
Cousins and Robinson [1985]	Sawdust (<10 mm)	Min 30 Max 200	160 1060	400*600	2.1 14.0
Barnhart and Laurendeau [1982]	Coal powder (<0.5)	Min 3 Max 12	25 100	150*250	5.7 22.6
Jaubert [1978]	Coal powder (<1 mm)	45	375	300*400	13.3
Fredriksson and Kallner [1993]	**Wood powder (<2 mm)**	**Min 10 Max 20**	**53 106**	**160*710**	**5.0 10.0**

4.3.2 Flow characteristics

Swirl number can be used to characterize and compare different cyclone configurations. By using **Equation 19** and **Equation 20**, with the value of S between 8 and 20 as recommended, the basic dimension of cyclone can be found. If the inlets are circular with diameter D_i, **Equation 20** can be written as:

$$S_{gT} = \frac{D_e.D}{n.D_i^2} \times \frac{T_{inlet}[K]}{T_{outlet}[K]} \qquad 22$$

Where n is the number of inlets. Refer to Figure 4.1.

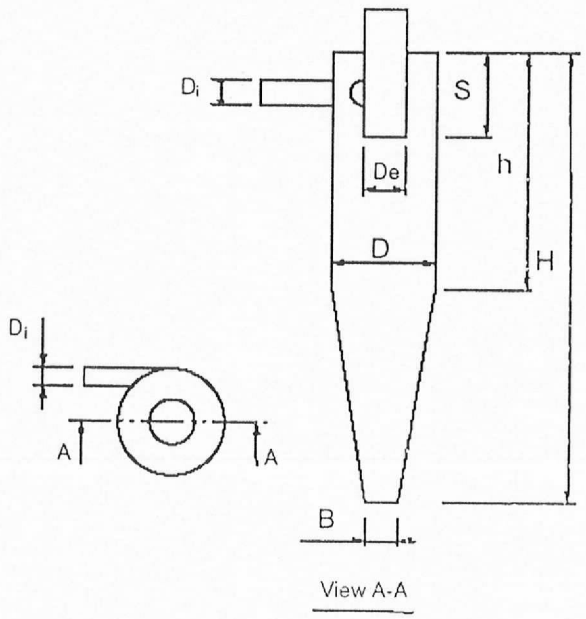


Figure 4.1 Dimensions of cyclone

4.3.3 Separation efficiency and pressure drop

According to Perry and Green [1984], performance regarding separation efficiency has been considered only to the design of cyclone as standard cyclone separator. Standard cyclone separator design gives relationships between cyclone dimensions. Typical values are $D_e = D/2$, $H = 4*D$, $h = 2*D$, $S \approx D/2$ [Perry and Green, 1984]. The optimum values for these ratios may vary depending on the purpose of the cyclone where cyclone separator is generally higher with smaller diameter than a cyclone combustor. The pressure drop increases if the cyclone outlet diameter D_e is reduced, so increases the separation efficiency.

4.4 Operating principle

Actually, the cyclone gasifier is the first stage of the two stage combustor. But for this study, consideration is only fall in the first stage where the combustible producer gas is the objective. Secondary system is not considered since the producer gas runs a diesel engine. It will directly flame up at the end of the exit if not supplied to the engine. Figure 4.2 shows the set-up of the cyclone gasifier system.

The sawdust is supplied to the cyclone inlets from the feeding system via screw feeders and two downcomers. The sawdust is injected into the cyclone by two tangentially air driven injectors into the cyclone gasifier. Gasification air will be supplied to the cyclone together with the sawdust via the downcomers and from injectors respectively. The injector directed the fuel/air mixture to enter the cyclone in a tangential direction, which generates swirl flow in the cyclone. The swirl will force the incoming sawdust particles to follow the trajectory close to the cyclone wall. The main part of reactions takes place mainly on the wall. Product gas exits the cyclone via the top outlet of the cyclone, while the ungasified particles fall downwards toward the bottom outlet into ash collector. The top outlet of the cyclone is connected to pipe line so that the product gas can be collected and analyzed.

The complete system drawings are shown in **Appendix A** and detailed calculations are mentioned in Chapter 5.

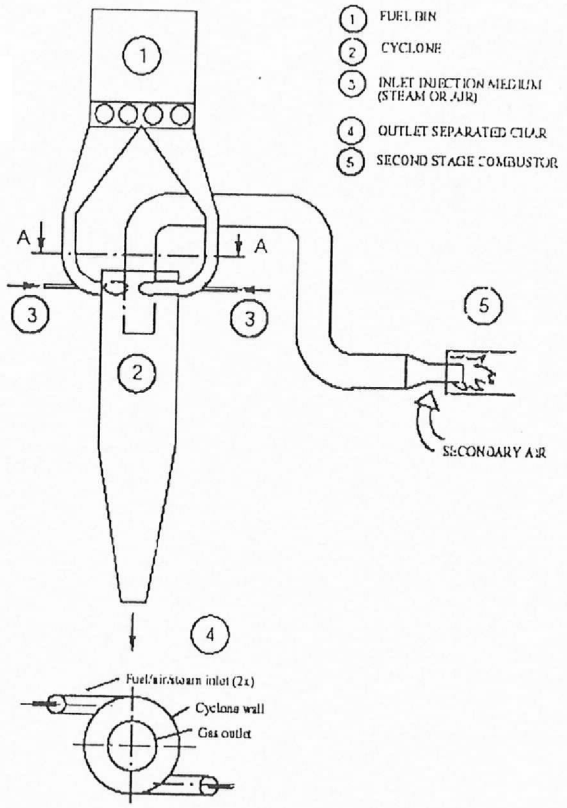


Figure 4.2 Set-up of the cyclone gasifier system [Fredriksson, 1999]

4.5 Feeding System

To make sure the flow inlet of the sawdust is fed in suitable range, a good feeding system is needed. There are many choices to feed the sawdust into cyclone, but the most suitable way is by using screw feeder. As mentioned before, the sawdust is fed into cyclone via two downcomers which are arranged so that the fuel can enter the cyclone tangentially.

4.5.1 Screw feeder

In general, a feeder is a device that can maintain a reasonably uniform flow of bulk solid. They are used as a means to provide control for the withdrawal of bulk solids from storage units such as bin or hopper. Among the various types of feeders available, the screw feeder is probably the one that is being used most extensively in the industry as they offer a lot of advantages when compared to the others. Below are some of the advantages that a screw feeder is well known for:

1. It is user friendly because of the simple mechanism and design.
2. It consists of simple components which are easily available in the market; therefore maintenance can be done easily.
3. No mechanism or bearings in contact with the product handled; lowering the machine breakdown risk.
4. It has total enclosure for safety, containment of dust, of the internal atmosphere and of dust explosion.
5. Compact cross section so that no return run of conveyor.

However, consideration must also fall into the limitation of the screw feeder such as:

1. Jamming of material; lumpy, fibrous, powder and sticky materials may often cause the feeder to jam or flood.
2. Power requirement can be high with solids that tend to pack.
3. Mechanical efficiency for transport is low.

For this study, screw feeder calculation and selection will be based on British Standard BS 4409 Part 1:1991, Part 2: 1991, and Part 3: 1982 ISO 7119 – 1981. This standard completely shows the standard specification and standard calculation methods for screw feeder. Lyn Bates [2000] in his book mentioned that the calculation method and material selection can be changed due to requirement of material handled. This may consider the previous experiences of designers when they built their screw feeder.

Feeder applications range from less than 1 kg/hour to over 100tonne/hour, delivered by means of screws from 10 to 600 mm diameter. The section of screw exposed to a flooded hopper is rarely longer than 4000 mm in the case of non-mass applications, or 2000 mm to serve mass flow extraction duties. Screws are used singly, as twins or in multiple arrays.

Feed screw rotational speeds may be fixed or variable, according to the type of discharge control required. Typical working speeds are in the range of 15r/min to 100r/min. Within these speeds the output volume varies linearly with speed, in fact this direct relationship of feed rate with output holds down to extremely low speeds of screw rotation. The feature which most affects feed regularity at very low speeds is how the material falls from the end of the screw.

4.5.1.1 Functional description

The material to be conveyed, which is fed to the screw conveyor via the feed spout or inlet, is caught by the rotating screw thread. When doing so, the material moves in same way as would a nut which, when prevented from rotating, travels forward in a straight line (direction of conveyance) on the rotating screw blades, and is guided towards the outlet.

The screw thread can be right-handed or left handed, and the direction of conveyance is determined by the thread direction and its direction of rotation. Both conveying and mixing can be carried out with the blade screw.

4.5.1.2 Performance characteristic

A great amount of bulk goods can be conveyed with the screw conveyor. The larger the grain size and the larger the percentage of this size of grain in the material, the larger the screw diameter should be. Very abrasive goods which could damage the screw thread and the through sheeting and are easily crushed and abraded are less suitable or absolutely unsuitable.

In general, material can be differentiated into 3 classes base on trough filling coefficient ϕ [British Standard, Part 3]:

$\phi = 0.45$: Class A	Easily flowing materials which cause little wear, e.g. flour, grain, rice and cereal, etc.
$\phi = 0.3$: Class B	Fine-grained and coarse-grained materials causing a small amount of wear and which do not flow freely, e.g. mineral mixtures, salts and fertilizers, etc.
$\phi = 0.15$: Class C	Strongly abrasive and coarse-grained materials, e.g. gravel, ash and soap powder, etc.

The conveying speeds of the various products depends upon the loading or resistance factor of each class of material, whereby the highest speeds for materials of class A and the lowest for those of class C. For this study, the trough filling coefficient, ϕ for sawdust is taken as 0.3

4.5.1.3 Calculation of the screw feeder capacity.

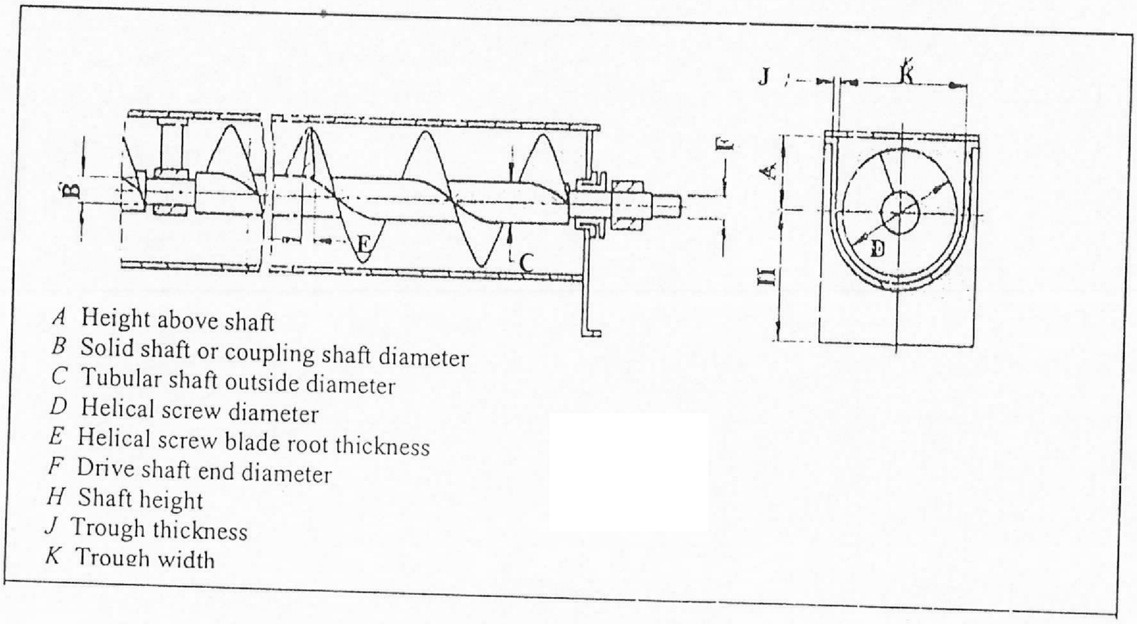


Figure 4.3 Principle dimension of a screw conveyor/feeder (fixed trough type) [British Standard 4409 Part 1]

The nominal capacity to be considered is the capacity per hour of the maximum volume that may be reached by a screw feeder. The volume flow rate I_V or ύ is the product of the working section of the section of the screw feeder A in square meters by the conveying speed, v in meter per second.

$$I_V = A + v \tag{23(a)}$$

$$I_V = \varphi D^2 \frac{\eta}{4} + S\frac{n}{60} = 60\varphi \frac{\eta}{4} D^2 Sn \tag{23(b)}$$

4.5.1.4 Drive power of loaded screw

The drive power of the loaded screw is given by the formula:

$$P = P_H + P_N + P_{St} \tag{24}$$

Where P_H is power necessary for the progress of the material, P_N is drive power of the screw conveyor at no load and P_{St} is power due to inclination.

$$P_H = \frac{I_M L\lambda}{367} \tag{25}$$

$$P_N = \frac{DL}{20} \tag{26}$$

$$P_{St} = \frac{I_M H}{367} \tag{27}$$

In practice, the capacity of conveyer is expressed by relation of mass flow rate and volume flow rate:

$$I_M = \rho . I_V$$

L = length of conveyor

λ = artificial friction coefficient or progress resistance coefficient

H = height of screw inclination; for this case H is zero.

For this case, where sawdust is used as the transport media, value of λ is taken as 1.9 from the table in Appendix B-01. Since the characteristic of the sawdust is seem to be closed as coal, flour, rice, and oat.

4.5.1.5 Size of screw plating

A screw conveyor is primarily made up of multiple circular plates that are cut at their center and stretched to the desired pitch. After that, they are welded together to form the length of the conveyor.

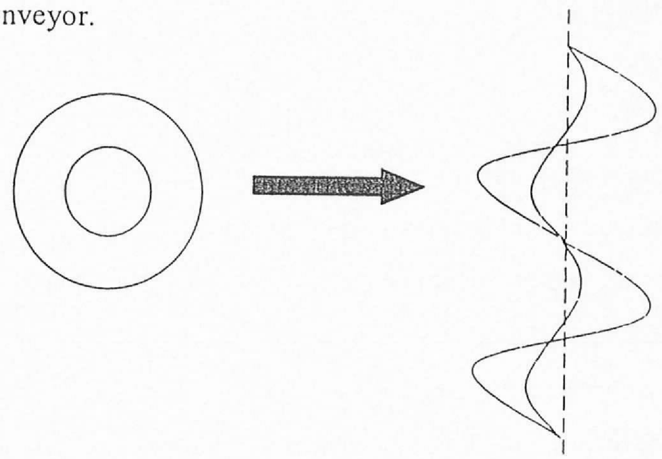


Figure 4.4 Formation of circular plate into helical screw form

To determine the required size of circular plating, the equation below can be applied:

$$D_{plat} = \frac{\sqrt{S^2 + (\eta D)^2}}{\eta} \qquad 28$$

Where D_{plat} is diameter of circular plating, S is the pitch and d is nominal diameter of screw. Dimension of D can be nominal diameter, D of helical screw and nominal outside diameter of tubular shaft, C.

4.5.2 Hopper

To supply the sawdust at suitable rate, screw feeder was used. Screw feeder is useless without a hopper where the sawdust will be stocked first. The hopper is attached onto the screw feeder so that the sawdust can enter the screw feeder inlet. Although a hopper is just as simple as a box, a proper design must be considered or in opposite the sawdust flow become poor then block the flow in screw feeder.

The most obvious and the most economical way of storing bulk solids is in a hopper with gravity flow. In this case the hopper consists of a cylindrical or rectangular part with a hopper. The hopper lets the product converge to the opening. This simple fact is the direct cause of most problems, such as: unsteady flow, segregation, remaining product, ageing or decay of the product, shaking or quaking of the hopper, flooding, or: flow does not occur at all.

One of the problems that should be considered in designing a hopper is the flow. Problems with flow are connected to the occurring flow pattern. In a hopper two important flow types are mass flow and funnel flow. Funnel flow is also called ratholing or core flow.

With mass flow, the whole contents of the hopper are moving, as soon as product is distracted from the hopper. This type of flow is characterized by:

- first in - first out;
- little segregation;
- steady flow and a well controllable discharge-capacity;
- no risk of ageing, decay, or contamination;
- Possibility of 'following' product batches with a specific composition.
- To induce the mass flow effect, the hopper angle should be above 45°.

Disadvantage of mass flow can be that in certain cases hopper quaking can occur. When dealing with abrasive products, the hopper wall will wear quicker. In general this will not be problem, because of the low flow velocities in a hopper.

In case of funnel flow the product flows through the core. Owing to this areas exist where the product is at rest (stagnant zones). This can result when the hopper is filled again before it is completely empty so that ageing and decay of the product will occur. Also if the hopper is used for several products, then contamination will occur. In some case, the stagnant zones grow, so that at a certain moment the product only flows from a channel (rat hole) above the opening. Then the risk is great where that flow will stop altogether. In the other hand, the collapse of stagnant zones can lead to uncontrollable flow of product (flooding). For these reasons funnel flow is only applicable for coarse, free flowing products, where ageing or decay is not important.

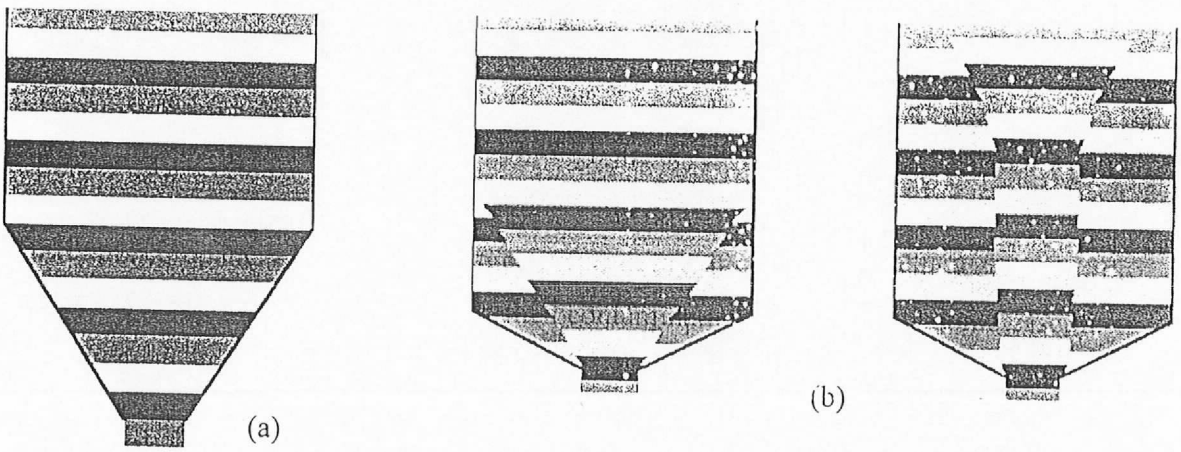


Figure 4.5 (a) Mass flow in hopper (b) Funnel flows in hoppers [www.bulksolids.nl]

CHAPTER 5

DESIGN CALCULATION

5.1 Overview

This chapter shows the calculation for every parameter based on information in Chapter 2, Chapter 3 and Chapter 4. This chapter will determine the dimensions of cyclone gasifier, specification of screw feeder, dimensions of hopper and ash collector and specification for air blower.

5.2 Input and output power requirement

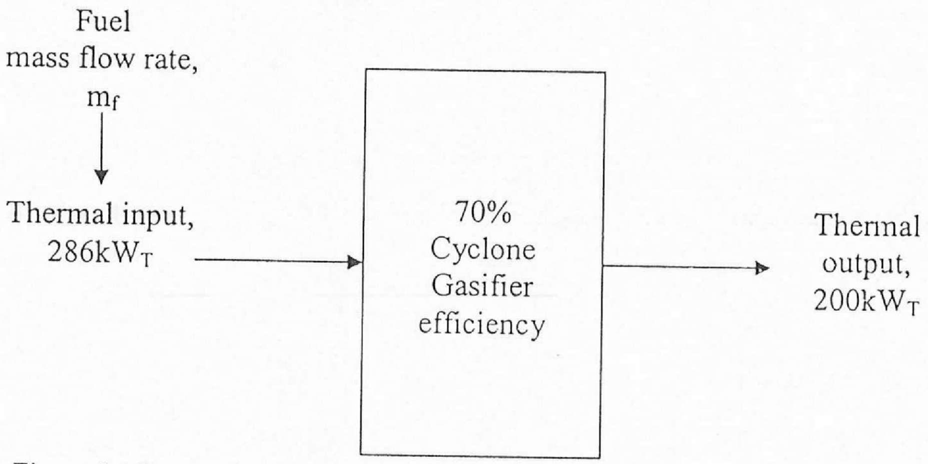


Figure 5.1 Power distributions in designed cyclone gasifier with 70% efficiency

As the required power output is $200kW_T$, with assumption 70% efficiency of cyclone, so that the minimum thermal input of sawdust that must be supplied is $286kW_T$ as shown in Figure 5.1.

Heating value (HHV) of sawdust at 0% moisture content is approximately 18MJ/kg.
So, thermal input,

$$Q_i = (HHV)_{sawdust} \text{ X } m_f$$

29

$$286kW_T = 18 \text{ MJ/kg X } m_f$$

$$m_f = 0.015889 \text{ kg/s}$$

$$= 57.2 \text{ kg/hr} = I_M$$

So, to provide input thermal energy of 286kW$_T$, sawdust should be fed at rate of about 60kg/hr.

Assuming N_2 in air is not reactive in the combustion process and there is about 79% of N_2 in air is remaining the same at 45% of N_2 in producer gas.

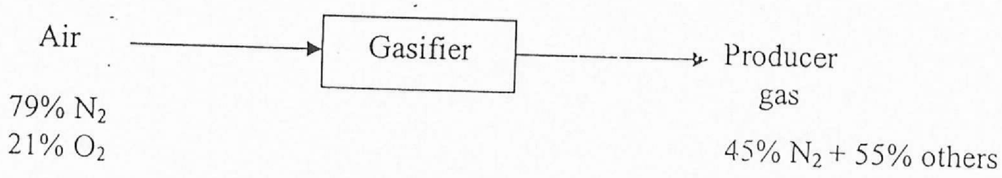


Figure 5.2 Input and output air/producer composition

Air flow rate ,

$$V_a = V_g \times \frac{45\%}{79\%} \qquad (30)$$

Assuming Lower Heating Value (LHV) of producer gas is 4MJ/m^3

Output thermal energy,

$$Q_{o/p} = (LHV) \times V_g \qquad (31)$$

$$200kW_T = 4MJ/m^3 \times V_g$$

$$V_g = 0.05\ m^3/s$$

$$= 3000\ \text{litres/min}$$

$$\therefore V_a = V_g \times (45/79)$$

$$= 3000 \times (45/79)$$

$$= 1709\ \text{litres/min}$$

$$= 60.35\ \text{cfm}$$

Equation 30 is true at the outlet of the gasifier. If the gas has to pass through gas cleaning and cooling system, the flow rate of V_a has to be increased or operate at higher pressure blower to prevent head loss. This means that the air that must be supplied by blower at minimum rate or 60 cfm (1700 litres/min) at pressure of 1 bar to 2 bar.

5.3 Calculation for cyclone dimension

The main idea to calculate the suitable dimensions of cyclone in this study was to use information and experiences gained by Fredriksson [1999]. Fredriksson [1999] in his cyclone was using high-pressure steam driven injector to inject fuel/air mixture into the cyclone. But in this study, modification had been made to change the high-pressure steam as transport media with a propane burner and air from blower as the transport media as well as to supply heat to the cyclone chamber. However, base on comparison that had been made by Fredriksson in Table 4.1, the cyclone dimension was calculated base on combustion intensity C.I where the recommended value is C.I = 5 MW/m^{3}atm.

From **Equation 21,**

$$C.I. = \frac{heat \quad release \quad rate}{combustor \quad volume \times pressure} kW/m^3.atm$$

$$C.I = \frac{Q}{V_c \times P} \quad \Rightarrow \quad V_c = \frac{Q}{C.I \times P} \qquad 32$$

Due to design requirement, heat release rate was taken as Q = 286kW$_T$, C.I = 5000kW/m^{3}atm, and pressure at 1atm. So, this equation will gives V_c = 0.0572m^3.

Referring to Figure 4.1, volume of the cyclone can be separated into two portions; a cylinder and a cone. Although the cone is not the same as a proper cone, where it doesn't has a peak, it still being considered as a complete cone since there is just a small different.

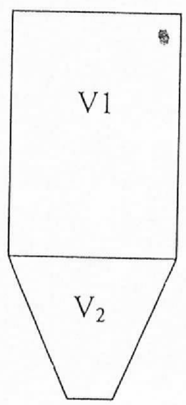


Figure 5.3 Basic volume of cyclone

As mentioned in section *4.3.3 Separation efficiency and pressure drop*, the typical dimensions for cyclone are:

$D_e = D/2$,

$H = 4*D$,

$h = 2*D$,

$S \approx D/2$

$$V_1 = \frac{\eta D^2 h}{4} \quad = \frac{\eta D^2}{4} \times 2D \quad = \frac{\eta D^3}{2} \qquad 33$$

$$V_2 = \frac{\eta D^2}{12} \times (H - h) \quad = \frac{\eta D^2}{12} \times 2D \quad = \frac{\eta D^3}{6} \qquad 34$$

$$V_C = V_1 + V_2 \qquad 35$$

$$V_c = \frac{\eta D^3}{2} + \frac{\eta D^3}{6} \quad = \frac{2}{3}\eta D^3 \qquad 36$$

By substituting the value V_c = 0.0572 m^3 in **Equation** 36, value of inner diameter of the cyclone can be obtained where D = 300 mm. By using this value, all of the typical dimensions can be determined. But dimension of inlet diameter, D_i is determine by using **Equation 22** where swirl number is taken as 12 (as recommended). In this case, inlet and outlet temperatures are chosen as 473K and 1073K respectively as recommended by Fredriksson [1999] to avoid that compound of sodium and potassium leave the cyclone in gas phase.

$$S_{gT} = \frac{D_e . D}{n . D_i^2} \times \frac{T_{inlet}[K]}{T_{outlet}[K]}$$

$$12 = \frac{150.300}{2.D_i^2} \times \frac{473[K]}{1073[K]} \quad \Rightarrow \quad D_i = 28.75mm$$

The result of the calculation for the cyclone dimension can be summarized in the Table 5.1

Table 5.1 Cyclone's dimensions summarization

Dimension	Value
D_i	28.75 mm (two inlet)
D	300 mm
D_e	150 mm
H	1200 mm
Cyclone's volume, V_c	0.0572 m^3
Fuel power	286 kW_T
Combustion intensity	5 MW/m^3atm

However, by considering experiments and evidences given by Fredriksson [1999], the dimension should be changed to gain a good result. This is totally based on result in Fredriksson's experiments which were tested and simulated. Then the suitable dimension is shown in Tabie 5.2 below.

Table 5.2 Modified cyclone's dimensions

Dimension	Value
D_i	28 mm (two inlet)
D	210 mm
D_e	80 mm
H	1080 mm

5.4 Feeding System

There are three main parts in feeding system – screw feeder, hopper and downcomers. However, for this calculation, only dimensions of screw feeder and hopper will be calculated.

5.4.1 Screw feeder nominal diameter and pitch

Since mass flow rate of the sawdust was calculated before, **Equation 23** can be used directly to obtain the value of nominal screw diameter D (Figure 3.8). Pitch, S is taken as S = 0.7D and trough filling coefficient, ϕ is 0.3.

$$I_V = 60\varphi \frac{\eta}{4} D^2 Sn$$

$$\dot{V} = \frac{\dot{m}_f}{\rho} = I_V = \frac{I_M}{\rho} = \frac{60kg/h}{210kg/m^3} = 0.286m^3/h$$

Number of rpm for the screw is taken as n = 30 rpm for maximum rotational speed. By substituting all off these value into **Equation 23**, nominal diameter for screw feeder can be determined.

$$I_V = 60\varphi \frac{\eta}{4} D^2 Sn$$

$$0.286 = (60)(0.3)(\frac{\eta}{4})(D^2)(0.7D)(30)$$

$$D = 0.099m = 99mm$$

By considering manufacturing factor, D is taken as 100mm so that pitch of the screw, S become 70mm. These values were found accurately as the value available in British Standard 4409 Part 1.

5.4.2 Drive power of loaded screw feeder

The drive power of the loaded screw is given by the formula:

$$P = P_H + P_N + P_{St}$$

Where P_H is power necessary for the progress of the material, P_N is drive power of the screw conveyor at no load and P_{St} is power due to inclination.

$$P_H = \frac{I_M L\lambda}{367} = \frac{(0.060 ton/h)(1)(1.9)}{367} = 3.12\times10^{-4}\,kW$$

$$P_N = \frac{DL}{20} = \frac{(0.1)(1)}{20} = 5\times10^{-3}\,kW$$

$$P_{St} = \frac{I_M H}{367} = 0$$

L = length of conveyor [m] → 0.1 m

λ = artificial friction coefficient or progress resistance coefficient → 1.9

H = lifting height of screw; for this case H is zero. [m] → 0

I_M = mass flow rate [t/h] → 0.060 ton/h

Minimum power required to drive sawdust in screw feeder is only 5.312 W ($P_H + P_N + P_{St}$)

.3 Size of screw plating

determine the size of screw plating, **Equation 28** was used. The nominal outer diameter this conveyor, D is 100mm with a pitch of 70mm (S). Nominal outside diameter of tubular ft, C is taken as 42.4mm base on data given in BS4409 Part 1 (Table 2).

$$_{t/inside} = \frac{\sqrt{S^2+(\eta D)^2}}{\eta} = \frac{\sqrt{70^2\times(\eta\times42.4)^2}}{\eta} = 47.89mm$$

$$_{t/outside} = \frac{\sqrt{S^2+(\eta D)^2}}{\eta} = \frac{\sqrt{70^2\times(\eta\times100)^2}}{\eta} = 102.5mm$$

efore, the nominal size of plat that will be cut is shown in Figure 5.4.

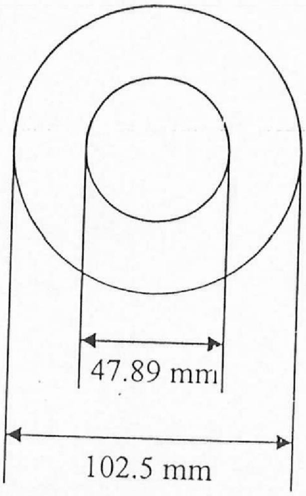


Figure 5.4 Nominal diameter of circular plating for screw feeder

Multiple circular plating as shown above is to be cut in the center and then pulled to the desired pitch before being welded together to form the helical screw.

5.4.4 Size and volume of hopper

One important thing in designing a hopper is the degree of inclination of the tapered side which is not to be less than 45° from vertical wall to make sure the hopper provide mass flow effect as discussed earlier. The rest is just to determine the suitable dimension of hopper.

In this study, the hopper is required to supply the sawdust at rate of 60kg/hour or 0.286m^3/hour in maximum two hours. This means that the operator must refill the hopper with sawdust at least every two hours.

Volume of sawdust required for two hours is 0.572 m^3.

By using standard shape of hopper, the dimension is adjusted to gain volume of 0.6m^3 as shown in Appendix A-05.

5.5 Summary of designed equipments.

After considering several conditions and calculate the suitable figures, technical drawings (Appendix A) of the system have been made to be fabricated. Here is the summary and brief description of the system.

Major item of system	**Item no. (Refer to drawing Appendix A-01)**
Cyclone (gasifier)	1
Char collector	2
Hopper	3
Screw feeder	4
Down-comer	5
Blower	6
Support Structure	-

Cyclone (gasifier)

Function: Main equipment for gasification process.

Description: Sawdust (as fuel) is fed about 60kg/hr and mixed with air at capacity of 60cfm then burnt together for gasification. Producer gas will exit via outlet and ash will be collected from char collector.

Material: The cyclone was made from combination of metal sheet, 50 mm thickness of calcium silicate, and 75 mm thickness of refractory cement. The refractory cement was formed so that gives an inner diameter 210 mm as desired. The calcium silicate and refractory cement were bonded by using an anchor (SUS 312) that was welded on the metal sheet. Five 8mm-diameter-pipes also placed at different points to be used as thermocouple socket. The product gas lines were insulated with heat resistant material.

Burner inlet

Function: Be the inlet of portable burner from LPG to start heating the cyclone chamber. After required temperature is achieved, the burner will be taken out and close the flange to prevent heat loss.

Description: The burner inlet was designed as same as air/fuel inlets but a flange is used to close the pipe after the burner taken out.

Char collector

Function: To collect the ash and char.

Description: A 600X300X260 mm^3 bin located at the bottom of the cyclone. A gasket was placed at the flange to make it air-leakage free.

Hopper

Function: To provide a suitable area for accepting sawdust and store it before drawn by screw feeder.

Description: Sawdust is stored and loaded here. A screw feeder will draw the sawdust into the cyclone.

Screw feeder

Function: To convey sawdust at maximum rate of 60kg/h from hopper to cyclone gasifier.

Description: Refer Table 5.3

Table 5.3 Summary of screw feeder specification

Specification	Description
Sawdust bulk density Max lump size (commercial sawdust)	210 kg/m^3 1mm (45%)
Required capacity Required speed of rotation Power required Torque	Minimum 60kg/h (30kg/h per down-comer) 30 rpm 1 hp (minimum) 3200 inch/pounds
Nominal outside diameter of tubular shaft Nominal diameter of helical screw Pitch Nominal thickness of helical screw blade	42.4 mm 100 mm 70 mm 5 mm (root), 2.5 mm (tip)
Motor type Reducer Gear ratio controlling device	AC, Class E, Single Phase; max 1400rpm 1/40 1Hp variable speed pulley

Down-comers

Function: To allow the feeding of the sawdust into two ways of tangential angle to the cyclone.

Description: Attached at the end bottom of the screw feeder. Can be changed to rounded shape or rectangular shape (depend on necessity)

Blower

Function: To provide air to be mixed with the fuel at rate of about 60cfm (pressure of 1atm to 2atm)

Description: Attached at either one side of cyclone inlet. Will connected with 'T' junction to allow the air and fuel, enter the cyclone together.

CHAPTER 6

MODELLING OF CYCLONE GASIFIER

6.1 Overview

This chapter will explain around what had been done in cyclone gasifier modelling. This chapter also shows what assumption had been made, how the geometry was built, and consideration of boundary condition. Unfortunately, the study on this cyclone gasifier modelling cannot be completed because of reasons that will be discussed later.

6.2 Objective

The main parameters that had been used to build cyclone dimensions are based on combustion intensity and swirl number. These parameters were compared with previous experiments. For this study, the designed cyclone's dimension will be tested in Computational Fluid Dynamic (CFD) software (FLUENT 6) to see the effect of that dimension on the flow in cyclone, to predict the product gas temperature and the residence time for a particle to completely gasified. This development of the model can be divided into three parts:

1. Modelling of the isothermal flow
2. Modelling of particle trajectories in isothermal flow
3. Modelling of combustion and gasification of solid particles

6.3 Isothermal flow model

This study was restricted to the most common reverse flow type of cyclone where the flow enters the cyclone through a tangential inlet and leaves via an axial outlet at the top of the cyclone. Theoretically, the main characteristic of the flow was an annular outer flow which was swirling down the cyclone and an inner core which was moving upwards towards the outlet pipe.

6.3.1 Geometry

The geometry and computational grid have been designed in Gambit with dimension as mentioned in previous chapter. The cyclone body was made up of number of blocks. The main cylinder was created by entering the value into Create Real Cylinder Volume form. The same way for the conical section creation but then adjusted to the bottom of the main cylinder. After that, two small cylinders were created horizontally as the inlet pipes then had been united with the main cylinder as shown in Figure 6.1. Lastly, the core cylinder as the outlet was created as in shown in the figure.

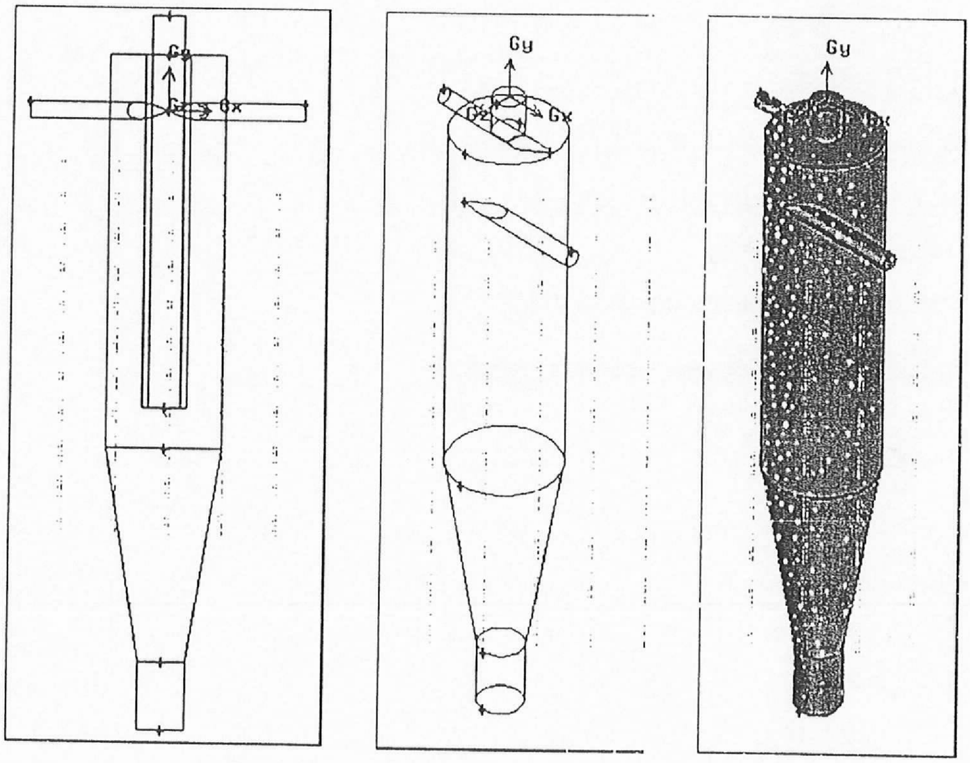
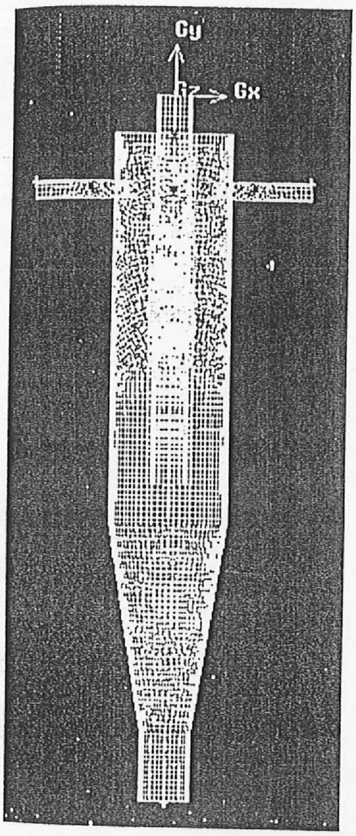


Figure 6.1 Cyclone's volume constructions in Gambit.

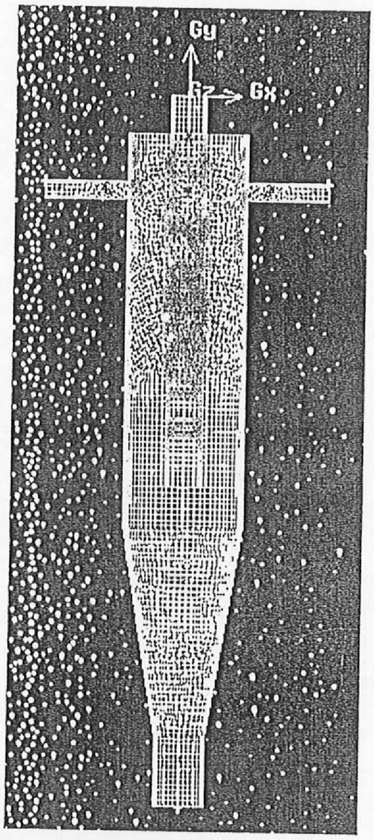
6.3.2 Computational grid

Two different grid designs were created which are referred to coarse and fine uniform grid. The fine grid was using 5 interval sizes spacing while 10 was used for coarse grid. The number of elements of this design was approximately 1,000,000. The meshed volumes are shown in Figure 6.2.



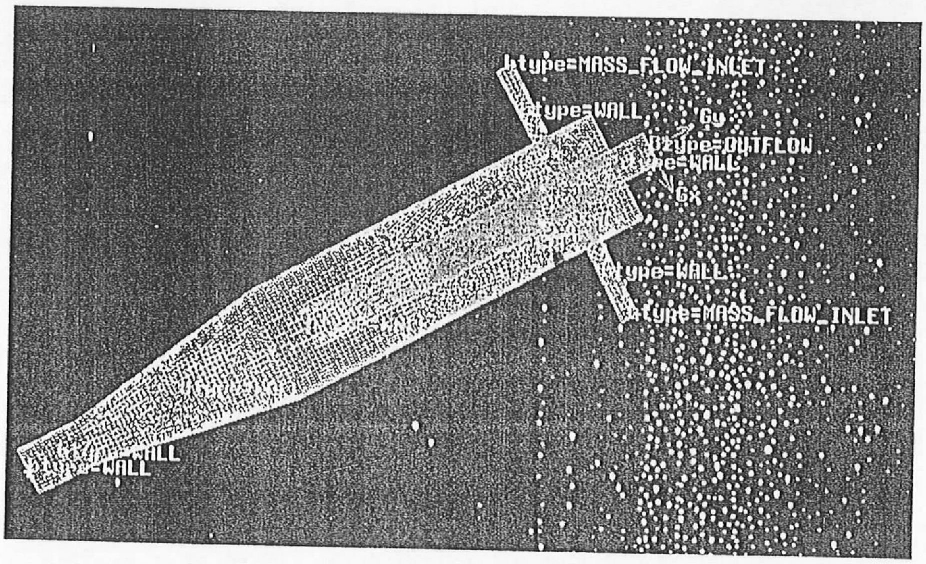
(a) After faces meshing

Element: Quad/Tri
Type: Pave
Spacing: 10 interval size



(b) After volume meshing

Element: Tet/Hybrid
Type: TGrid
Spacing: 10 interval size



(c) After setting boundary condition

Figure 6.2 Meshed volume

The design of the control volumes is important for several reasons. Firstly, the control volumes have to be small enough to be able to resolve the significant processes. This means that a higher cell density is needed in more complicated flow to be able to capture the correct flow field. But, more cells lead to computationally larger problems and more CPU-time. So, it is needed to decrease the total number cell in area where the flow calculation is less sensitive to the cell size, thereby increase the mesh size. However, the size of two adjacent cells should be not differing by more than 30% to avoid numerical problems during the solution procedure.

6.4 Limitation

The progress for cyclone modelling however was just stopped at meshing step. For a complete work, it is needed to run and simulate the meshed volume in FLUENT software. Then from this software the isothermal flow can be observed by using turbulent flow models that available in FLUENT. The recommended turbulent model for this case is RNG k-epsilon (k-ϵ). RNG k- ϵ is eddy-viscosity model that is simple, numerically robust and fairly easily converged. However, it generates poor results for highly swirling flows.

The value of k and ϵ in that model is given by:

$$k_{in}l = 1.5(ti \cdot u_{in}l)^2 \qquad 37$$

$$\varepsilon = \frac{k_{inl}^{1.5}}{0.3D} \qquad 38$$

where u_{inl} is the mean inlet velocity, ti is turbulent intensity at the inlet and D the dissipation length scale. D = 4 A/P, A is the inlet area and P is its perimeter. Normal stresses are set equal to $(2/3)k_{inl}$.

Unfortunately, with time limitation and limited licensed-FLUENT-installed computer, this modelling cannot be carried out so that the objectives of this chapter cannot be accomplished.

CHAPTER 7

FINAL REMARKS

7.1 Discussions and conclusions

As mentioned in the introduction of this report, the objective of this project is to study the fundamental aspect in designing cyclone gasifier and develop the cyclone gasifier using sawdust as the fuel. To achieve this objective, a reasonably deep study had been made on fundamental concept of solid waste gasification and principle of cyclone separator. Then detailed design and computer modelling had been carried together to gain the result.

It was found that, in order to develop this cyclone gasifier successfully, at least four stages must be carried out. The first one is to know the desired output and the required operating condition of the system. This needs for precise study on that system in order to gain a satisfaction result. Second, the gained information needs to be tested in computer simulation to predict some parameters that cannot be found in literature. One should know and alert that the computer simulation doesn't give the accurate information but on the other hand, that information can be used to predict unknowns and relatively it's close to the actual result. So, as the third stage, a model of cyclone should be constructed to study the isothermal flow so that it can help the result gained in computer simulation. After the computer simulation and isothermal modelling, any information in that stage will be used to fabricate the actual cyclone gasifier. From the actual cyclone gasifier, experimental study will be made to compare the data with that gained in computer simulation such as product gas composition, product gas temperature, gas and ash separation and then the thermal output of the system.

Model of the cyclone was successfully constructed but time and facility are the main barriers to completing the simulation. "Trial and error" method was the only way to achieve the accurate and suitable meshed volume for that complex shape of cyclone, thereby a lot of time was consumed even a lot of information learnt. There was a choice to make the simulation in 2-D system, but it will not giving the desired value.

The cyclone gasifier was design base on combustion intensity, C.I and geometrical swirl number, S_g in order to determine the suitable dimensions. Actually one other parameter that can be taken is the residence time of the sawdust in the cyclone; so that the height of the cyclone can be determined first.

Sawdust as fuel requires relatively long residence time and good mixing with the oxidant to be completely burnt. That means how long the sawdust must be swirled in the cyclone before it is completely gasified. However, compared to pulverized coal, wood powder contains high fraction volatiles. A higher fraction of the fuel will be converted to gas immediately upon rapid heating. The released volatile gas reacts instantaneously with the oxygen present. In this sense a wood fuel will behave more like a gaseous fuel [Najim et al., 1981]. So, with the high temperature at inlet, the volatile part of a solid fuel will behave similar to gaseous fuel and react immediately at the entrance region of the cyclone. The decrease in density due to the temperature rise will force the products towards the center and outlet pipe as a result of the centrifugal force field. This buoyancy effects will in a similar way transport partially burned products and air, with a lower temperature and higher density, towards the wall. Particle also will move outwards due to the centrifugal forces. This stratification of the flow is beneficial from the point of view of that the unburned material can be suspended in the cyclone long enough to be completely burned.

In order to design the cyclone, a few assumptions have been made. The calculations for geometrical swirl number were made with neglecting wall roughness. Since the refractory cement was used, the face of the wall cannot be smooth very well. However, it's still being used to prevent heat loss in the cyclone where it cans restraint to temperature of about 1450°C. As an addition and experimental device, five thermocouples were used to detect and monitor the temperature distribution in five different points in the cyclone. These thermocouples will prove the assumption that the temperature in cyclone is uniformly distributed.

By considering the cyclone configuration and calculation made, the original design was modified to improve the performance of the cyclone gasifier in several aspects. The design in this study is using air as the gasifying agent while in the original design was using steam for that purpose. As discussed earlier, the final dimensions are hoped to give an improvement in separation efficiency. However, this only can be proved after experimental study done in future. The final dimensions that recommended are shown in Table 5.2.

At the first, feeding system is considered as an auxiliary system to this system. But when considering suitable fuel feed rate for the cyclone, this system is a must. So, a proper screw feeder with a hopper was design together with cyclone gasifier. The constraint to the design is fall into the determination of suitable pitch and nominal screw diameter because that will be different if the transport media is different. It is depending on the trough filling coefficient, ϕ of the media to transport. This coefficient is classified by the abrasiveness of the media where the more abrasive the media, the lower the value of the coefficient.

In this study, the hopper was designed to provide the sawdust to the screw feeder just only in two hours because of some reasons. Firstly, because of space limitation, so that it is unsuitable to design a huge hopper on that such high and small space. It also can cause the difficulties for the operator to refill the hopper with sawdust. Secondly, if continuous feeding is desired but the size is maintained as what available now, the system needs an auxiliary system where a screw conveyor will be used. This, of course, will increase the cost of this project and unnecessary since this project still in a development.

As the conclusion, this dissertation, at this stage has achieved its objective to study the fundamental aspect in designing cyclone gasifier and develop the cyclone gasifier using sawdust as the fuel. For that, a few considerations have been taken in order to select and determine the appropriate parameters as discussed earlier.

It is hoped that the results obtained here will be useful in future development of this cyclone gasifier which is among the first in Malaysia. From this study, it can be said that cyclone gasifier can be one of the alternative energy source as the Malaysian government stated that 5% of its energy basket should come from renewable energy by the year 2006.

7.2 Recommendations for future work.

There is a lot of room for improvement since this type of gasifier still new in Malaysia. Also in this study, there are few sections that cannot be finished successfully – computer simulation and isothermal flow model. Hence, there are a few recommendations that author would like to put forward for the development of this project. Among these recommendations are:

a. After the fabrication of the cyclone gasifier finished, one should run the experiment to observe the result and compare with what obtained in this study. The main parameters are the inlet temperature, outlet temperature, gas temperature, gas composition and separation of gas and ash.

b. Computer simulation for this study should be started earlier to make sure the time is fit enough to complete the work. This is because it needs for a lot of trial and one must understand deeply the flow characteristic of the medium in cyclone. The volume must be constructed and meshed correctly, and boundary conditions must be stated properly to prevent problems when run it in FLUENT. Furthermore, result from this simulation is very useful to predict the actual condition. So, more study on RNG k-ϵ turbulence model and single particle gasification are needed.

c. To help to determine some of the value required in FLUENT, isothermal rig model should be constructed. It can help to predict some parameter such as inlet velocity, outlet velocity and residence time for a particle flowing in the cyclone. May be this information can help in some place in future study.

d. Particle tracking in the cyclone also must be considered in computer simulation as well as in practical experiment to visualize the flow behavior.

e. As in this stage of study, the product gas is just leaves the cyclone freely in the air, a secondary system must be designed to store and study that product gas. It can be an incineration system to process the product gas or supply to a diesel engine.

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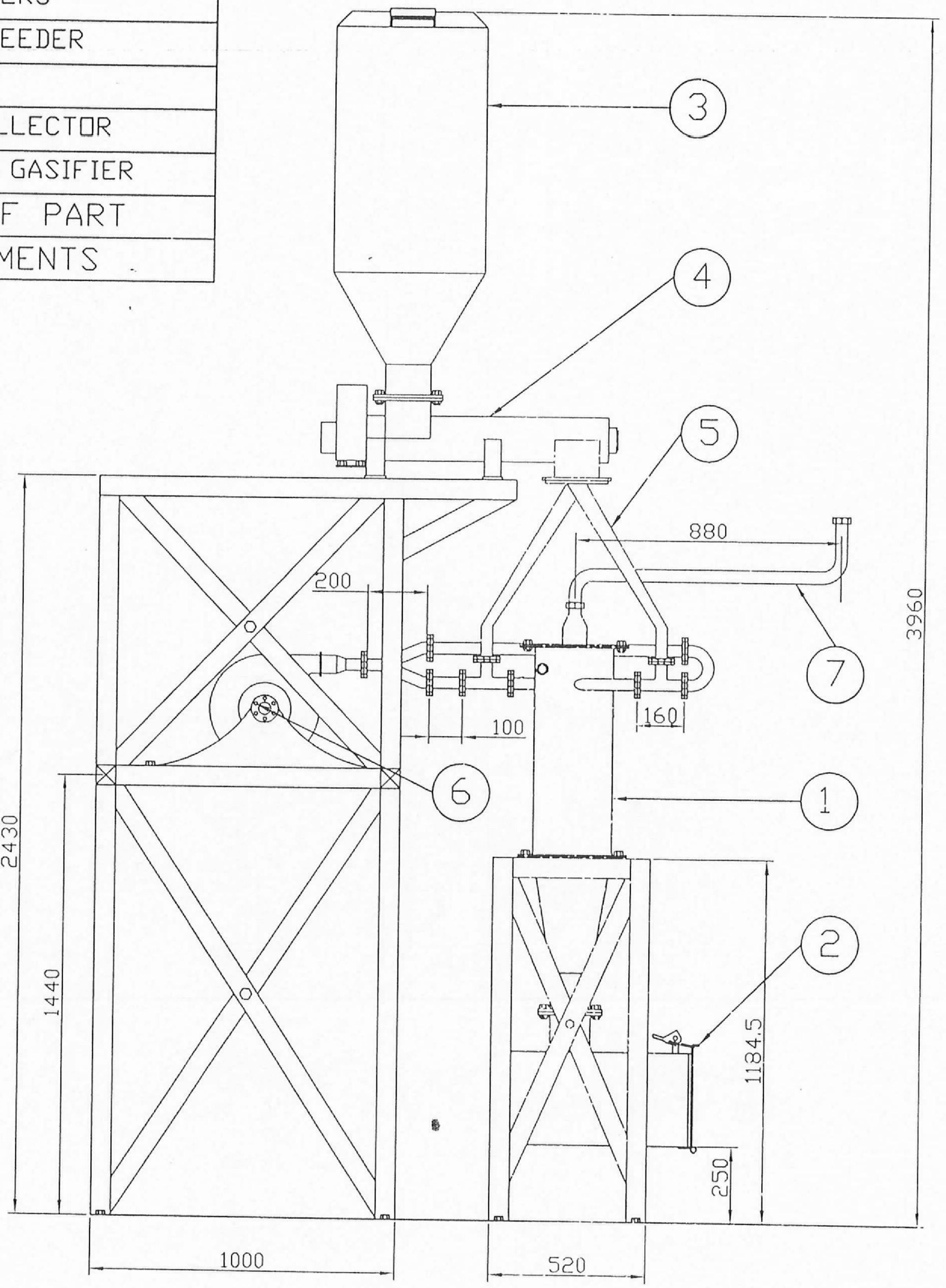
PRODUCED GAS OUTLET
BLOWER
DOWNCOMERS
SCREW FEEDER
HOPPER
CHAR COLLECTOR
CYCLONE GASIFIER
NAME OF PART
EQUIPMENTS

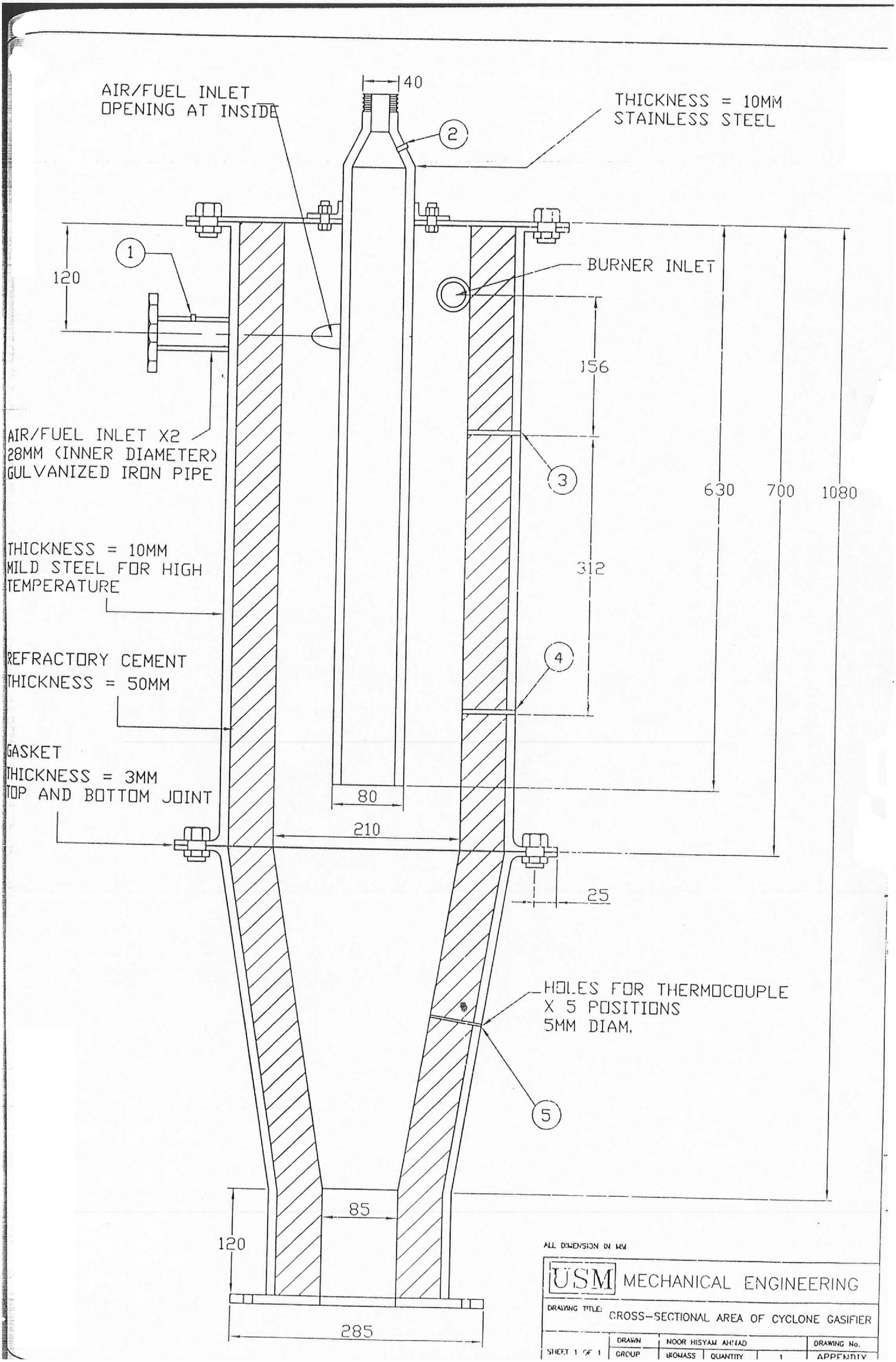


ALL DIMENSION IN MM

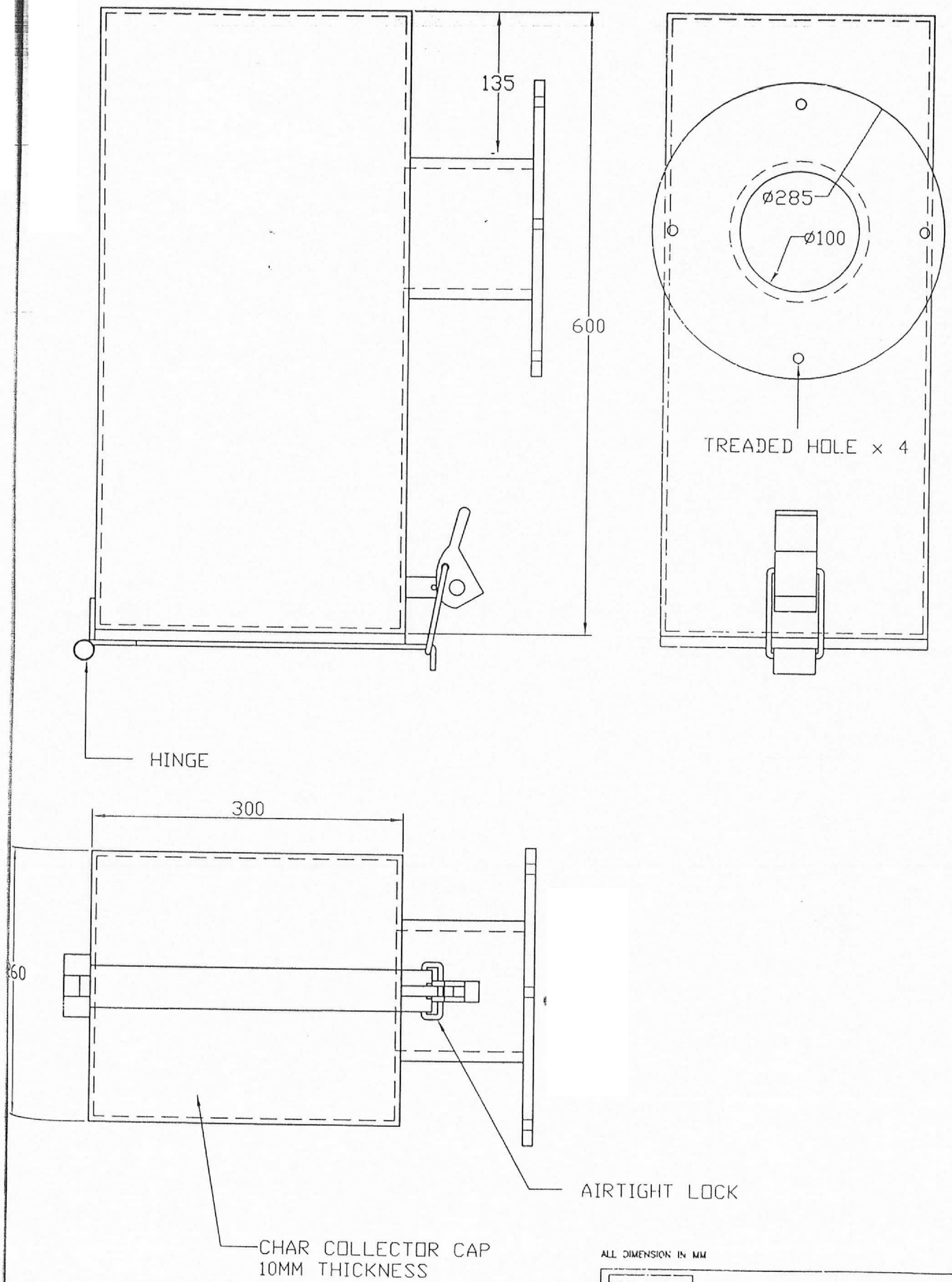
USM MECHANICAL ENGINEERING

DRAWING TITLE: CROSS-SECTIONAL AREA OF CYCLONE GASIFIER

SHEET 1 OF 1	DRAWN	NOOR HISYAM AHMAD				DRAWING No.
	GROUP	BIOMASS	QUANTITY	1		APPENDIX
	SCALE	1 : 5	DATE	18/12/2003		A-01

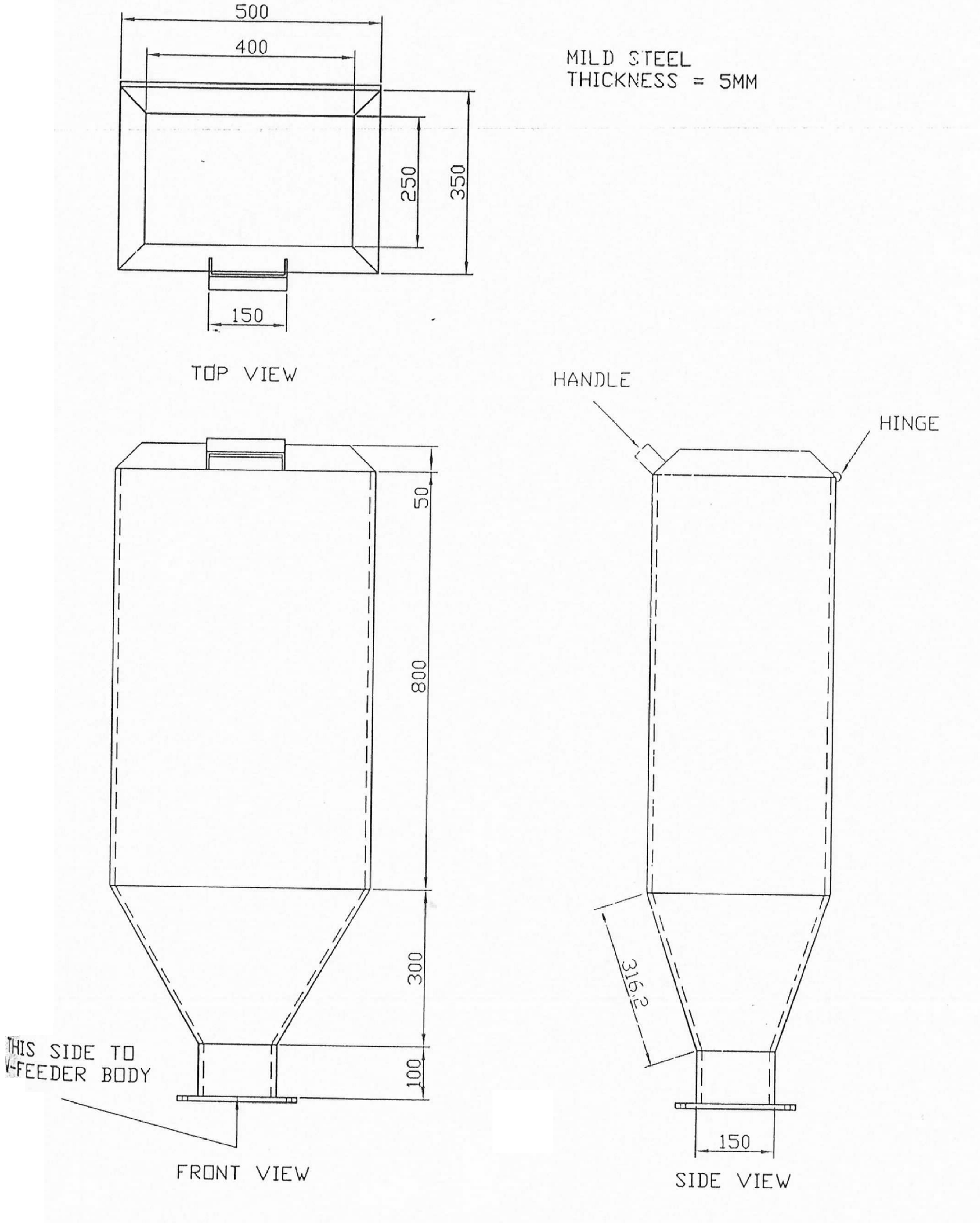


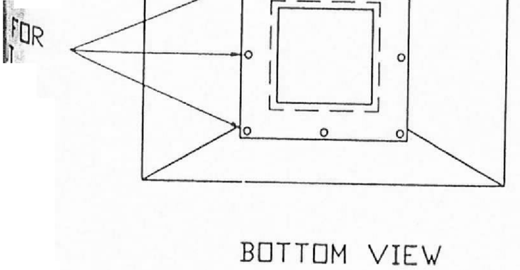
40
AIR/FUEL INLET
OPENING AT INSIDE
THICKNESS = 10MM
STAINLESS STEEL
2
1
120
BURNER INLET
156
AIR/FUEL INLET X2
28MM (INNER DIAMETER)
GULVANIZED IRON PIPE
3
630
700
1080
THICKNESS = 10MM
MILD STEEL FOR HIGH
TEMPERATURE
312
REFRACTORY CEMENT
THICKNESS = 50MM
4
GASKET
THICKNESS = 3MM
TOP AND BOTTOM JOINT
80
210
25
HOLES FOR THERMOCOUPLE
X 5 POSITIONS
5MM DIAM.
5
85
120
285
ALL DIMENSION IN MM
USM MECHANICAL ENGINEERING
DRAWING TITLE: CROSS-SECTIONAL AREA OF CYCLONE GASIFIER
DRAWN
NOOR HISYAM AHMAD
DRAWING No.
SHEET 1 OF 1
GROUP
BIOMASS
QUANTITY
1
APPENDIX



ALL DIMENSION IN MM

USM MECHANICAL ENGINEERING				
DRAWING TITLE: ASH COLLECTOR				
SHEET 1 OF 1	DRAWN	NOOR HISYAM AHMAD		DRAWING No.
	GROUP	BIOMASS	QUANTITY 1	APPENDIX





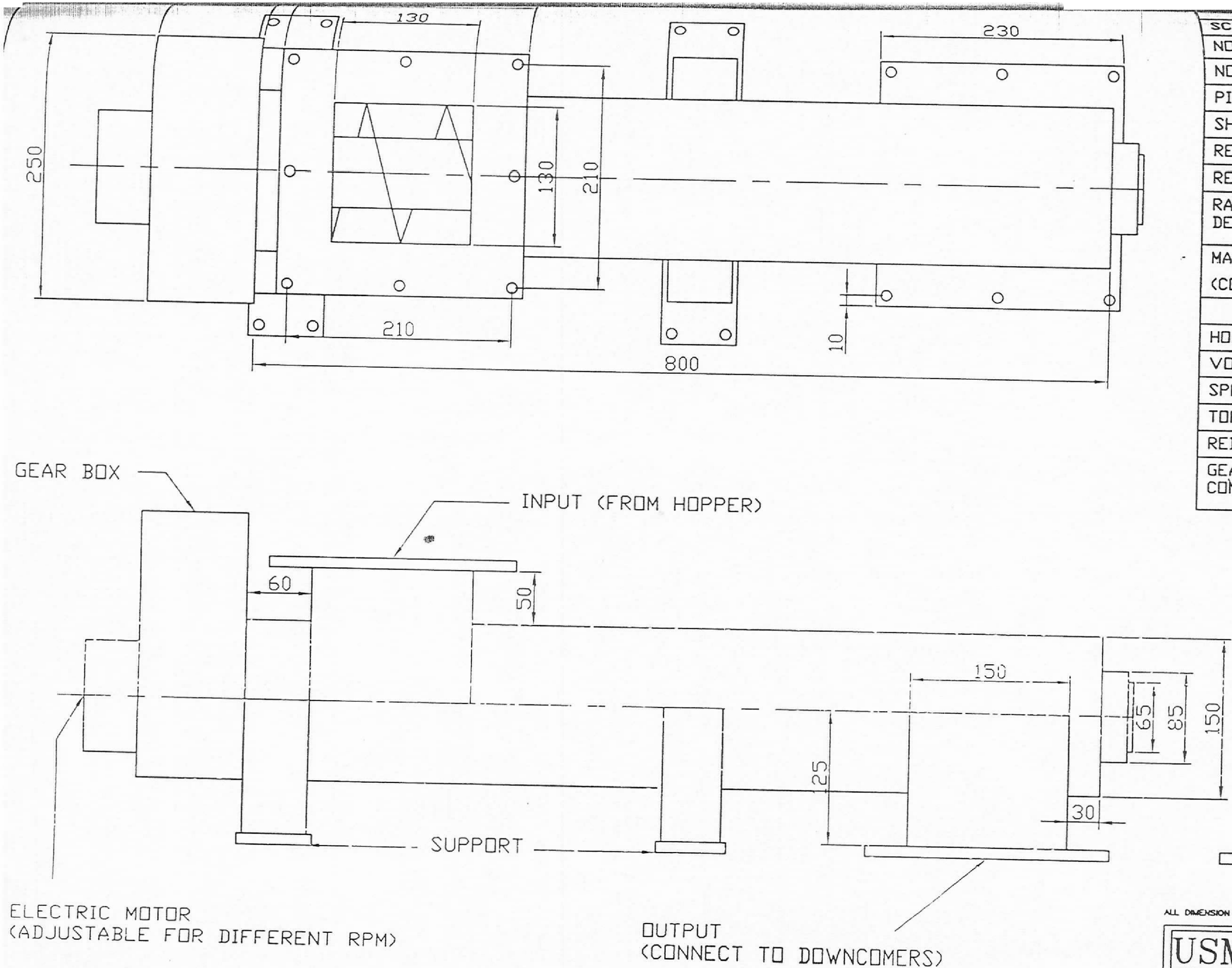
BOTTOM VIEW

ALL DIMENSION IN MM

USM MECHANICAL ENGINEERING

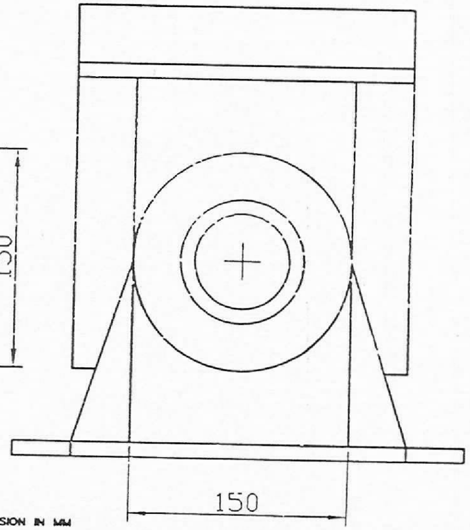
DRAWING TITLE: FEEDING SYSTEM (HOPPER)

SHEET 1 OF 1	DRAWN	NOOR HISYAM AHMAD			DRAWING No.
	GROUP	BIOMASS	QUANTITY	1	APPENDIX
	SCALE	1 : 10	DATE	01/11/2003	A-05



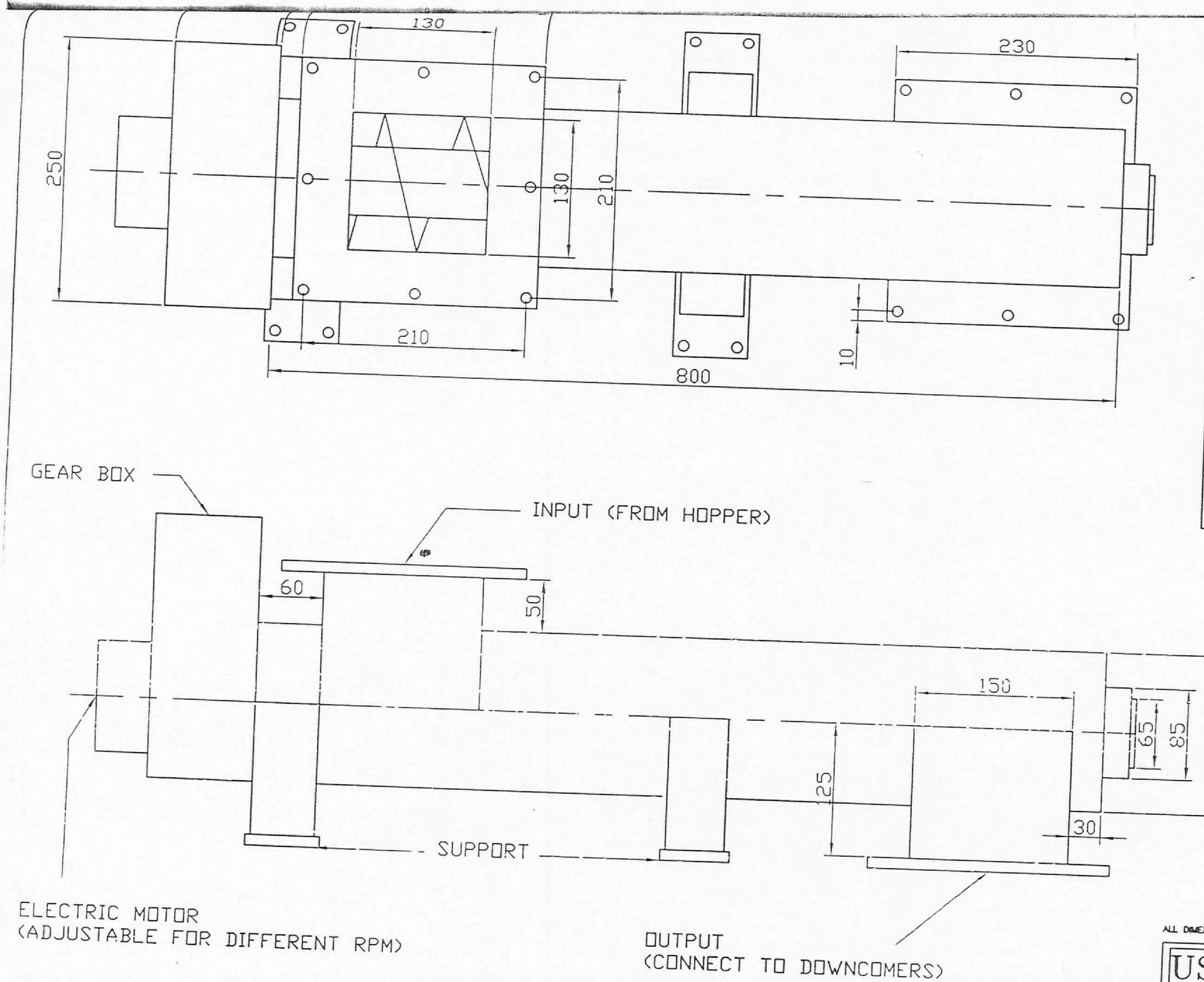
SCREW PROPERTIES	
SCREW THICKNESS	5MM (ROOT)
NOMINAL SHAFT DIAM.	42.4 MM
NOMINAL SCREW DIAM.	100 MM
PITCH	70 MM
SHAFT MATERIAL	MILD STEEL
REQUIRED RPM	30 RPM
REQUIRED CAPACITY	60KG/HR
RAW MATERIAL BULK DENSITY	210 KG/M3
MAX. LUMP SIZE (COMMERCIAL SAWDUST)	1MM (0.45%)

ELECTRIC MOTOR PROPERTIES	
HORSE POWER	1.5 HP
VOLTAGE	240V
SPEED (MAX)	1400 RPM
TORQUE	3151.25 Inch/pounds
REDUCER	1/40
GEAR RATIO CONTROLLER	1HP VAR. SPEED PULLEY



ALL DIMENSION IN MM

USM MECHANICAL ENGINEERING					
DRAWING TITLE: FEEDING SYSTEM (SCREW FEEDER)					
	DRAWN	NOOR HISYAM AHMAD			DRAWING No.
SHEET 1 OF 1	GROUP	BIOMASS	QUANTITY	1	APPENDIX



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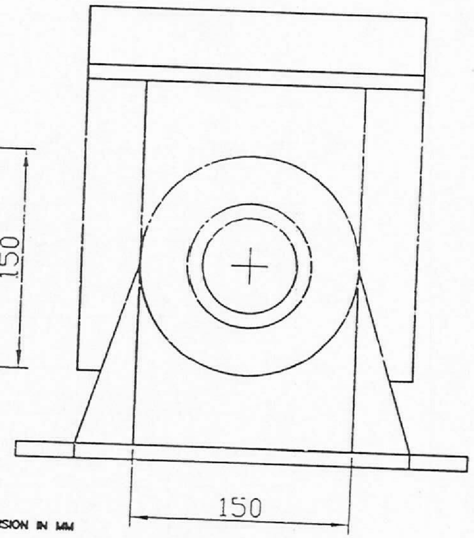
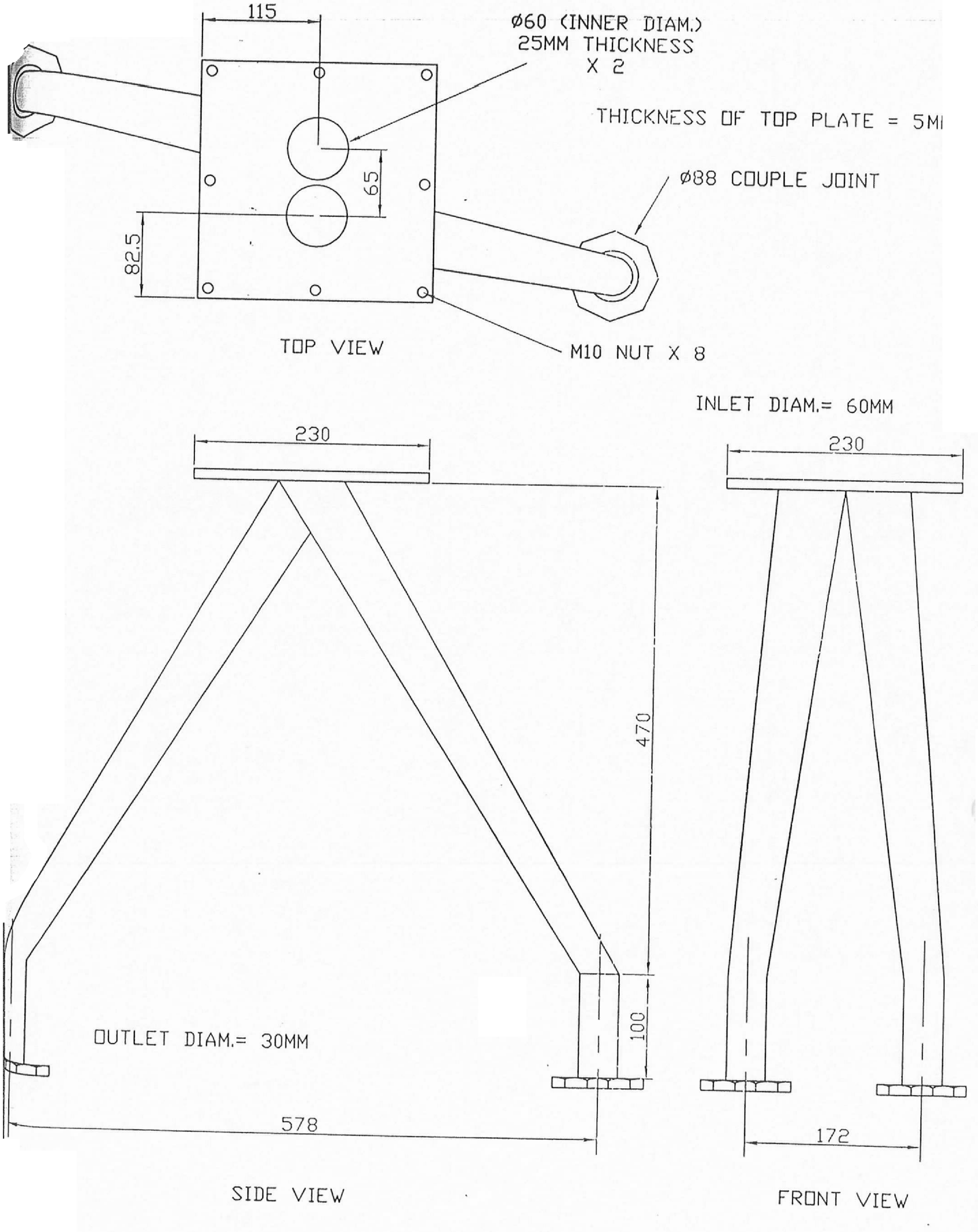


ALL DIMENSION IN MM

USM MECHANICAL ENGINEERING

DRAWING TITLE: FEEDING SYSTEM (SCREW FEEDER)

SHEET 1 OF 1	DRAWN	NOOR HISYAM AHMAD		DRAWING No.	
	GROUP	BIOMASS	QUANTITY	1	ARDEN[illegible]



ALL DIMENSION IN MM

USM MECHANICAL ENGINEERING					
DRAWING TITLE: FEEDING SYSTEM (DOWNCOMERS)					
SHEET 1 OF 1	DRAWN	NOOR HISYAM AHMAD			DRAWING No.
	GROUP	BIOMASS	QUANTITY	1	APPENDIX
	SCALE	1 : 5	DATE	05/11/2003	A-07