MUNICIPAL SOLID WASTE DRYER

BY USING WASTE HEAT DESIGN

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CERTIFICATION

I, Chatchawan Lawanangkul, declare that this thesis, submitted in fulfillment of the requirements for the award of, Master of Science in International Cooperation Policy in the Graduate School of Asia Pacific Studies, Ritsumeikan Asia Pacific University, is wholly my own original work unless otherwise referenced or acknowledged. The document has not been submitted for qualifications at other academic institutions.

Chatchawan Lawanangkul
15 July 2013

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EXECUTIVE SUMMARY

In today society, energy is essential necessity and waste elimination is essential necessities for modern life. Fossil fuels include coal, oil and gas, which are formed out of organic matter deposited and decomposed under the earth's surface millions of years ago. It is important because, 81 percent of the world's energy is produced by fossil fuels, which are nonrenewable resource, meaning that at some point they will run out (World energy report, 2012). This will have economic and global impact to our way of life. Without fossil fuels today commerce would grind to a stop because most vehicles will not be able to deliver produce and manufactured goods since they run on gasoline. Also, electricity would also be severely depleted since ninety percent of the world electricity is produced by coals, also nonrenewable fossil fuels. (Renewable Global Status Report 2012). Thailand is also no exception. Thailand, energy is mostly produced by using conventional resource called fossil fuels, or fuel formed by natural resource such as anaerobic decomposition of buried dead organisms. It has only 8 percent of renewable energy (4% in electricity production, 1% in heating and 3% in transportation sector). Moreover, Thailand consumption of power is rising rapidly. In term of power consumption in 2009, the electricity consumption in Thailand was 140,492,000 MWh. In 2010 this number increased by 5% which amounted to 32,389 ktoe of oil utilized in 2011. (Electricity power in Thailand, Annual report 2011)

In addition, Thailand has encountered problem of garbage and waste management. 41,023 tons of waste is created per day, or in other words, an average Thais create 1.2 Kg of waste per day (Pollution Control Department, 2008). Major landfills and dump sites are being filled and more are being creating to manage the ever increasing waste collection. The use of landfills and dump sites are now starting to create environmental and social problems with the people in the minority community.

Thus, my thesis aims to examine the feasibility of tacking both problems by designing an improved fuel drying system for the gasifier. A gasifier is a machine that converts carbonaceous materials, such as petroleum biofuel and bi coal into carbon dioxide, methane, carbon monoxide, water vapor, hydrogen, and other organic and inorganic gases etc, in the gasification process. Such gas compositions are results from the reactions of the raw material at elevated temperature

with fixed quantity of steam and oxygen. The byproduct from the mixture is synthesis gas or syngas and is by itself a combustible fuels/ gases. In addition, gasification process can be started using materials that are not fossil fuels such as organic waste or biomass.

The research will focus on a real gasifier power plant which is located in existing landfill site in Samutsakorn province, Thailand. The site has more than 500,000 tons of deposited waste and more than 300 tons of municipal solid waste (MSW) added daily that need to be treated. The plant is designed to produce an electrical power output 400 kW using combustible waste or refuse derived fuel as fuel.

After careful deliberation and research to improve the thermal efficiency of the system, a new designed of the improved gasifier was chosen. It dries moist MSW by recovered waste heat, which is not only commercially profitable but also environmentally friendly since the utilized fuels are biomass. This is done by finding the most suitable type, size and material of dryer to reduce the moisture of the MSW from 50% to 20%. Thus, as moisture content decreases, the lower heating value (LHV) of MSW is increased. This means that lower amount of MSW input could be utilized to produce the same amount of output energy. (The lower the moisture content, the higher is the heating value) As a result, the gasifier with dryer system will effectively generate a higher amount of energy to the Samutsakorn power plant at a lower input cost, thereby, creating a saving cost of saved 2,695.7 baht per day with the breakeven point at 586 days after implementation.

In addition, this dryer design not only solves the real world problem from Samutsakorn power plant but also took into consideration the financial aspect of the implementation of the design. This includes the construction cost, operation cost, maintenance cost, as well as the construction loan cost. Also, given the total cost and profit per day from implementing the design, an exact breakeven point could be found to be 586 days.

Finally, this design is only in the beginning phase, further improvements could and need to be made for the betterment of the system to increase efficiency as well as effectiveness of the whole system for a better plant and thereby a better society, and a greener world. Lastly, I hope my designs could be used as a basis for improving the gasifier worldwide.

CHAPTER 1

INTRODUCTION

Generally speaking, resource and energy are necessity to human's daily life in term of economy, environment and society not only for Thailand but also the world. Nowadays, in Thailand, energy is mostly produced by using conventional resource called fossil fuels, or fuel formed by natural resource such as anaerobic decomposition of buried dead organisms. Realizing that these resources may run out in very near future, Thailand's government has supported the usage of renewable energy resources in order to increase the production of alternative energy, alleviate the country's fuel importation and reduce global warming.

Renewable energy is energy generated from natural resources which are naturally replenished or in other words renewable for example as waste, geothermal heat, tide, water, sunlight, wind, and biomass. Given the location and weather conditions of Thailand, some of these options are not economically viable for producing energy. Thailand, however, is an agricultural country; as such there are plenty of biomass and waste which can be used to produce energy. (Global Status Report, Renewables 2011)

Biomass is biological material derived from living organisms and is considered to be organic matter. Wastes on the other hand are the substances or objects which are disposed of or are intended to be disposed of which can be divided into organic and inorganic matter such as metal, glass and hydrocarbon compound. The organic matter and hydrocarbon compound can be used to produce energy via the process called "gasification" and result in the product called "syngas". (Lynn and Judy Osburn, 1993)

Gasification is a process that converts carbonaceous materials, such as petroleum biofuel and bi coal into carbon dioxide, methane, carbon monoxide, water vapor, hydrogen, and other organic and inorganic gases etc. Such gas compositions are results from the reactions of the raw material at elevated temperature with fixed quantity of steam and oxygen. The byproduct from the mixture is synthesis gas or syngas and is by itself a combustible fuels/ gases. In addition, gasification process can be started using materials that are not fossil fuels such as organic waste or biomass. The process can be done by using "gasifier". (Klass, Donald L., 1998)

A gasifier is a machine in which the biomass or waste are fed into and burnt in the shortage of oxygen process called reduction atmosphere. Although there are many types of gasifier, improvement are still feasible in term of thermal efficiency, environmental concerns and applications.

This study examines the feasibility of improving the thermal efficiency of the gasifier by design a new fuel drying system before being fed into gasifier by using recovered waste heat. The research will focus on a power plant which is located in existing landfill site in Samutsakorn province, Thailand. The site has more than 500,000 tons of deposited waste and more than 300 tons of municipal solid waste (MSW) added daily that need to be treated. The plant is designed to produce an electrical power output 400 kW using combustible waste or refuse derived fuel as fuel. Currently, the gasification process is used in the plant to generate the electricity. In addition, gasifier is also used as a major part of gasification process; still there are possibilities of further improvements in term of thermal efficiency and environmental concerns which will be addressed within this thesis.

1.1 BACKGROUND

1.1.1 Background on Thailand's Energy Consumption

1.1.1.1 Preface

In term of power consumption in 2009, the electricity consumption in Thailand was 140,492,000 MWh. In 2010 this number increased by 5% which amounted to 32,389 ktoe of oil utilized in 2011. (Electricity power in Thailand, Annual report 2011)

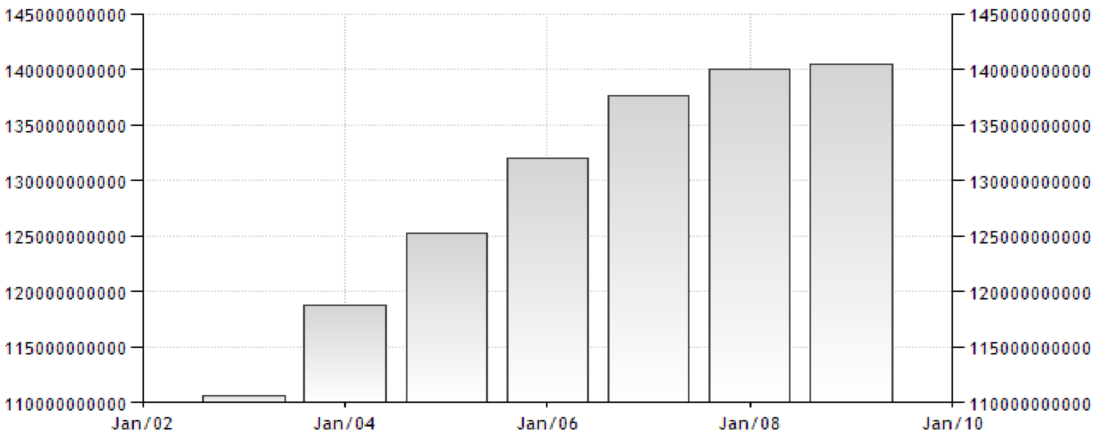


Figure 1.1: Thailand electricity consumption

Source: www.tradingeconomics.com

• Natural gas consumption for electric generation in 2011 totaled 865,561 MMscf, or 2,371 MMscfd in average, decreased 15.5% over the previous year, and accounted for 65.1% of the total fuel consumption of national grid generation.
• Coal and lignite consumption for electric generation in 2011 totaled 24,044 thousand tons, or 66 thousand tons per day, increased 17.1% from the previous year, and accounted for 26.4% of the total fuel consumption of national grid generation.
• Fuel oil consumption for electric generation in 2011 was 447 million liters, increased 85.5% from the previous year, and accounted for 1.3% of the total fuel consumption of national grid generation.
• Diesel consumption for electric generation in 2011 was 32 million liters, decreased 17.9% from the previous year, and accounted for 0.1% of the total fuel consumption of national grid generation.
• Renewable fuel consumption for electric generation in 2011 was 9,530 thousand tons with an average rate of 26 thousand tons per day, increased 32.9% over the previous year, and accounted for 6.1% of the total fuel consumption of national grid generation. All renewable fuel (paddy husk, bagasse, garbage, and agricultural waste) was consumed by private power producers and very small renewable energy power producers.

Table 1.1: Thailand's energy utilization divided by sources

Source: Annual Report electric power in Thailand 2011, Department of Alternative Energy Development and Efficiency

1.1.1.2 Power plant at Samutsakorn province.

Samutsakhon is one of the central provinces of Thailand. It is surrounded by Bangkok, Ratchaburi, Nakhon Pathom, and Samut Songkhram provinces.

Figure 1.2: Map of Thailand highlighting Samutsakhon Province

Source: http://www.samutsakhon.go.th/index_n.htm

Area	
• Total	872.3 km^2 (336.8 sq mi)
Population (2011)	
• Total	499,098
• Rank	Ranked 53rd
Density	570/km^2 (1,500/sq mi)
• Density rank	Ranked 4th
Electricity consumption (2011)	6,953 GWh/year

Table 1.2: Information of Samutsakhon Province

Source: http://www.samutsakhon.go.th/index_n.htm

The power plant located in Samutsakorn province, Thailand. The plant was designed with the electrical power 400 kW output using combustible waste (RDF) as fuel which is from existing landfill site in Samutsakorn province. The site has more than 500,000 tons of deposited waste and more than 300 tons of municipal solid waste (MSW) added daily that need to be treated.

Municipal Solid Waste (MSW) management poses serious environmental problems in large cities throughout the region. The suitable management systems and treatment technologies are required to tackle these problems. The best solution is to turn problems to benefits or in other words turn waste to energy.

There are many processes for the front-end treatment. The residues, i.e. plastic, wood, paper, polymer, etc. and still remain the problems. The proposed Gasification and Engine-Generator System, however, is the solution.

Gasification is a process that enables the extraction of energy from many different types of materials, such as wood, biomass and also combustible waste.

The process is to convert carbonaceous materials, such as coal, biomass or plastic into carbon monoxide, hydrogen, carbon dioxide, methane, water vapor etc. by the reactions from the raw material at high temperature with a controlled amount of oxygen. The resulting gas mixture is called synthesis gas or syngas and is itself a fuel. (Beychok, Coal gasification and the Phenosolvan process)

1.1.2 Background on the gasification

1.1.2.1 The definition of gasification

As stated earlier, Gasification is a process that enables the extraction of energy from many different types of materials, such as wood, biomass and also combustible waste into carbon monoxide and hydrogen through high temperature reaction with controlled amount of oxygen and/or steam. The temperature is elevated to more than 700°C by means of chemical processes, which differentiate it from typical biological processes that results in biogas such as anaerobic digestion. The resulting gas mixture is a fuel called synthesis gas or syngas. Syngas can then be processed directly in the internal combustion engines to generate methanol and hydrogen, or synthetic fuel via the Fischer-Tropsch process. (James G. Speight, 2011) Nowadays, gasification of fossil fuels is commonly used by worldwide countries in the generation of electricity due to is cheaper cost and availability. In reality, any type of organic material could be employ as the raw material for the gasification process such as biomass, wood, or even plastic waste. If the raw material utilized for the gasification process is obtained from biomass such as household waste or compost, it is considered to be a source of renewable energy. (IPPCB, 2008)

The major advantage of gasification is the fact that it can also begin with fuel materials that are otherwise not useful, such as organic waste or biomass. Also, it’s by product, the syngas, has a lot higher combustion efficiency than its original combustion fuel form since it is possible for combustion at higher temperatures, which correspond to Carnot's rule that stated the increase in efficiency in thermodynamic upper limit. Moreover, from otherwise problematic fuels, the high temperature combustion purifies acidic compounds such as potassium and chloride, allowing clean gas production. (Klass, Donald L., 1998)

Figure 1.3: Gasification process

Source: Biogate, ARTES Institute, University of Flensburg

1.1.2.2 Historical background

Over 180 years ago in Europe gas producer started the gasification process whereby organic feeds combustion was used in blast furnace. At first, peat and charcoal are utilized as input material to the gasifier to obtain heating and power generation Later on in the century petroleum became widely utilized as a fuel. However, it faced shortage in supplies during both world wars and particularly during World War 2 which led to extensive re-introduction of gasification. Thus, within in 1945 the gas was introduced as a mean to power buses trucks, industrial machines and agricultural tools.

In 1956, Sweden continued its development on gas technology due to the general decline in cheap fossil fuels and Suez Canal crisis. Thus, research by the National Swedish Institute for Agricultural Machinery Testing was created to find suitable designs of wood gasifiers for transportation usage, and it is still in progress even today. Lastly, the oil crisis in 1973 further increased the number interests in gasification technology particularly in small scale gasifier for municipal waste.

In conclusion, the gasification process can be traced back to 1800s where it was first used to in towns as a mean for cooking and lighting. Later on gas was replaced by natural gas and electricity for these type of applications, however, in 1920s gasification process became a norm for the production of synthetic chemicals and fuels due to is efficiency. (Ed. D. Yogi Goswami, 1986)

1.1.2.3 Gasification process

For commercial usage, there are four possible types of gasifier that are currently available in today's market: co-current-fixed-bed, counter-current fixed bed, fluidized bed, and entrained flow.

1. The counter-current-fixed-bed gasifier is composed of a fixed bed of carbonaceous fuel such as biomass or coal, through which air, steam, and/or oxygen flows through in a counter-clockwise direction. The ash is either removed from the dry's bottom as a slag. The process of the gasifier denotes that high mechanical strength is needed in the fuel in order for it to form a permeable bed. Thus, output of this gasification process is small; however, the efficiency thermal energy is elevated. This means the methane and tar produced is highly substantial at normal operating temperatures, or in other words, the syngas needed be purified prior to utilization. (Kamka, Frank; Jochmann, Andreas, 2005)

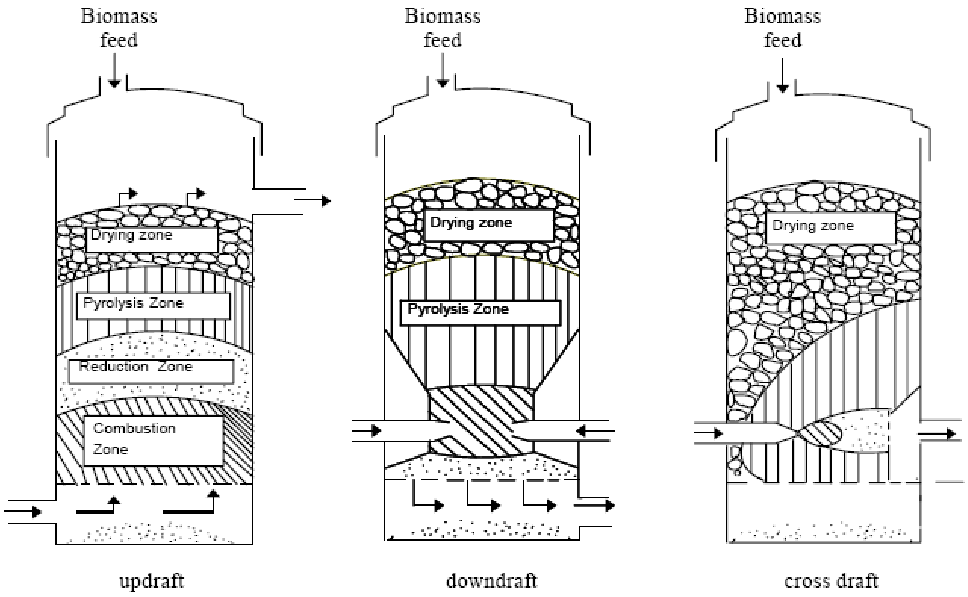
2. The co-current-fixed-bed gasifier is comparable to the Counter-Current-Fixed-Bed Gasifier, with the exception that oxygen flows downwards. Heat is added to the upper part of the bed through form combustion with small amounts of injected fuel and/or external heat sources. As a result, the produced gas leaves the gasifier at soaring temperature whereby the excess heat is transferred to the gasification agent and added to top of the bed. This results in similar energy efficiency to the Counter Current method. However, in this configuration, tars travels through a hot bed of char; thus, the levels of tar are much lower than Counter Current gasification. Thus, the overall gasification process has lower overall efficiency since a high amount of heat content is carried over by the hot gas.(Clarke, 1981; Reed and Das, 1988).

3. In the fluidized-bed reactor, the fuel is fluidized in steam and air or oxygen. The fuels therefore have to be highly reactive since their operating temperature is much lower. This means that low-grade coals are particularly suitable. However, the efficiency of conversion could be rather low due to elutriation of carbonaceous material. The fixed bed gasifiers are suitable for small-scale applications (<10MWth) and the fluidized bed configurations are cost effective in large-scale applications that generate over 15 MWe (Barker, 1996; Carlos, 2005; VTT, 2002 and Rajvanshi, 1986, Sims, 2003).

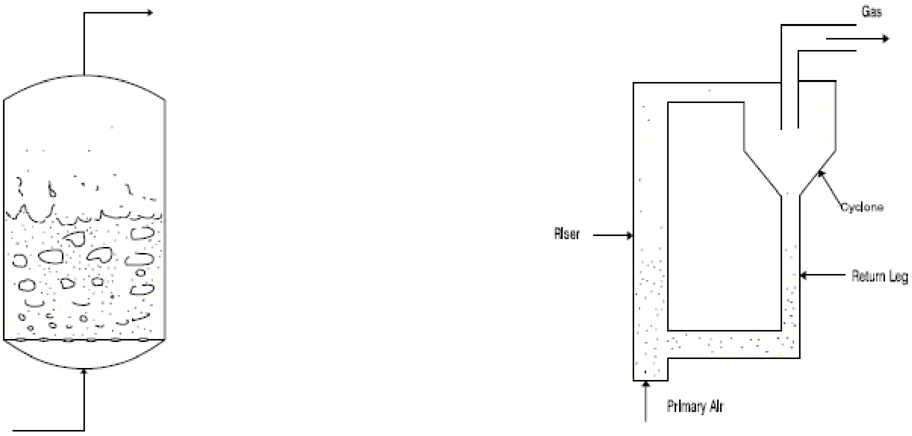
4. As for the entrained-flow gasifier, a liquid fuel and/or a dry-pulverized solid fuel is gasified with oxygen in co-current flow. The gasification process happens in a dense cloud of very fine particles. Most coals are suitable for entrained-flow gasifiers because of its particles are well separated from one another at high operating temperatures. By utilizing high pressures and temperatures, elevated result of the product can be achieved. Nevertheless thermal efficiency of this type of process is reduced since the gas has to be cooled before it can be purified with existing technology. The high temperatures in this gasification process mean that methane and tar are not present in the produced gas. Still, more oxygen is required when compared with the other types of gasifiers. (James G. Speight, 2011)

1.1.2.3 Types of gasifier

Fixed-bed updraft, bubbling fluidized bed, circulating fluidized bed, fixed-bed downdraft, and fixed-bed cross-draft gasifiers are the five major types of classification.



i) Fixed Bed Gasifiers



a) Bubbling Fluidized Bed **b) Circulating Fluidized Bed**

ii) Fluidized Bed Gasifiers

Figure 1.4: Different kinds of gasifier configurations

Sources: Bhattacharya and Salam, 2006

1.1.2.4 Comparison of biomass gasification technologies

The choice of gasifier utilized is dictated by fuel input; its final available size, moisture content, form, and ash content. Table 1.3 lists the advantages and disadvantages for various gasifier types.

Table 1.3: Relative advantages and disadvantages of gasifier types

Gasifier	Advantages	Disadvantages
Updraft fixed bed	Mature for small-scale heat applications Can handle high moisture No carbon in ash	Feed size limits High tar yields Scale limitations Low heating value gas Slagging potential
Downdraft fixed bed	Small-scale applications Low particulates Low tar	Feed size limits Scale limitations Low heating value gas Moisture-sensitive
Bubbling fluid bed	Large-scale applications Feed characteristics Direct/indirect heating Can produce higher heating value gas	Medium tar yield Higher particle loading
Circulating fluid bed	Large-scale applications Feed characteristics Can produce higher heating value gas	Medium tar yield Higher particle loading
Entrained flow fluid bed	Can be scaled Potential for low tar Potential for low methane Can produce higher heating value gas	Large amount of carrier gas Higher particle loading Particle size limits

Source: EPA-CHP, 2007

1.1.3 Background on energy from waste

1.1.3.1 Waste

Waste is classified into 3 categories as the followings:-

1. Municipal Solid Waste (MSW)

2. Industrial or Hazardous Waste

3. Hospital Waste

Our concern is to deal with MSW only. MSW is composed of the followings, (see Appendix A3)

- Organics	50 %
- Inerts	10 %
- Recycles	10 %
- Combustibles	30 %

When mention about MSW, we should consider 2 issues:-

1. Fresh MSW

2. Landfilled MSW

Presently the suitable MSW treatment for the oriental people like Chinese or Thai is conceptually agreed as the diagram below.

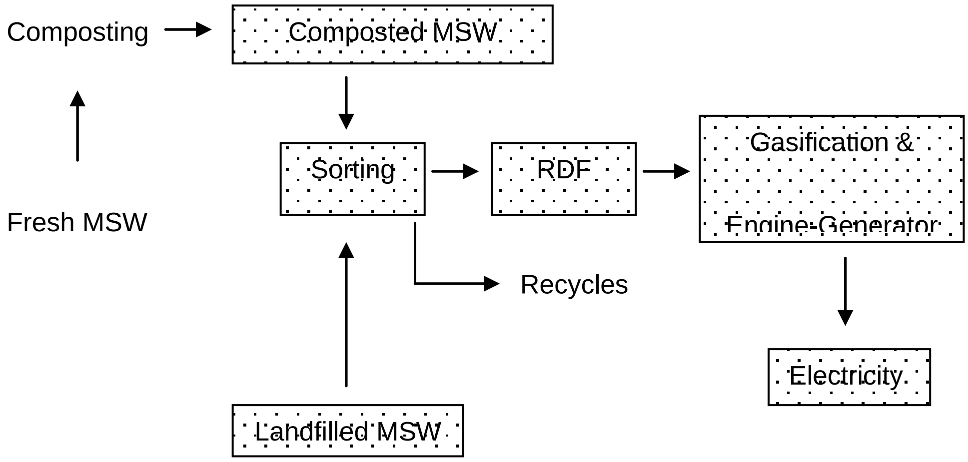


Figure 1.5: The diagram of suitable MSW treatment for Thailand

Source: Waste management, Department of Alternative Energy Development and Efficiency

For the first stage, I will confine myself to tackle the problem of land filled and composted MSW treatment only.

Major city has encountered problem of garbage and waste management. Landfills and dump sites are commonly used to solve and manage municipal waste after collection. The use of landfills and dump sites are now starting to create environmental problems with the people in the community which strongly started to reject such methods.

The objectives of this proposed waste management system are to recover waste into useful benefits such as recycles, and refuse derived fuel (RDF). Recycles are utilized in the proper means accordingly. RDF is processed through our gasification and engine-generator system. The outcome is electricity.

The system can minimize utilization of landfills and minimize environmental problems.

1.1.3.2 Energy from Waste

Energy recovering from waste is of my interest. My process technology is to rehabilitate the existing landfill sites and composted waste to get the combustible residues which technically called refuse derived fuel (RDF).

The gasification process technology which has been developed by our technical experts is successfully using RDF to produce syngas or fuel gas.

Syngas from the gasification process contains mainly carbon monoxide, hydrogen and methane which are theoretically considered as fuel in gaseous phase.

The obtained Syngas could be divided into 2 types of generated energy.

Type 1: Heat or thermal energy of the syngas itself that is obtained directly from burner systems.

Type 2: Electrical energy is obtained after using the syngas as fuel in the internal combustion gas engine to generate electricity.

The exhaust emission contains mainly carbon dioxide and water vapor which are not toxic and meet the emission control standards.

1.1.3.3 Waste to Energy (Electricity) Process

Using combustible waste (RDF) as fuel by processing it through gasification and engine-generator system, we can get the electricity as the following schematic diagram.

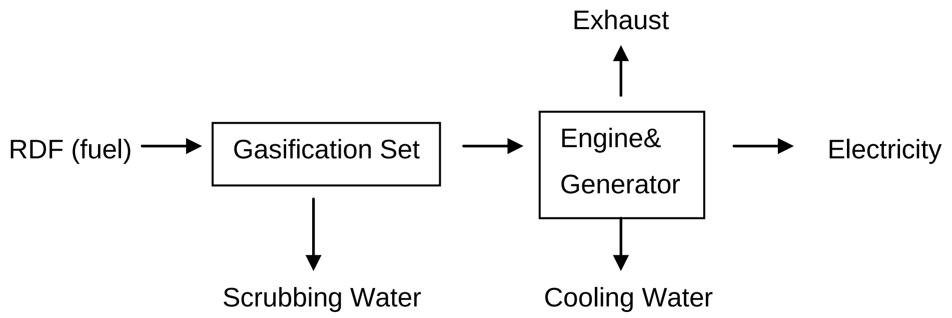


Figure 1.6: The schematic diagram show the process of electricity production

Source: Waste management, Department of Alternative Energy Development and Efficiency

From schematic, there are 3 steps in the process as the following items:-

1. Fuel preparation

Combustible waste (RDF) from the rehabilitation process such as plastic residue, wood, paper, cloth, polymer and etc. will be shredded to 5-10 mm in size. Moisture content is controlled less than 20%. Then it is ready for use as fuel.

2. Gasification

Fuel is fed to gasifier and burnt in the shortage of oxygen process which technically called reduction atmosphere. Burning temperature is 500-750˚C. The combustion product is syngas which contains mainly carbon monoxide and hydrogen gases.

Tar and dust of syngas are removed in the cyclones and wet scrubbers. The syngas temperature is also cooling down here. Then the clean and cool syngas is ready for use.

3. Electricity generation

Clean and cool syngas from step 2 is fed to specially design internal combustion gas engine-generator set for producing electricity. Internal power consumption for the plant is about 5% the rest could be utilized or sold commercially to the power grid as desired.

There are 2 matters to be concerned regarding to the environmental regulations below:

1. Water

1.1 For gas cleaning process

- Tar and fine dust laden gas will be removed in the wet scrubbers as they counter flow through spray water.

- Colloidals in contaminated water from wet scrubbers are precipitated in the sediment pond. The clean water after precipitation shall be re-circulated and sprayed in the wet scrubbers continuously.

- Neutralization in the sediment pond is to be chemically controlled and the sediments need to be removed periodically.

- A small amount of fresh water is sometimes refilled to replace evaporation.

- The above described process is a closed system. Therefore, no polluted water emits to surrounding.

1.2 For engine cooling

- To cool down the engine temperature to a normal condition.

- The water is a closed loop circulated in the cooling pond.

2. Exhaust

Exhaust from the gas engine set contains carbon dioxide (CO_2) and water (H_2O) like the exhaust coming from vehicles on the road which meets the environmental regulations.

In conclusion, no water is emitted to surrounding. The emitted exhaust from engine is like from vehicles.

1.1.3.4 Process Technology

The process to convert combustible waste to energy by gasification and engine-generator system can be described below.

RDF (Fuel) is combustible waste which can exist in the forms of organic material such as rice husk, wood, etc. or inorganic material such as plastic, cloth, etc. Every fuel contains the same elements as C, H, O, N and S but different in molecular forms. For examples; C, H, O , N and S in wood has a cellulose form but C, H, O , N and S in plastic has a polymer or polyolefin form.

RDF (Fuel) with proper size and moisture content is fed through the gasification process to get synthesis gas. The reaction is incomplete combustion i.e., the supplied amount of air is only 20-30% of stoichiometry. The out coming is syngas or fuel gas which contains CO, H_2, CH_4, CO_2, H_2O and N_2.

The chemical reaction can be derived as the followings

1. Complete Combustion Stage

The fuel elements firstly react with the supplied oxygen at temperature of 200-300 ^oC. The reactions are

$$C + O_2 \longrightarrow CO_2$$

$$2H + \frac{1}{2} O_2 \longrightarrow H_2O$$

$$N + \frac{1}{2} O_2 \longrightarrow NO$$

$$S + O_2 \longrightarrow SO_2$$

These exothermic reactions deliver heat at the earlier stage and consume a small amount of fuel. The heat emitted will help increasing the inlet air temperature to 200 degree Celsius.

2. Incomplete Combustion Stage

The reactions start around 800-900 ^{o}C and co-reactions as Water Gas Shift Reaction, Methanation Reaction occur as well at this stage.

$$C + CO_2 \longrightarrow 2CO \quad \text{(Endothermic)}$$

$$C + H_2O \longrightarrow CO + H_2 \quad \text{(Endothermic)}$$

$$CO + H_2O \rightleftarrows CO_2 + H_2 \quad \text{(Exothermic)}$$

$$C + 2H_2 \rightleftarrows CH_4 \quad \text{(Exothermic)}$$

$$CH_4 + H_2O \rightleftarrows CO + 3H_2 \quad \text{(Endothermic)}$$

The constituents of syngas are CO_2, CO, H_2, CH_4, N_2 and H_2O. The compositions are approximately:

CO_2 (mol %, DB)	8 %
CO (mol %, DB)	31 %
H_2 (mol %, DB)	19 %
CH_4 (mol %, DB)	2 %
N_2 (mol %, DB)	40 %
H_2O (mol %, DB)	10 %

When syngas passes through wet scrubbers, fine dust and acid gas such as NO_X and SO_2 are trapped. The outlet gas temperature is cooled down to 30-40 ^{o}C, which is ready for use in the internal combustion engine.

The chemical reactions in the Internal Combustion Engine are:

$$CO + ½ O_2 \longrightarrow CO_2$$

$$H_2 + ½ O_2 \longrightarrow H_2O$$

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$$

They are complete combustion reactions. Fuel reacts with oxygen in the air giving CO_2 and H_2O before leaving exhaust stack to environment without toxicants.

The water system for use in the wet scrubbers is a close loop design. No polluted water goes out to harm the surrounding.

The schematic below explains the function and the handling method of scrubbing water.

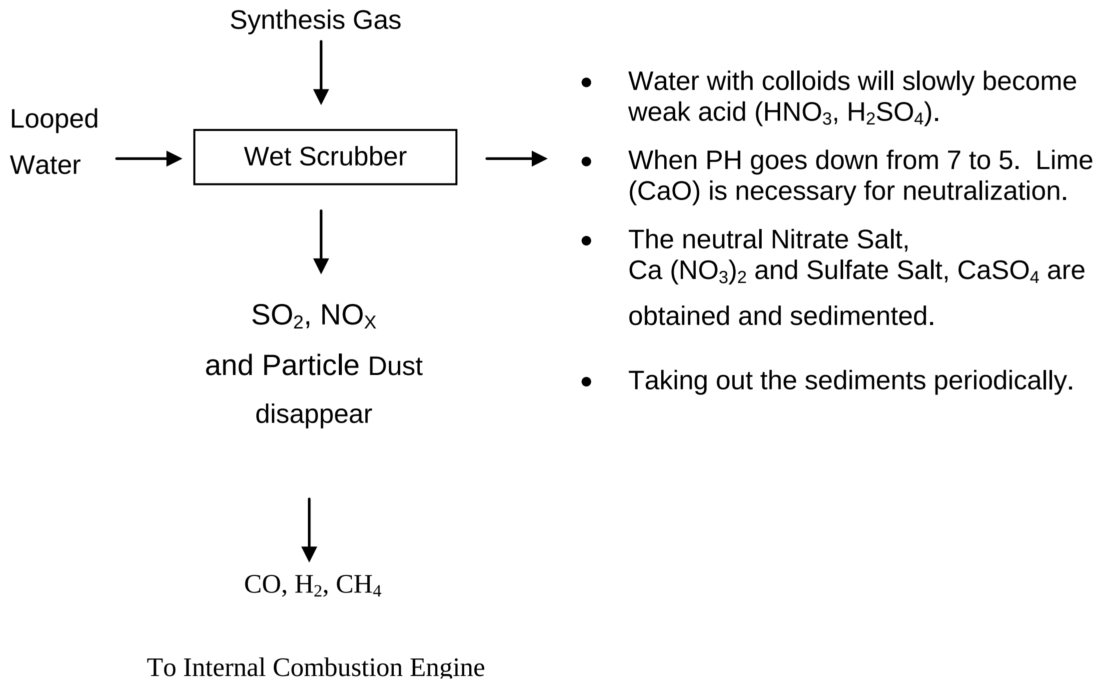


Figure 1.7: The schematic indicates method of scrubbing water.

Source: Waste management, Department of Alternative Energy Development and Efficiency

1.1.3.5 Conclusion

Waste is the major problem of each community. The above-described gasification and engine-generator system is accepted to be a proven and realistic technology. This system can help solving the problems effectively and beneficially.

Syngas, as a fuel can be beneficially utilized by 2 ways:

1. To generate the heat through gasification systems.

2. To generate the electricity through the gasifier and engine-generator system.

My purposes reflect the principles and the implementation procedures of turning waste to energy (electricity) by the gasification and engine-generator system which is the profitable solutions.

1.2 OBJECTIVE

To design a dryer system that recovers waste heat (hot fuel gas heat) from the internal gas engine to dry the exiting MSW and reduce their moisture content.

Research Questions: What type of dryer should I use?

- What should be my dryer dimension?
- What is type of material should I use?
- What are the specification of the bower and damper?

How much energy is needed to dry the MSW?

- What is the needed temperature output?
- How much hot fuel gas should I use?
- What is the right mass flow rate of the mixed gas?
- What velocity should mixed gas flow?

What is the total cost of the dryer system?

- What is the operating cost?
- What is the maintenance cost?
- What is the construction cost?
- What is my loan cost?
- When is the breakeven point?
- What is the profit from implementing the dryer system?

1.3 EXPECTED OUTCOMES

What type of dryer should I use?

We have been able to find the most suitable type, size and material of dryer to reduce the moisture of the MSW from 50% to 20%.

How much energy is needed to dry the MSW?

In term of thermal efficiency, we have been able to utilize the correct mixture of air and recovered waste heat gas to dry the MSW to the expected moisture content and temperature. Also, the correct mass flow rate and velocity of the mixed gas was found to implement the safety factor for the dryer.

What is the total cost of the dryer system?

As designed, the new design of the dryer has generated a cost saved for the power plant. The financial cost saved also took into account the construction cost, operation cost, maintenance cost, as well as the construction loan cost. Given the total cost and profit per day from implementing the design, an exact breakeven point could be found.

1.4 SCOPE OF WORK

The project emphasizes on the study of feasible improvement on thermal efficiency of the existing gasifier by design new fuel drying system before being fed into gasifier by recovered waste heat from internal gas engine. The existing gasifier that we use to do the project is a part of the power plant located in Samutsakorn province, Thailand. The plant was designed with the electrical power 400 kW output using combustible waste (RDF) as fuel. So, this project is to use the plant as a case study. Then, I do the calculations base on the collected data by using knowledge of thermodynamic and heat transfer. After that, the feasible improvement will be analyze whether it worth for economic and environmental point of view.

The scope of this project, however, does not cover building an actual prototype of the drying system. The project instead designed the dryer system in Design Software which can be viewed in Chapter 5, project outcome. For a plain view of the dyer system, the diagram could be concluded as follow,

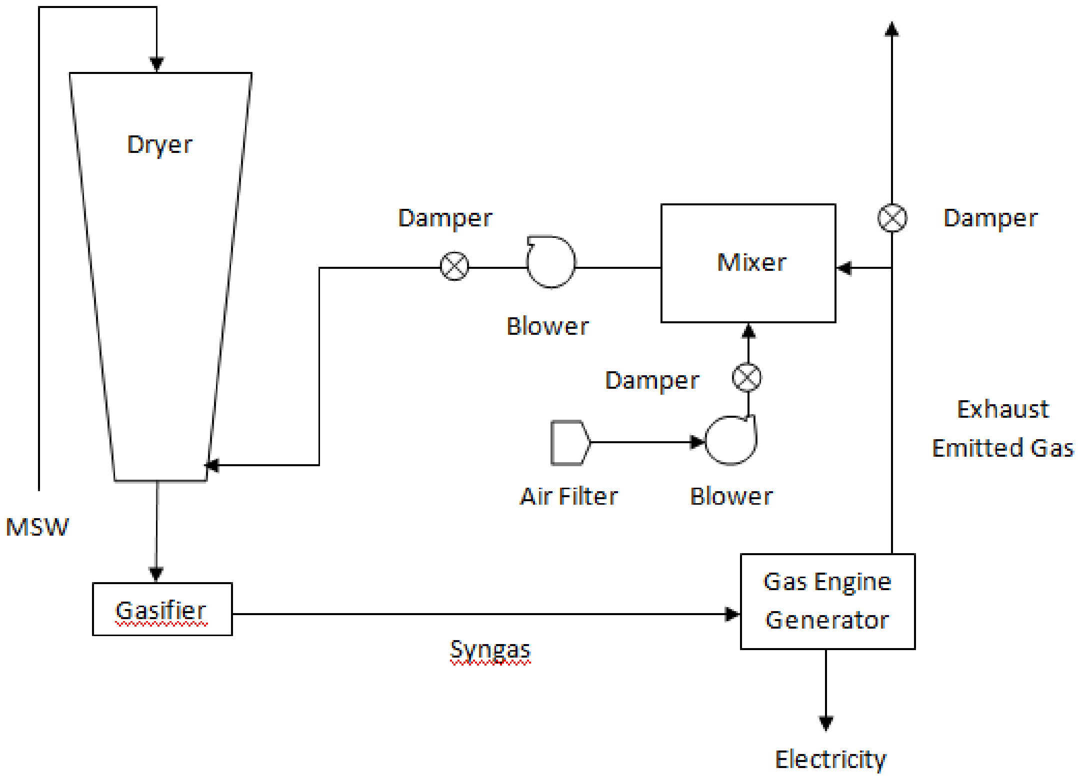


Figure 1.8: Scope of the Project; design fuel drying system by recovered waste heat

1.5 METHODOLOGY

There are 7 Steps:

1. Introduction and background on the power plant at Samutsakorn province.

2. Literature review: Find information and study prior researches and articles done on this topic and speculate which research topics can further be studied and developed. Some examples of topics are as the followings,

- Design a gasifier and material selection, basic on gasifier information.

- Dryer system with gasifier and other applications.

- Effects of relative humidity on thermal efficiency of gasifier.

- Applications on waste heat recovered system.

3. In literature review, it's shown that there are many ways to improve the thermal efficiency such as reduction of length along process, insulated gasifier, useful dryer, etc. Thus, this step is to select the right type of dryer for our design. The criteria of choosing the dryer type are done through the decision matrix whose factors and weights are jointly decided by the CEO, chief operating officers and me.

4. Collect necessary information and data at the power plant: Visit the plant to study the overall process and equipments, in order to investigate and collect the general information concerning with the drying system. Also, the information on internal gas engine such as hot flue gas temperature and flow rate are collected.

- Analyze the obtained data and information to calculate and design the dryer system (i.e. fuel drying system by using recovered waste heat) to improve the thermal efficiency of the gasifier by reducing the MSW from 50% to 20%.

- Analyze whether our designed improvement is worth for construction based on economic and environmental concern.

5. Project outcome: After all analysis and calculation, this will show you a real figure of this project in term of

- Engineering part (including CAD)

- Financial part in which construction cost, operation cost, maintenance cost, as well as the construction loan cost were calculated. By adding all the cost together we get “Total Cost.” After that, we calculated the “Cost Saved” from implementing the Dryer System by finding the reduced amount of MSW needed for the same amount of energy produced. Thus, given the total cost and profit per day from implementing the design, an exact breakeven point of the implementation could be found.

6. Discussion: Since the power plant used as the case study is a real pioneer plant, there normally might be some problems to discuss.

7. Final conclusion

CHAPTER 2

LITERATURE REVIEW

2.1 GASIFIER: Gasifier for damp fuel

Fluid fuels such as oil are a lot better-quality than producer gas. However, their supplies are limited and decreasing every day. Thus, we have to resources ourselves to producer gas through industry gasifiers for future economic sustainability. Thus, it is in our best interest to be motivated in the development, research, and, betterment of gasifiers (Rui Xiao, Mingyao Zhang, Baosheng Jin, and, Yaji Huang, 2006).

2.1.1 Previous attempts with wet wood

Recent development has shown us that gas produced from coal has been substituted by wooden gas. In this matter, experience has also taught us that it typically more economically beneficial to use raw and unrefined fuel than its converted quality fuel form because the efficiency gained from quality fuel normally does not match the costs and complications associated with the refinement process.

To improve the efficiency of this process, a variety of techniques have been created. Since the fuel quality is equivalent to the temperature in the combustion/reaction zone, heat recapturing technology has been developed to recapture lost away heat and utilized to preheat the fuels.

One such method of removing moisture from the fuel is to condense stream from the fuels in advance. In such process, the top part of the gasifier is left unheated so that the moisture could be condensed and transported to separate compartment. In theory, this methodology to pre-heat the fuel is sound. However, wooden gasifiers is not capable of working with damp fuels, thus it has always been commonly perceived as impossible especially with car gasifiers. (Yaji Huang, 2006).

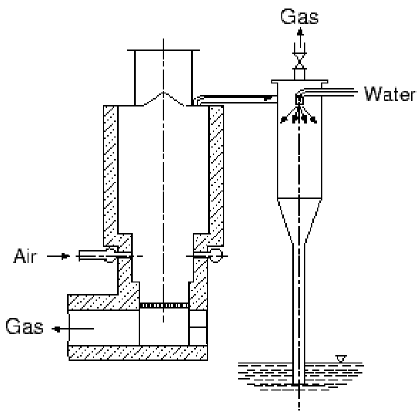


Figure 2.1: Copper Mill Gasifier at Outokumpu.

Source: Prof.Harald Kyrklund, 2000

Still research around this problem is conducted all over the world to overcome this "impossibility." As a result, a large, stationary, gasifier was built at Outokumpu copper mill at Vuoksenniska. Its fuel's container was attached with a spray condenser, which pumped out the moisture and thus, dryings the fuel in the process. By this method, completely damp wood could be utilized as fuel; however, the condenser had to have adjustable valve that allows permanent gases to be expelled. Else, its condensing capabilities would become deficient and the quality of the gas would become too low.

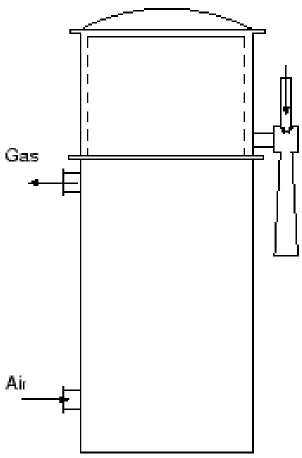


Figure 2.2: Drying of fuel with an ejector.

Source: Prof.Harald Kyrklund, 2000

Also, the Institute of Technology in Helsinki has been conducting research with the aims of removing steam from vehicle’s gasifier by means of ejector. For this process, the vehicle’s exhaust gas was utilized as a powering medium. As a result, considerable enhancement of gas’s quality could be detected. Still, some combustible gases were lost in the process.

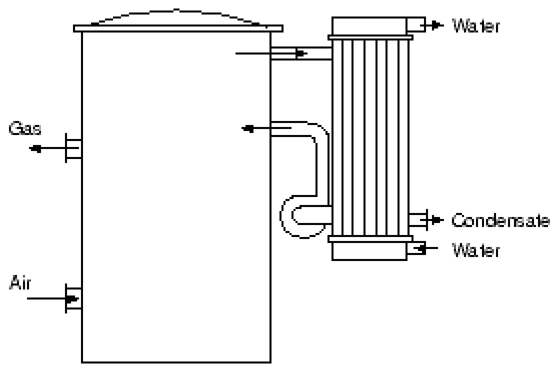


Figure 2.3: Drying device suggested by Lutz
Source: Prof.Harald Kyrklund, 2000

2.1.2 Monorator Invention

An essential key to this dilemma was solved with the invention of monorator. Its creation is pure coincidence to thank for its birth. S P J Keinänen, a well-known racing driver in Sweden, found out that gasifier's container need to be low in order for him to clearly see out the rear view mirror. However, by doing so, the container’s width had to increase its width so that it has room for enough fuel. These particular circumstances combined with the inventor's lack of knowledge regarding earlier gasifier’s designs gave birth to the monorator which was relatively differed from the orthodox type created by Imbert.(Eleanor Imbert, 1920) (Figure 2.4).

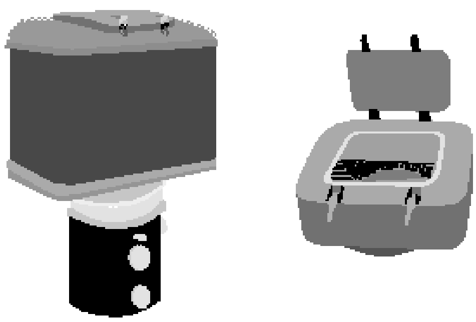


Figure 2.4: Monorator
Source: Prof.Harald Kyrklund, 2000

Thus, the improvement in the monorator container design was entirely baffling. The inventor himself was not aware of what he had invented. Thus, when he got an offer to the manufacturing rights, he couldn't sell the patent. In practical experiences, the car not only operated exceptionally with regular dry aired fuel, but it also worked with wood fuel. In the latter case, the motor ran with great reliability and considerable power.

2.1.3 The principle of the monorator

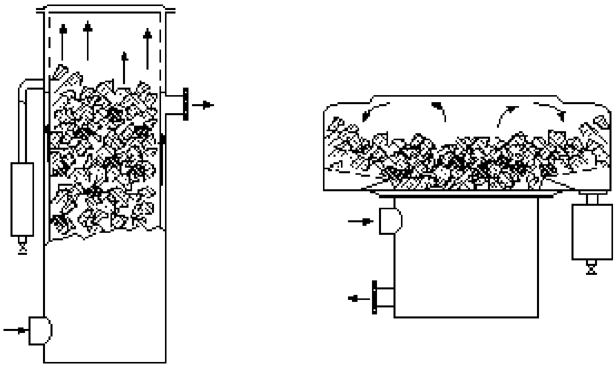


Figure 2.5: To the left a standard model Gasifer and to the right a monorator container.

Source: Prof.Harald Kyrklund, 2000

Figure 2.5 shows the difference between a standard model Gasifer with regular cooling container, and monorator container. In a typical gasifier, the fuel's container is lean and tall. With this design, its bottom is heated to full extent, its wall is surrounded by warm gas and its small top is the only cooling surface. On the other hand, the monorator has a low fuel tank. Its design is usually rectangular, circular, or oval with a cool bottom surface that has considerably larger surface area. This is important since in the typical gasifier the fuel container experience heat from both the hot gases around the container as well as the hearth. On the contrary, in the monorator, only parts of the fuel receive heat from the hearth. The majority section of the fuel is sheltered from the heat thanks to special form of the cooled bottom which is a result from the shape of the fuel container whereby large area of the surfaces come into contact with the ambient air.

Thus, the circulation of gases inside the container will be fully fixed. Thus, only a portion of the fuel is dried and carbonized since vaporization and heating took place exclusively in the center and in a limited quantity. Also, overpressure is avoided since vaporization keeps within such limits. In this design, the hot damp air rises up to the center of the container and is then diverted to the side's surfaces whereby it is cooled down by the large cold outer walls and by the cool main fuel supply. The outer walls operated as a surface condenser whereby it cools the air and formed moisture, which descends the container's wall. The liberated gas from the moisture are then return to the process.

Contrary to the predetermined circulation of gases and moistures in the monorator, the circulation of gases in a standard gasifier is totally chaotic. Given that its wall is heated directly, the entire fuel container would be simultaneously warmed, resulting in sudden and severe reaction/ vaporization. Thus, the sudden and unpredictable pressure would force the steam away from the reaction zone, which decreased the total quality of the gas. Moreover, a drying process also took place since the outer walls of the fuel container are heated. In the drying process, the hot gases ascend, thereby obstructing the occurrence of the predetermined flow of air as describe above. Without sufficient cooling surface any condensed water will again be heated by the rising hot air/gases or from the conduction by the heated bottom, thus, a major art of it once more is once again vaporized and effective separation of moisture form the gas cannot be achieved. (Teknisk Tidskrift, 1945)

2.1.4 Conclusions

In conclusion, the research found out that regardless if the gasifier is a standard or monorator gasifier, the drier the fuel, the better gas. Also, with the monorator gasifier a slightly better gas was achieved than with the standard gasifier. Moreover the monorator gasifier is able to accept very damp fuel, while the standard gasifier was completely incombustible. Furthermore, blacker gases can be observed from the standard gasifier than the monorator gasifier when damp fuel is in use.

2.2 DRYER: Application of pulse combustion technology in spray drying process

2.2.1 Introduction

The investigation on pulse combustion, heat excited acoustic oscillations and its applications dated back to the 18th century where Higgins observed the so called hydrogen "singing" flames in tubes. During pulse combustion, high heat transfer and oscillatory mixing between the fuel gases and chamber’s walls took place, which minimizes NO_x production when compared to traditional combustion systems.

Nowadays pulse combustors are found in many practical devices such as water and air heaters as well as drying devices where pulse combustors is utilized as a high temperature and high turbulent drying device. However, there are some disadvantages, the pulse combustor is noisy operation and can reach up to 130 dB, equitant to a military jet craft taking off (Zinn, 1992).

There are three main sources of this noise:

1) The intrinsic detonating character of combustion

2) The vibrations of metallic combustor’s wall

3) The difference in velocity flow of gases from the combustor and ambient air.

A number of methods to decrease the noise level have been implemented by Hansen in 1994. Apart from the apparent methods such as decreasing the combustion intensity and acoustic insulation, the most popular methodologies are (Hansen, 1994):

(1) Coupling the two combustors so that they work in counter-phase,

(2) Application of ejectors at the inlet and outlet,

(3) Shielding the space between the outlet, inlet, and ejectors.

2.2.2 Pulse Combustion Drying Application

Pulse combustion in drying process is found in many Industrial applications such as:

(1) Spray drying,

(2) Fluid bed drying,

(3) Flash drying.

Figure 2.11 shows the new type of pulse combustors in the spray drying process with cylindrical rotary valves created by Hosokawa Bepex and Sonodyne Industries Inc., USA.

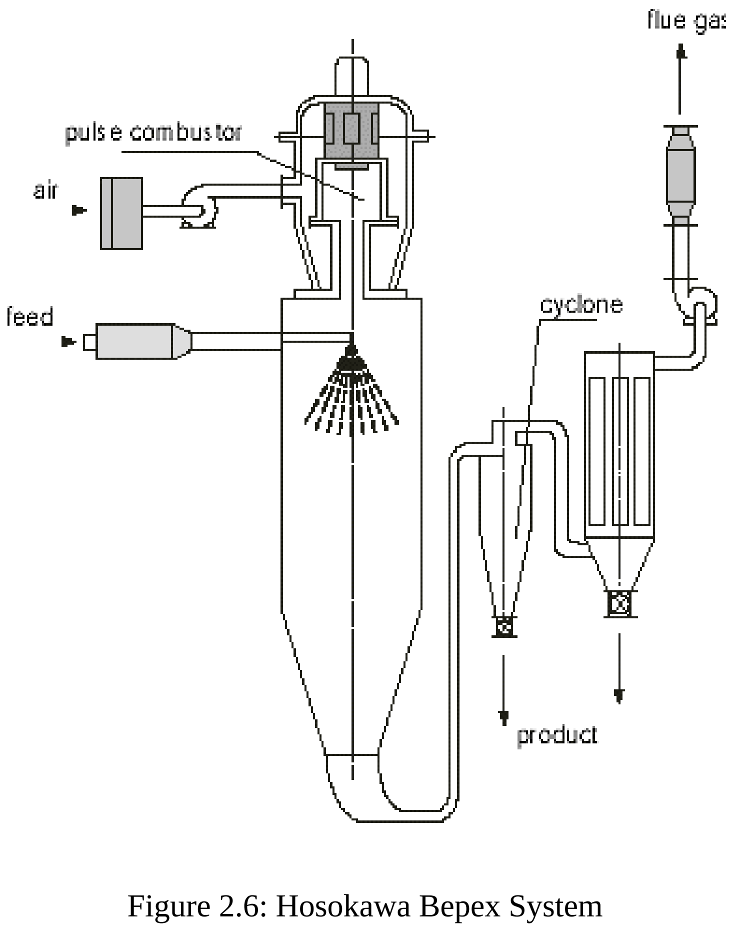


Figure 2.6: Hosokawa Bepex System

Source: Ozer, 1993.

This new type of pulse combustors have been used to dry many chemical and pharmaceutical products, food, and polymers. It also enables and high quality products at low production costs. However, there problems were problems with the feeding system where dried material are deposited on walls near the air inlet (Ozer, 1993).

On the other hand, another spray drying developed by Sonodyne Industries, Inc. (Sonodyne Industries, Inc., 1984) fixed the problem by equipping 2 ton/h of evaporated water in valueless pulse combustor as a source of a drying agent. This pulse combustion drying has the advantages of high energy efficiency by utilizing low air consumption and also allows drying of a wide range of materials.

Today, pulse combustors like the one developed by developed by Sonodyne Industries, Inc. are often used in drying industrial wastes. An example is the Foundation for Industrial Research, The Netherlands, which utilized pulse combustion vibro-fluidized bed dryer called IMPULS which has the capacity to dry 20,000 ton of evaporated water per year. The dryer can be used to dry dangerous wastes (acid wastes, toxic wastes, and urban deposits), biological deposits (spent brewery yeast, sawdust, and sludge) and many more (Kudra and Mujumdar, 1995).

On the other side of the world, Novodyne Ltd, Canada has conducted research to construct a pulse combustion drying system for sawdust and dry wood waste for the wood industry. Figure 2-12 shows the flash dryer, which is equipped with the valved pulse combustor. Since drying of sawdust and dry wood waste are big particles, large energy parameters are required in the drying process (Buchkowski, 1999).

Still, preliminary results showed that:

(1) the device operation is stable and safe,

(2) thermal efficiency is similar to the efficiency of flash dryers,

(3) electrical energy consumption is 40 – 50 % less than for conventional flash dryers,

(4) capital costs are 10 – 15 % less in comparison to classical flash dryers, because of a compact design of the system,

(5) emission of toxic substances is low.

The successful story of the Novodyne flash dryer further stirs the interests of pulse combustion technique in the drying process.

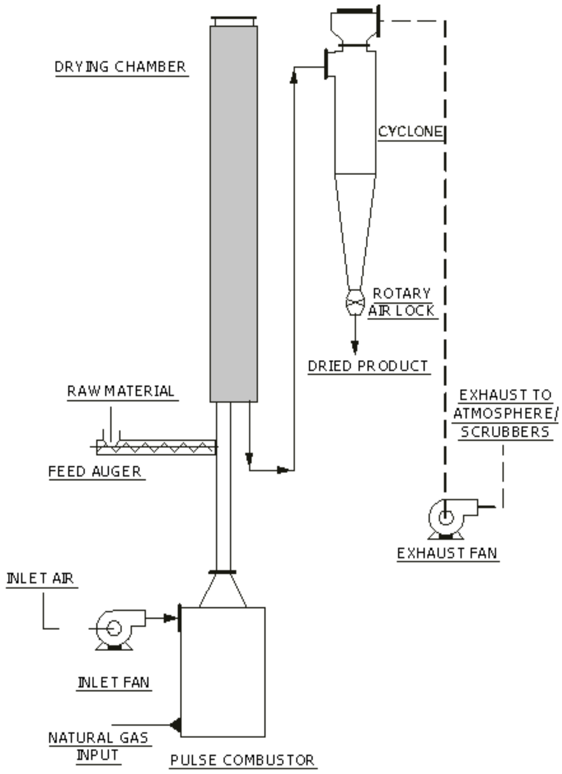


Figure 2.7: Novodyne Ltd flash dryer

Source: Buchkowski, 1999

2.2.3 Pulse Combustion Spray Drying Unit

Thus, through the development of Hosokawa Bepex and Sonodyne Industries Inc., USA and Sonodyne Industries, Inc, the pulse combustion drying system was developed and optimized. For case study, experimental valved pulse combustion drying spray system like Figure 2.13 was set up. The dryer is made of stainless steel with diameter and length of 0.29 and 1.2 meters respectively. In the experiment, raw material is injected into the drying chamber by a pneumatic nozzle. After that, water vapor and dry product are transported into the cyclone chamber and separated from each other. The chamber is also equipped with quartz windows in order to perform Phase Doppler Anemometry (PDA) and Laser Doppler Anemometry (LDA) measurements. This includes an optical probe which traverses 5 points along the length of the drying chamber and 15 points along the diameter.

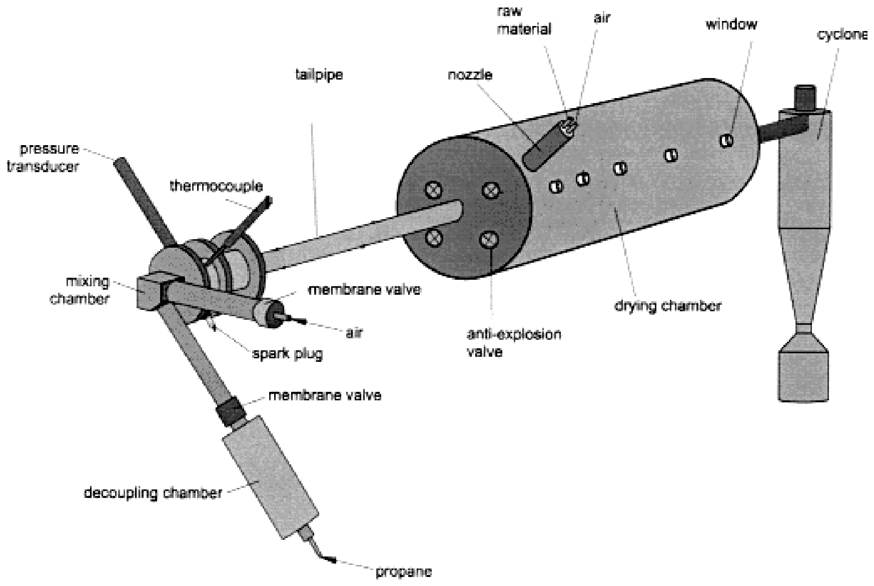


Figure 2.8: Valved Pulse Combustor Drying Installation

Source: Keller et al., 1992

Figure 2.14 shows the result of the measurement which confirms complex nature of the pulsating flow in the drying chamber. The flow is not axis-symmetrical and the oscillations of the axial velocity exceeded a couple of hundred percent of average value which confirms Keller et al. (1992)'s theory.

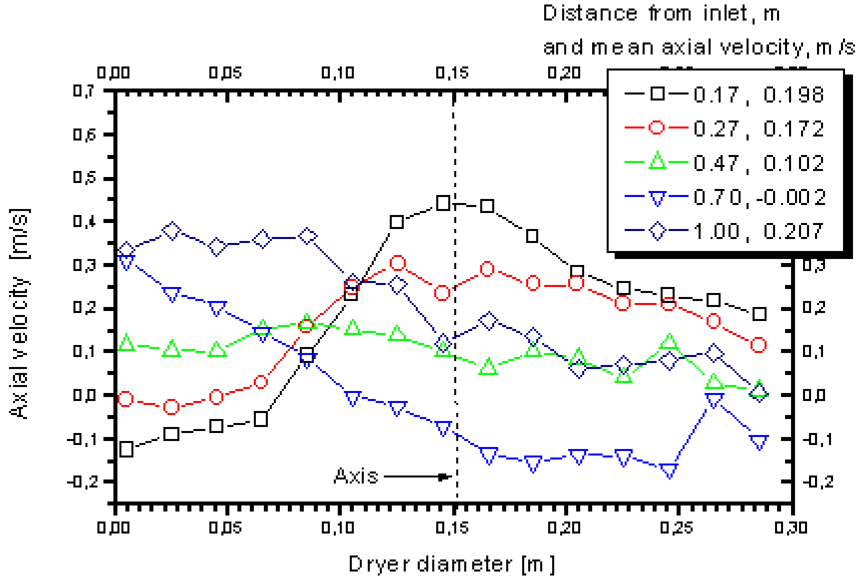


Figure 2.9: Axial velocity as a function of the drying chamber diameter

Source: Keller et al., 1992

2.2.4 Modeling of Evaporation and Drying Process In Time Dependent Pulsating Flow

Mathematical modeling by Celik et al., 1993, Akulicz et al., 1998, Zbiciński et al., 1999 was utilized in the calculation of pulse combustion process. Also, Computational Fluid Dynamics (CFD) technique was used to calculate the time dependent flow in the chamber.

Modeled geometry of this system is presented in Figure 2-16.

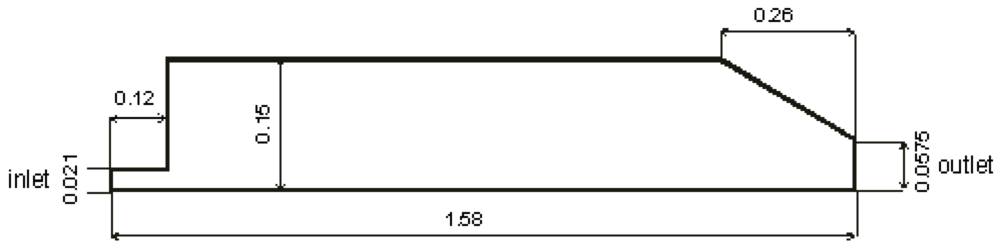


Figure 2.10: Scheme of modeled geometry

Source: Zbiciński et al., 1999

2.2.5 Conclusions

In summary, the research paper in pulse combustion technology reveals that pulse combustion drying seems to be an effective and competitive way of dehydration. The experiment show analogies in spray and pulse combustion spray drying process in terms of stream lines, velocity and temperature distributions of continuous and dispersed phase. Computational Fluid Dynamics (CFD) calculations of steady and transient multiphase flow generated by pulse combustor in the drying chamber were performed and the flow produced by a pulse combustor a rapid equalization of property distributions in the drying chamber is observed.

2.3 WASTE HEAT RECOVERY SYSTEM

2.3.1 Case Study Wood Waste Gasification & Thermal Oxidation, Project Location Little Falls, Minnesota

In the case of Wood Waste Gasification in Little Falls, Minnesota, wood waste is utilized to fuel a thermal oxidize design gasifier which has a feed rate of two hundred eighty-eight tons per day. In this particular system the thermal oxidizer exhaust is utilized to provide 35 million Btu's per hour of thermal energy for drying duty. Also, super-heated steam from the gasifier is sent to backpressure turbine to produce approximately one megawatt of electricity. Moreover, the spent distillers' syrup and grains, DDGS, from the ethanol manufacturing are normally dried and sold as animal's food. However, the DDGS contains volatile organic compounds which must be destroyed in order to comply with the air quality regulations.

There are three typical methods to destroy these organic compounds: direct thermal oxidation, regenerative or recuperative thermal oxidation. However, each of these three methods has the same drawbacks; the exhaust from the DDGS dryer will plate on to the heat recovery surfaces of recuperative thermal oxidizers, rendering heat recovery system mute.

The solution, however, comes from the combination of solids gasification and thermal oxidation. This solution is depicted in figure 2.17 where gasification technology is applied to the system in order to supply the auxiliary fuel for thermal oxidation eliminates the need for fossil fuel, thus, stabilizing the energy costs.

As seen below, the core of the process is atmospheric updraft gasifier. It will convert biomass materials such as waste wood into a hot, combustible synthesis gas, which consists primarily of hydrogen and carbon monoxide. The byproduct is the directed hot synthesis gas leaving the gasifier to the green thermal oxidizer where it is combusted in order to thermally convert the volatile organic compounds within the dryer exhaust into water and carbon dioxide. Gas leaving the thermal oxidizer is then split into DDGS dryer and heat recovery system generator.

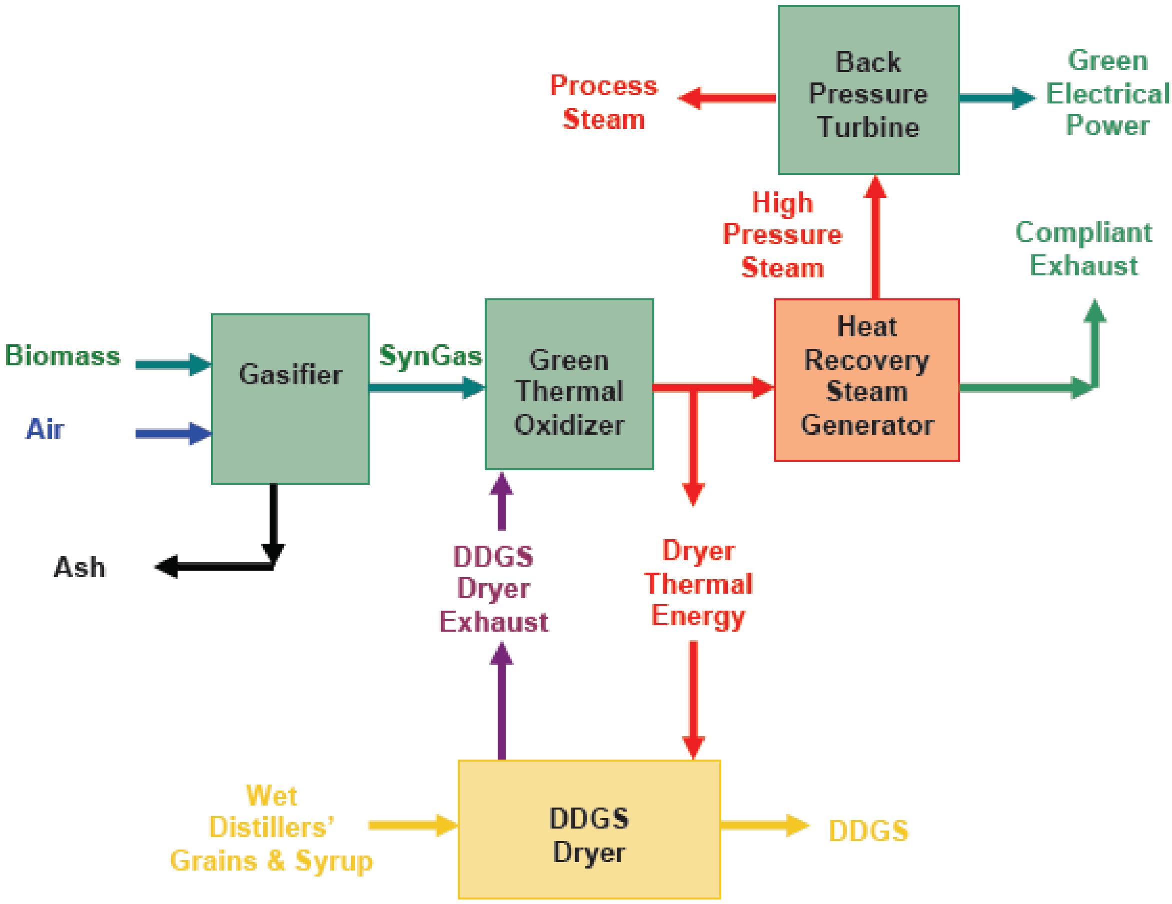


Figure 2.11: The Little Falls Project Diagram

Source: Primenergy L.C.C., 2006

In short, the combination of thermal oxidation and biomass gasification provides not only a unique solution for environmental aids, but also displaces the requirement for fossil fueled ethanol plant. Moreover, this process ensures an extremely clean exhaust which is fully and efficiently utilized by the system through its back pressure turbine.

2.3.2 Gasification: An Alternative Process for Energy Recovery and Disposal of Municipal Solid Wastes

Currently, cities around the world are facing the problem of large quantities of municipal solid waste (MSW). Landfills are the main destination of waste disposal, accounting for 60% of the total waste. These landfills have major environmental impacts, thus cleaner and are environmentally friendly method needs to be implemented. One such alternative is known as waste to energy (WTE); it not only reduces the amount of waste sent to landfills but also reduces the amount of fossil fuels needed to generate electricity. There are two commercially viable methods of WTE, gasification and combustion. In today's industry, gasification is in maturing phase while wastes combustion is a familiar technique. This paper will access the possibility of Municipal Solid Waste's gasification is ZEWTE process (zero emission waste to energy) as an alternative to today's typical industrial combustion process.

In US, 33 million tons of MSW are combusted per year; this takes approximately of 1,600 million gallons of oil. Moreover, through the combustion process, furans/dioxins are created in exhausts which are harmful to the environment. Over the past 10 years, progress has been made in effective capturing techniques to reduce these gases from 4 kg per year to 0.4 kg per year.

On the other hand, gasification is a thermo chemical process which converts liquid and/or solid hydrocarbons into low or medium gas. Today, there are 100 waste gasification facilities worldwide. A typical gasification process has quite a few advantages over conventional MSW combustion process; its process takes place in a low-oxygenated environment thereby limiting the development of toxins such as NO_x and SO_x. As a result, the volume of exhaust that needs to be clean is low. Moreover, according to chemical thermodynamics $\Delta G = -RT\ln(P1/P0)$, the lower volume of exhaust gas equates to higher pressure of contaminants which enables a better contaminants absorption and capture. Lastly, the byproduct of gasification is syngas which can be converted to electricity.

Two gasification plants studied in this paper are the design by TPS Termiska and Battelle-Columbus Laboratories. The TPS Termiska uses partial combustion with air at atmospheric pressure in a bubbling fluidized bed, followed by a circulating fluidized bed vessel containing dolomite that catalytically “cracks” the tars.

The Battelle-Columbus Laboratories, on the other hand, is a pressure gasifier that utilized indirectly heating to produce medium gas (Figure 2.18) by avoiding nitrogen in the fuel stream. This particular gasifier was designed so that the advantage of biomass’s low sulfur, ash, and high reactivity composition could be effectively exploited. Also the byproduct, medium gas, leaves the gasifier with only a low degree of char. In the process, the sand is recaptured, recycled, and then transported to the gasification vessel whereby the fluidized bed combusted the char to generate steam, reheat the sand, and dry any biomass feed. Lastly, the resulting fuel gas has a heating value of 13-18 mJ/m^3 and is free of nitrogen because heat is supplied externally from the sand circulating between the char combustor and the gasification vessel during the endothermic gasification process.

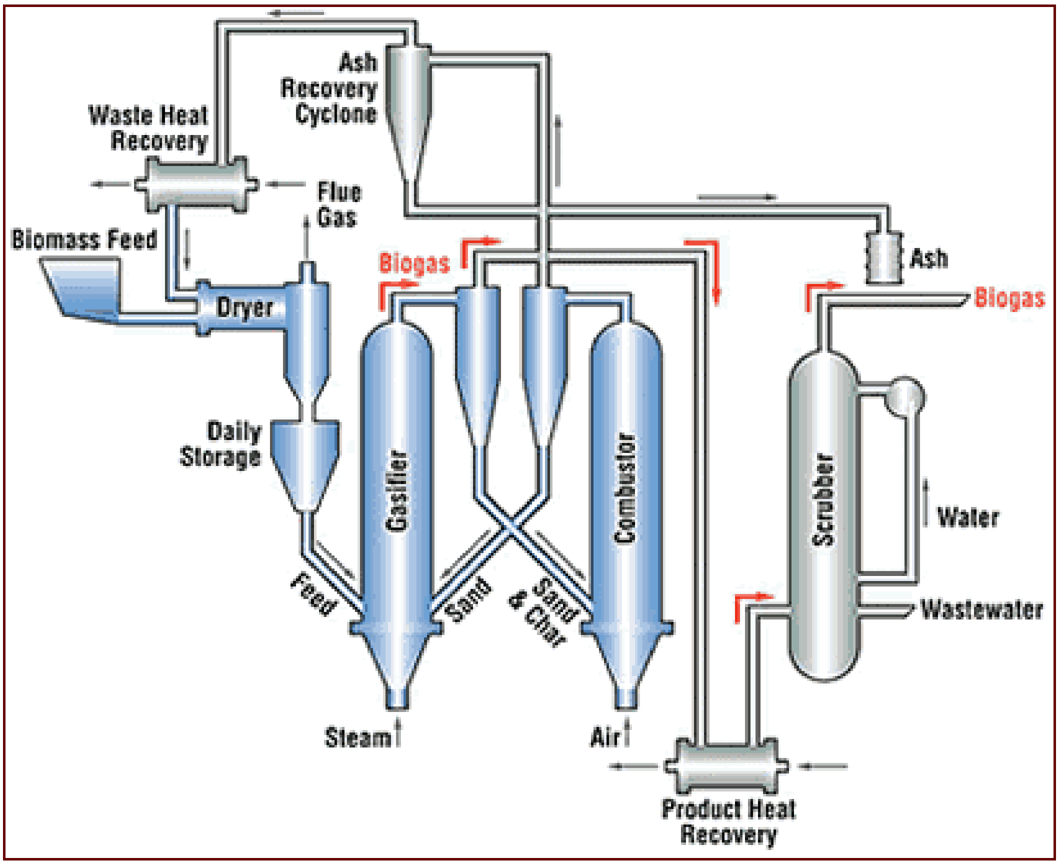


Figure 2.12: Battelle Indirectly-Heated Low Pressure Gasifier

Source: http://www.eren.doe.gov/biopower/projects/ia_tech_gas4.htm

Both processes at the plant site are zero emission waste to energy process (ZEWTE), which have zero atmospheric emissions. Thus, the paper finished by concluding that waste gasification process is a feasible and cost-competitive solution to the traditional combustion method. Still, large scale gasification plants' operation needs to be demonstrated before it is considered a viable solution to global waste disposal problems.

CHAPTER 3

PROJECT WORK PROCEDURES

3.1 SELECTING THE PROCESS OF IMPROVEMENT

After literature review, it's shown that there are many ways to improve the thermal efficiency such as reduction of length along process, insulated gasifier, useful dryer, etc.

Because of the time limit and the actual existing gasifier at Samutsakhon powerplant, which could not be modify since it has already been setup (already brought) and already in used; the dryer is the properly case to improve the thermal efficiency or in other word enhance the efficiency of the existing gasifier.

3.2 INFORMATION OF DRYER

Dryer is a machine used in a mass transfer process whereby water moisture is removed through evaporation. To achieve this, a source of heat and an agent/ solvent is needed. This process is commonly used in food manufacturing or pharmaceutical industry, where the most commonly used solvent is water.

In the most dying case, convection is applied to a gas stream which transports the water vapor away as humidity. Other drying case involves vacuum drying, which utilized conduction techniques such as microwave and/or radiation. Another indirect dying process is the drummed process whereby heated surface is used to synthesize the vapors which are drawn away by aspirators.

Freeze drying/ lyophilization is another special form of drying methodology which the solvent is first frozen and later warmed in a vacuum so that the ice sublimes. Typically, Freeze drying process is often done in high vacuum chamber thereby allowing the drying to take place at reasonable rate. Thus, it avoids the disintegration of the product's structure, resulting in low density and highly porous solid. In biological or foods industry, freeze drying is considered as the best method of preserving the initial properties of the product. The process of removing the moisture also has less effect on the food’s taste than a typical dehydration process. Moreover, the freeze drying rehydrate quickly and easily because of its retention of porous structure. The first users of freeze drying in the industry are to produce dehydrated vaccines for creating dehydrated blood which is utilized for the war’s wounded/ casualties. The dehydrated vaccines keep the Vitamins and protein quality intact.

Types of dryer

Dryers are made in these general types, the type determined by the method used in transferring heat to the material being dried.

The majority types of dryers use indirectly heating through external heat transfer jacket or internal exchanger coil. The advantage of these types of external heating allows the utilization of ater or oil to precisely control temperatures inside the dryer. They can also be divided into further classification as below (Arun S. Mujumdar, 2000):

Direct dryers - is the most common type utilized by 85% of the industry. However, it has relatively low thermal efficiency due to the difficulty in recovering the latent heat from the vaporization that is contained in the exhaust. The direct-heated type may have the flame from combustion impinging on the material being dried, or the gases of combustion may be mixed with additional air so that the mixture in contact with the material is reduced in temperature.

Indirect dryers – also known as heat types dryers, the gases of combustion pass through spaces surrounding, or in the drying chamber, without coming into contact with the material i.e. heat is usually transported using steam, hot gas, and thermal fluids as heat transfer medium. Normally, heat transfer surfaces have temperature around -40º C (as in freeze drying) to about 300º C.

3.2.1 Rotary Dryers

In the rotary dryer, its construction consists of large, rotating cylindrical tube which is supported by steel beams. Its dryer's slope inclines slightly in order for it to convey the material through the dryer using gravity. The materials are showered in a hot stream of air with temperatures up to 600°C while it travels through the dryer.

Advantages
• Ideally suited for large capacity applications and uneven particle size distribution
• Continuous operation and versatile application
• Low operating & maintenance cost

Direct Rotary Dryers

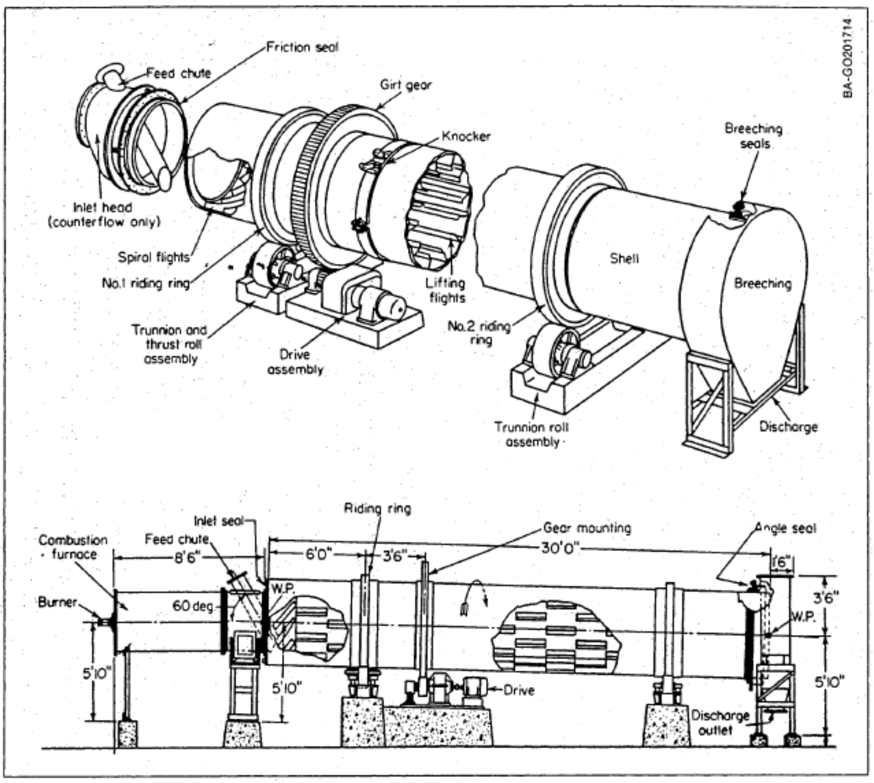


Fig. 3-7. Direct-heat rotary dryer (Source: Perry 1973, Figs. 20-35, 20-36)

Figure 3.1: Direct Rotary Dryers

Source: Möjj Engineering System LTD., 2005.

Direct Rotary Dryer composed of inclined rotating shell in which a hot stream of air flows. The wet material in the rotary shell is carried by spiral configuration while being showered in hot flowing air. Usually the diameter and length and dryer is customized in accordance to the characteristics of the product. Also the hot air can be co-current or counter current depending on the properties of the product. Typically the rotating shell is designed to create uniform distribution for the material across its surface area. Lastly, its surface is sealed to reduce air/heat leakage in order to decrease thermal energy loss.

Indirect Rotary Dryers

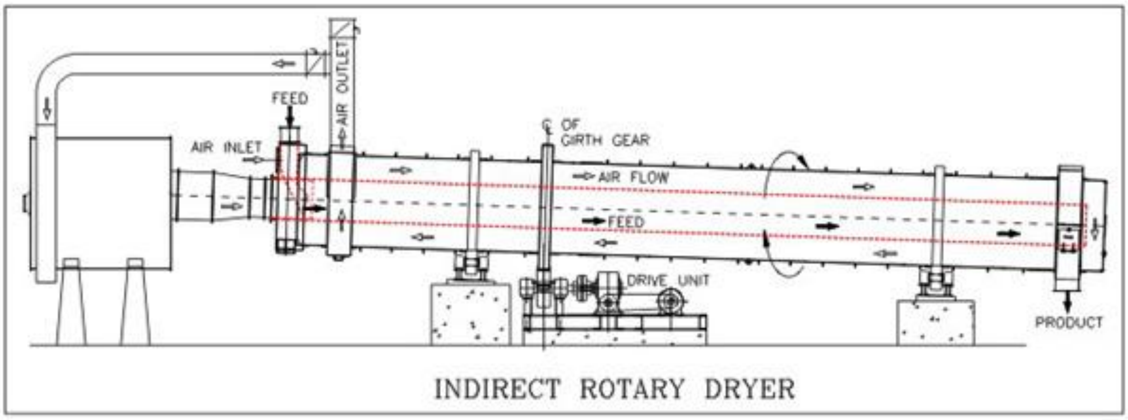


Figure 3.2**:** Indirect Rotary Dryers

Source: Möjj Engineering System LTD., 2005.

Indirect Rotary Dryers are also made of rotating shells with concentric inner shell. The material is rotated in the inner coil without coming into contact with the outer shell which has radiation/ conduction properties. This allows rapid heat exchange resulting in significant evaporation if the of the material. The rapidity of the evaporation enables the drying of materials with different heat sensitivities without thermally degrading them.

3.2.1 Spray Dryers

Spray drying is a rapidly drying process of liquid to powder using hot gas. Heat and cleaned air is transported in to the column exhaust using suction fan. The liquid is sprayed into the column into very small drop to create rapid evaporation. his method is the also preferred by the industry for thermal sensitive liquids such pharmaceuticals.

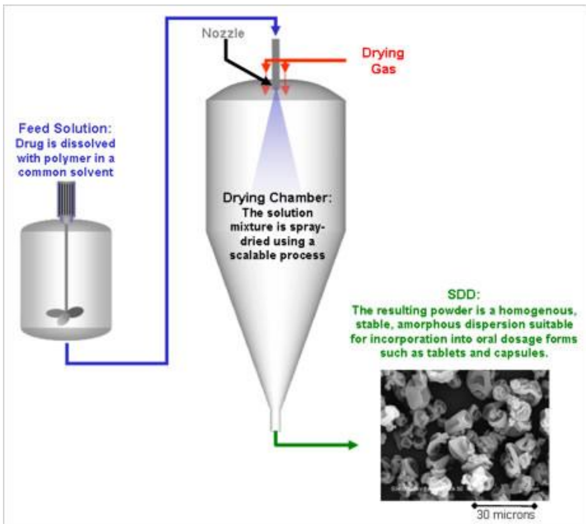


Figure 3.3: Spray Dryer

Source: GEA Niro, 2011.

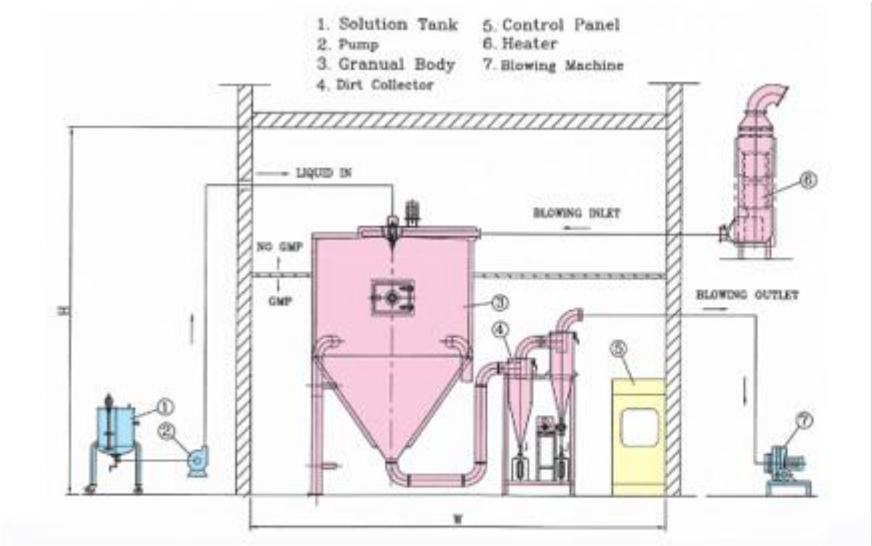


Figure 3.4: Flow Chart of Spray Dryer

Source: ALMIL, 2011.

Capacity : The spray dryers having water evaporation capacity ranging from 1kg/hr to 18,000kg/hr.
Operating temperatures : The spray dryers having operating temperatures up to 1100°C.
Typical applications of spray dryer are Dyestuffs, pigments, starch, detergents, milk powder, fruits, pharmaceutical, herbal extracts, food flavors, ceramics, china clay, enzymes etc.

3.2.1 Continuous Fluid Bed Dryers

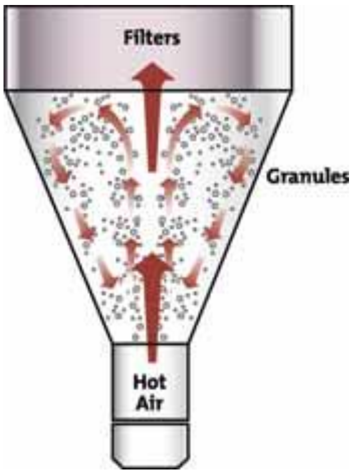


Figure 3.5**:** Continuous Fluid Bed Dryers

Source: Mukesh Gohel, Rajesh Parikh, 2007.

The Continuous Fluid Bed Dryers process has air flowing through the bed which has special perforated distributor plate. The air is browned at a very high velocity in order for the particles to be supported in a fluidized state within the distributor plate. This allows intense particle movement which promotes Bubbles formation and collapsation of the fluidized material.

Advanced method of drying wet/semi wet solids
• Unlike in Tray Drying every solid particle is floating in the HOT STREAM of Air which is blown from down to up creating material layer in fluidized state
• Almost every wet particle directly receives the heat energy from hot Air resulting in uniform and quick drying
• Features of Continuous Fluid Bed Dryers:
• Very versatile process equipment for uniform and efficient drying of products.
• Fully automatic operation based on PLC control / without PLC control
• Minimum handling and more hygienic
• Lifting & tilting device of product container for easy handling
• Option - steam heated or electric heated blower
• Applications :Chemical / Fertilizer / Food - salt, sugar / Mineral - Sand, Aluminum / Ore calcining / Metal oxidation / Sludge Incineration / Pyrolysis of Plastic Waste / Pigment etc.
• Capacity available from 5 kg/hr to 2000 kg/hr water/solvent evaporation.

3.2.1 Tray dryers

The tray dryers are made up of containing trays which are connected to heated gas/air. The air temperature is usually around 50 and 70°C. In the tray dryers, the air flows from the bottom of the chamber as it rises through the trays containing the material it dries the material. To further increase practically, the trays are designed to force the air to flow in a zigzag route in order to increase the period of contractility with the air as shown in in Figure 3.6.

Figure 3.6: Basic parts in a Practical Tray dryer

Source: Barrie Axtell, 2002.

For tray dryers, there are 3 basic types: the batch, semi-continuous and cross flow dryers.

Batch cabinets are a simple large wooden chamber with internal pipes that support the trays. Thus they are the cheapest and simplest to create. The air is blown from the bottom of the chamber through the trays until the materials are dried. Thus, the bottom most trays dried first and the top most trays is the last.

The advantages and disadvantages of Batch cabinets are:
• Simple, low cost chamber
• Low labor costs - simply load and then unload
• A tendency to over-dry the lower trays
• Low efficiency, in terms of fuel consumption, in the later stages of drying when most of the trays are dry

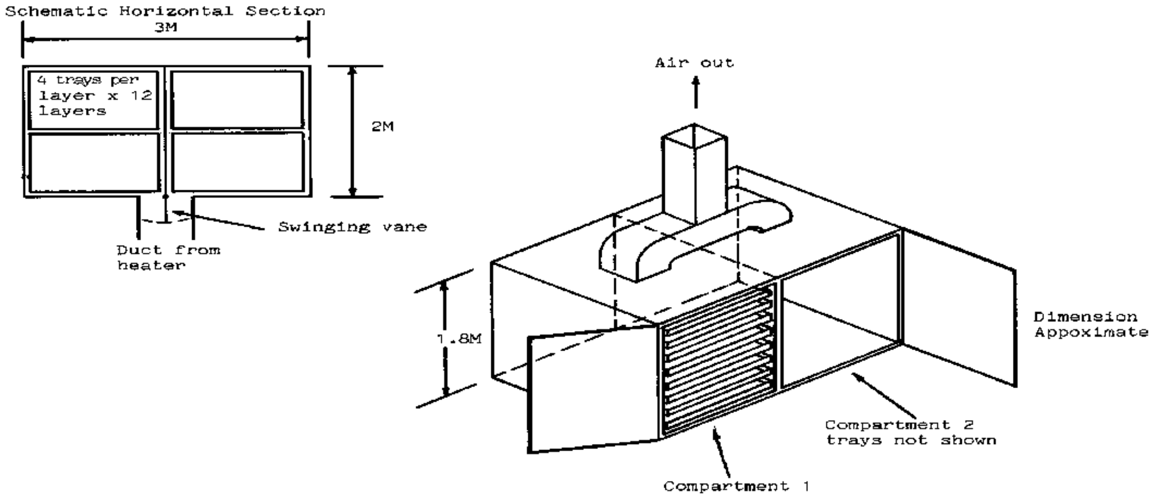


Figure 3.7: A typical double chamber batch dryer

Source: Barrie Axtell, 2002.

Semi-continuous cabinets are invented by Practical Action to improved the disadvantages of the batch cabinet. It has a lift which allows the bottom tray to be removed as soon as the material is dried. Also it allows a fresh tray to be input at the top of the cabinets.

The advantages/disadvantages of this system are:
• Over-drying is avoided
• Product quality is higher
• Fuel efficiency is considerably increased
• A higher daily throughput is possible
• The cabinet is however more expensive to construct
• labor costs are higher due to loading and unloading trays at regular intervals
• In order to maximize output 24 hour working is recommended

Typical semi-continuous dryers are shown in Figure 3, which shows the lifting mechanism and the gap above the lowest tray that is ready for removal.

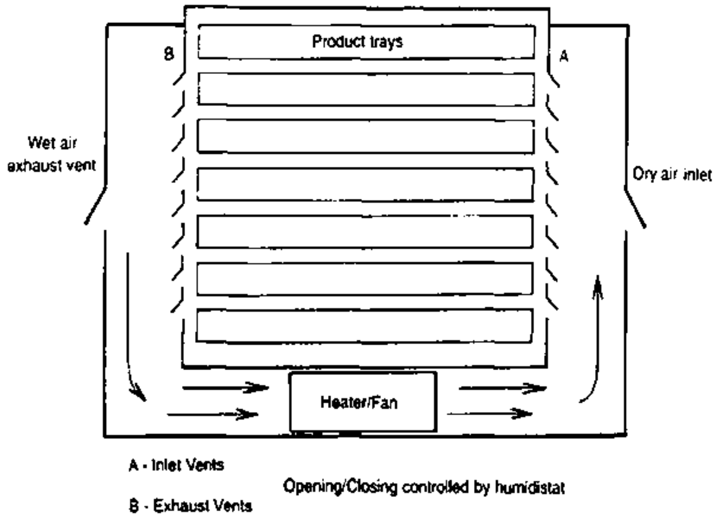


Figure 3.8: Schematic diagram of a cross flow cabinet

Source: Barrie Axtell, 2002.

The last type is the cross flow chambers in which the hot air is blown, through a series of louvers, which circulated the air all over the heater. Thus, this cross flow chambers triumph over the batch and semi-continuous cabinets. It advantages are as followed:

- Labor costs are low as it works like a batch dryer
- All the trays dry at the same rate
- Fuel efficiency is maximized.

However, it is much more complex and requires automatic humidity sensors to control the percentage of air vented during each air blown cycle.

3.3 Selection of Dryer

Today, there is hundreds of drying machine designs. The types, detailed design, and size of a dryer selected for a specific dryer design must take into consideration the material to be handled, available sources of fuel or heat and of power, space occupied, operating labor required, costs of erection and maintenance, and most importantly, whether the type and size selected will give the desired production at the lowest cost. This cost composes of thermal efficiency, materials used in construction, interest and depreciation on erected cost, and cost of maintenance.

3.3.1: Selection Criteria (see Appendix A7)

The Criteria that help consideration consist of material to be handled, dimension of material, size of material, space occupied, construction cost, operating cost, maintenance cost, feed rate, source of heat and quality of dried product. All of the criteria are divided into weight percentage, which is utilized to find a suitable type of desired dryer for the power plant. Higher percentage means higher importance within the consideration criteria. (Criteria come from discussion with the power plant owner, their engineering team and worker including not only the design aspect, but also the financial, safety of work employee, durable, space etc.)

- Material to be handled (25%): In order to select the type of dryer, the most important that must take into consideration is the Material to be handled, which is fed into dryer. This criterion is the most important because it compel dryer, whether the operation can operate or not. The physical properties such as shape, rigidity and weight. The chemical property such as liquid, rigid, viscosity and melting point. High suitable material to dry operation means high score.

- Dimensional of material (15%): Size of material is also important for dryer type some design can run with big size such like granular, and some can run with very small size such like powder. High suitable dimension to dry operation means high score.

- Space occupied (15%): Due to the limited space from the plant, the space occupied is established. High score means smaller space occupied from dryer

- Feed rate (10%): The difference of feed type should be considered, which are continuous feed and discontinuous feed (which is called batch) .For capacity to operate, each dryer type can carry different of capacity at the given time. High suitable feed rate to dry operation means high score.

- Operating cost (10%): Due to the feed motor and blower, operating cost is produced. Low operating cost means high score.

- Maintenance cost (5%): Due to blower lubrication and life time, maintenance cost is produced. Low maintenance cost means high score.

- Construction cost (5%): Differences between dryer types are from the size and complexity of operation. Low construction cost means high score.

- Quality of dried product (5%): The product should not be melted along the dry operation, otherwise the material could stick or block up the pipe that may increase the maintenance cost. High quality product means high score.

- Source of heat (5%): The input heat to blower should be considered. Whether the heat is enough for dry operation. High input heat means high score.

		Score			
Criteria	**Criteria weight**	**Spray dryer**	**Tray Dryer**	**Rotary dryer**	**Continuous Fluid bed dryer**
Material to be handled	25	2	8	8	10
Dimensional of waste	15	5	8	10	9
Space occupied	15	10	6	5	10
Feed rate	10	5	5	10	10
Operating cost	10	5	10	8	8
Maintenance	5	5	8	6	7
Construction	5	5	10	7	7
Quality of dried product	5	3	10	10	10
Source of heat	5	10	10	10	10
Weighted		490	750	770	885

Table 3.1: Dryer Decision Matrix

3.3.3 Conclusion of selection

Material to be handled: According to feed of material to dryer is solid property, with light weight and slice shape. Thus, rotary dryer, continuous fluid bed dryer and tray dryer can handle this kind of material. Note that continuous fluid bed dryer is the most suitable because it's normally handle on light weight material, which MSW is also light weight. Spray dryer is not preferable because, normally spray dryer is normally used to handle liquid material and powder.

Dimensional of material: The capability of drying which respective large-to-small size of material are Rotary dryer, Continuous fluid bed dryer and Tray dryer. The MSW is 10 mm, so the mentioned dryers can operate with this MSW. Because spray dryer can operate only for very small size of material such as powder, so it's not practical to use this dryer type.

Space occupied: Because of Spray dryer and Continuous fluid bed dryer required less space than the other dryers.

Feed rate: According to type of feed through gasifier is the continuous feed, so rotary dryer and Continuous fluid bed dryer are the most suitable to this feed type. But Tray dryer is conventional used for discontinuous feed (batch). Due to the low capacity of feed if compare to another types, it is not quite practical.

Operating cost: Due to equipment of drying system, Tray dryer provides the lowest operating cost. For spray dryer, it has higher operating cost because it contains high pressure equipments.

Maintenance: Normally maintenance cost of dryers, respectively from low-to-high, are as follow Tray dryer, Continuous fluid bed dryer, Rotary dryer and Spay dryer.

Construction cost: According to Tray dryer is the most simply design, so the construction cost is reduced. For spray dryer, it's the most complex design.

Quality of dried product: For Rotary dryer, continuous fluid bed dryer and Tray dryer produce same property of product, which is not melted. So it's more suitable for use. But the spray dryer can melt the material during operation, thus it is it's not suitable to use.

Source of heat: Source of heat is hot gas that can be suitably used in all type of dryer.

According to the suitable of score that given to each type of dyer, we can conclude that the most suitable type of dryer is continuous fluid bed dryer. Continuous fluid bed dryer is close to the criteria. By the way, Rotary dryer and tray dryer come later. But the Spray dryer is not practical for the criteria.

CHAPTER 4

CALCULATION AND SOLUTION

This chapter is divided into two main parts, i.e. technical or design part and financial part.

4.1 Technical calculation (Design of drying system)

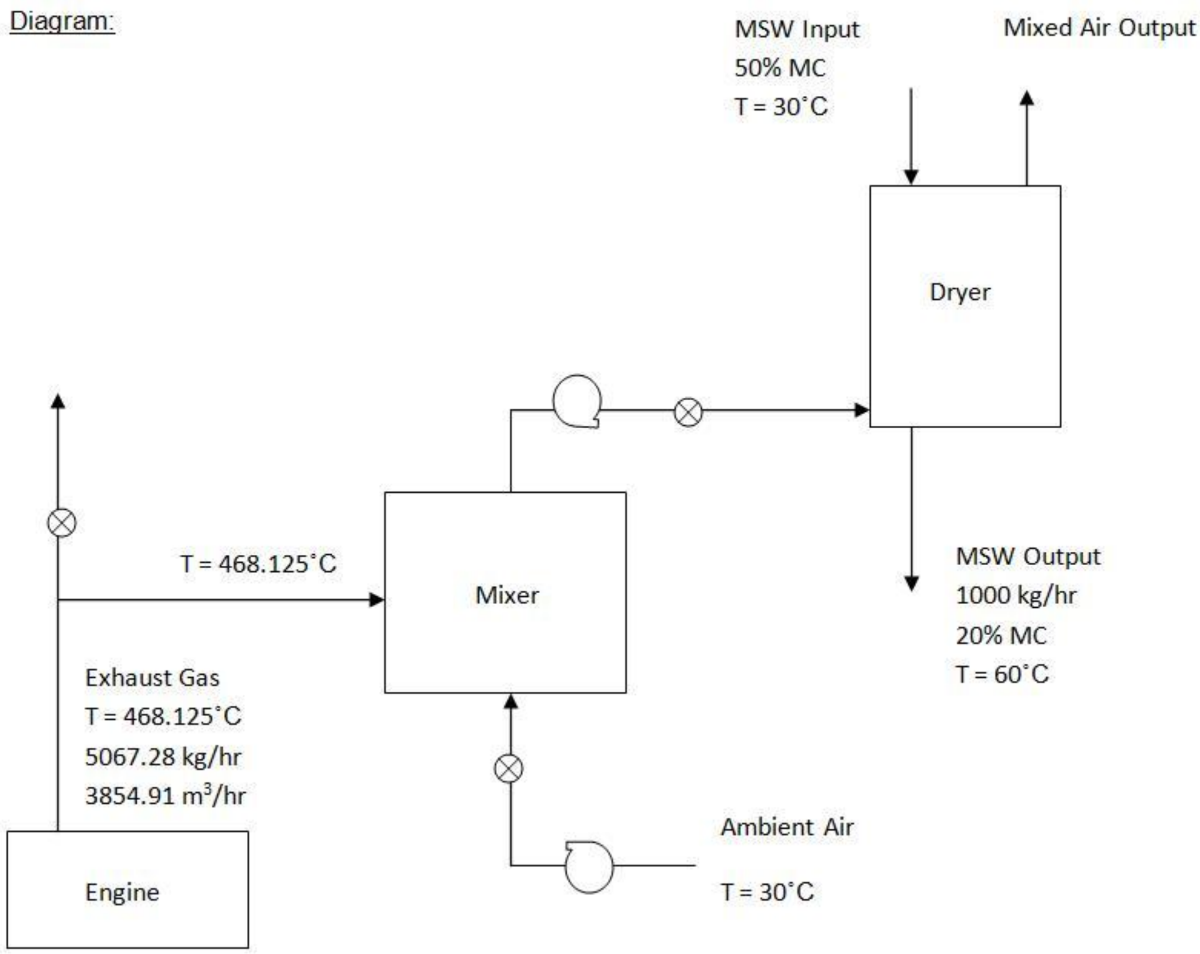


Figure 4.1: A diagram shows the drying system, i.e. a mixer and a dryer

<u>Requirements:</u>	1. MSW output (from dryer) is 1000 kg/hr 20% MC	
	2. MSW output (from dryer) is 60˚C	
	3. Since we are designing the dryer system on the pre-existing power plant, the space available for setting up the dryer and the type and size of material available in the market available is another constrain.	

The temperature of dried MSW (60˚C) which is processed through the dryer has been discussed among power plant operators.

The suitable temperature is preferred around 60˚C. The reasons are;

1. Safety concerns

    - Very less opportunity to self-ignite.

    - Not harmful to human skin.

2. Equipment concerns

    - Handling equipment can be used of conventional type which is less cost.

3. Technical concerns

    - The fuel feed rate is considerably quite slow, so fed MSW is consequentially heated up to the desired higher temperature before stepping in fire bed.

<u>Information:</u>	<u>MSW</u>	1. MSW input (to dryer) is 50% MC (see Appendix A3)
		2. MSW input (to dryer) is 30˚C (ambient)
	<u>Hot flue gas</u>	1. Hot gas (exhaust from engine) is 468.125˚C
		2. Hot gas (exhaust from engine) is 5067.28kg/hr (see Appendix A4)
	<u>Air</u>	1. Ambient air (into the mixer) is 30˚C

The calculation can be divided into seven steps,

Steps: Step: 1 At the dryer: - Find total amount of needed heat into the dryer

Step: 2 At the mixer: - Find mass flow rate of hot flue gas

Step: 3 At the dryer: - Find the velocity of mixed air into the dryer

Step: 4 At the dryer: - Find size of the dryer

Step: 5 At the mixer: - Find mass flow rate of ambient air

Step: 6 At the dryer: - Find temperature out of the mixer

Step: 7 At the dryer: - Find LTU and NTU for the dryer

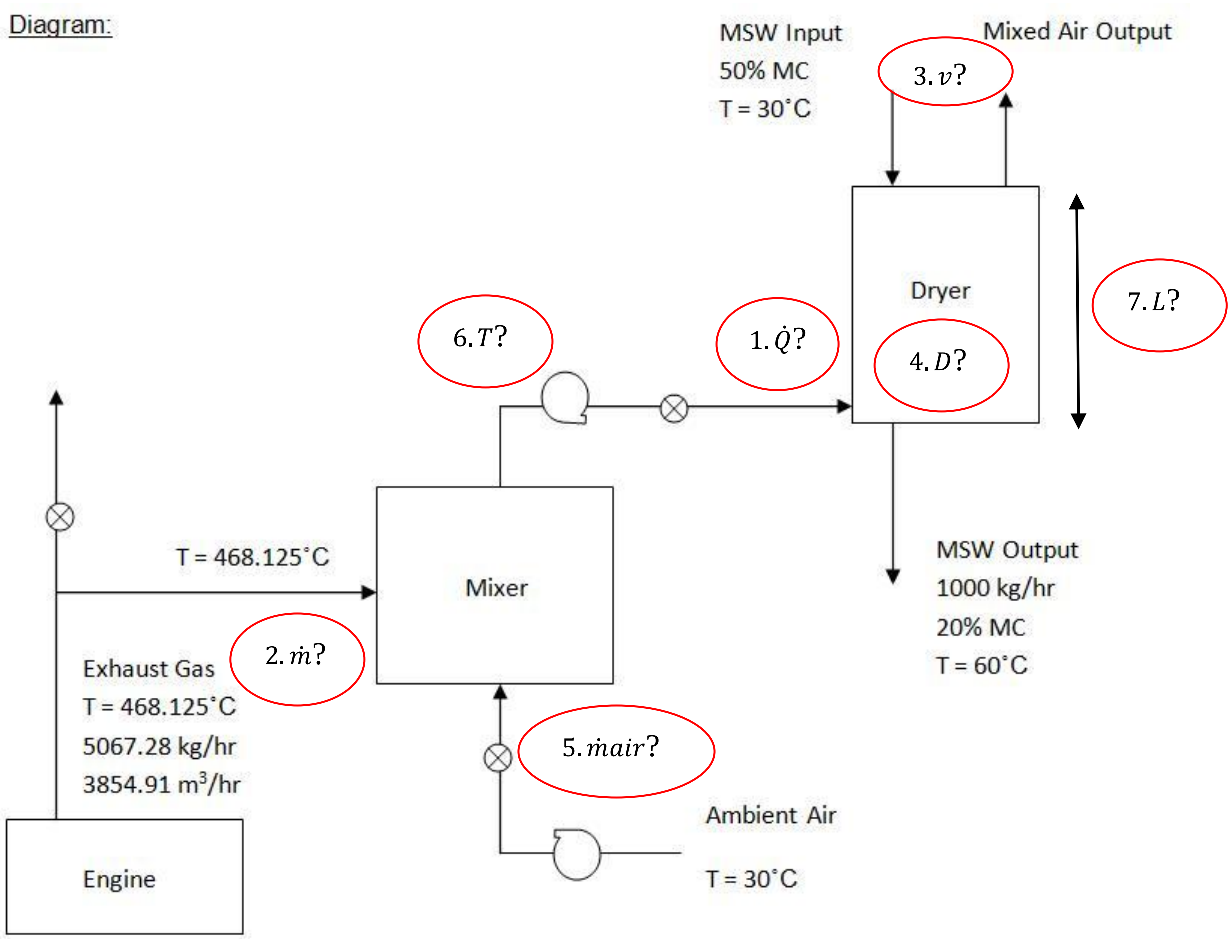


Figure 4.2: A diagram shows the drying system with finding values

Step 1: At the dryer: - Find total amount of needed heat into the dryer

Data for calculation:

From amount of moisture: Dry basis (DB)

$W = w/ (1-w)$

W = moisture kg/kg dry stock

w = moisture kg/kg wet stock

The amount of moisture of MSW with 50% Moisture Content (MC) is

$W = 0.5(1-0.5) = 1$ kg/kg dry stock

The amount of moisture of MSW with 20% Moisture Content (MC) is

$W = 0.2(1-0.2) = 0.25$ kg/kg dry stock

Required MSW output product after being dry 1000kg/hr, 20% MC is 800 kg/hr DB (Dry Basis)

Apparent density of MSW is 300 kg/m^3 (see Appendix A3)

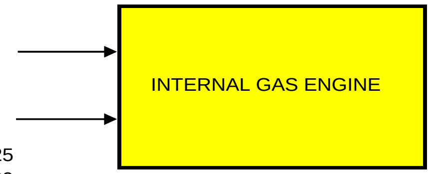
Hot capacity of dry basis 0.3 kcal/kg dry stock

Figure 4.2 shows the information of internal gas engine used in the power plant. The exhaust gas composition, temperature and mass flow rate, were then used in the calculation.

SYNTHETIC GAS FIRING IN INTERNAL GAS ENGINE

Synthetic gas at 40 C	
CO2 (kmol/hr)	4.565
CO (kmol/hr)	22.88
H2 (kmol/hr)	17.97
CH4 (kmol/hr)	2.1
N2 (kmol/hr)	27.48
SO2 (kmol/hr)	0.0033
HCl (kmol/hr)	0.0052

Air at 30 C (0% excess)	
O2 (kmol/hr)	24.625
N2 (kmol/hr)	92.6369
H2O (kmol/hr)	0.253638
Total	117.5155



Flue gas output
Material balance:

CO2 (kmol/hr)	29.545
H2O (kmol/hr)	22.42364
N2 (kmol/hr)	120.1169
O2 (kmol/hr)	0
SO2 (kmol/hr)	0.0033
HCl (kmol/hr)	0.0052

Energy balance:
INPUT:

GAS	Nm3/hr	Cp	Temp diff.	kcal/hr
CO2	102.256	0.334	10	341.535
CO	512.512	0.516	10	2644.562
H2	402.528	0.316	10	1271.988
CH4	47.04	0.6	10	282.24
N2	615.552	0.405	10	2492.986
SO2	0.07392	0.5783	10	0.427479
HCl	0.11648	0.3388	10	0.394634
	1680.078			
AIR				
O2	551.6	0.3115	0	0
N2	2075.067	0.405	0	0
H2O	5.68148	0.404	0	0
TOTAL				7034.133

REACTION OCCURRED:
HEAT RELEASED:

CO + 1/2 O2 --> CO2	(283000 kJ/kmol)
H2 + 1/2O2 --> H2O	(242000 kJ/kmol)
CH4 + 2O2 --> CO2 + 2 H2O	(803000 kJ/kmol)

12510080 kJ/hr
2989981 kcal/hr

TOTAL 2997015 kcal/hr

OUTPUT:
OUTPUT OF ENERGY TO ENGINE = 344168.3 kcal/hr
OUTPUT OF FLUE GAS: 2652847 kcal/hr

	Nm3/hr	Cp	Temp. diff	kcal/hr
CO2	661.808	0.334	1752.5	387379.4
H2O	502.2895	0.404	1752.5	355626
N2	2690.619	0.405	1752.5	1909700
O2	0	0.3115	1752.5	0
SO2	0.07392	0.5783	1752.5	74.91576
HCl	0.11648	0.3388	1752.5	69.15965
				2652850

TEMP FLUE GAS OUTPUT = 1782.5 C
(without cooling by cooling water)

TEMP FLUE GAS OUTPUT AFTER COOLING WITH WATER AND LUBRICATION 468.125 C Based on 25% efficiency and constant Cp

	Nm3/hr	Cp	Temp. diff	kcal/hr	kg/hr
CO2	661.808	0.334	438.125	96844.85	1299.98
H2O	502.2895	0.404	438.125	88906.49	403.6255
N2	2690.619	0.405	438.125	477425.1	3363.273
O2	0	0.3115	438.125	0	0
SO2	0.07392	0.5783	438.125	18.72894	0.2112
HCl	0.11648	0.3388	438.125	17.28991	0.1898
				663212.4	5067.28

Difference in energy = 1989637 kcal/hr

Amount of water to be used without lubrication = 30609.8 kg/hr
(Temp. not exceeding 100 C) 30.6098 m3/hr
0.510163 m3/min
(0.60 m3/min)

Figure 4.3: Information of internal gas engine (see Appendix A4)

At a dryer

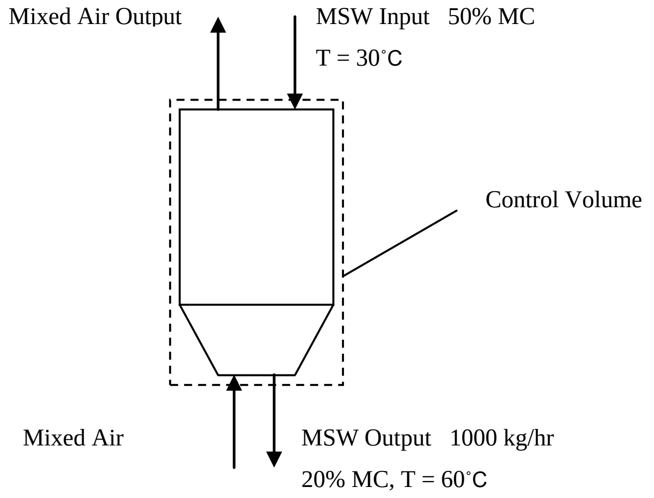


Figure 4.4: Control volume: Dryer

Assumption: 1. Steady state

2. Control Volume

3. Steady flow

4. No heat loss

The amount of heat used:

1. Amount of heat used to dry MSW from 50% MC to 20% MC

2. Amount of heat used to raise the temperature of MSW to 60˚C

Water: The amount of heat used to raise the temperature from 30ºC to 100ºC and to vaporize into vapor state.

From $\dot{Q}$ = $\dot{m}_{mc}\, c_{water}\, \Delta T + \dot{m}_{mc}\, L$

And $\dot{Q}$ = rate of heat transfer

$\dot{m}_{mc}$ = Moisture Content flow rate

ΔT = Temperature difference

L = latent heat

c_{water} = heat capacity

$\dot{m}_{mc}$ = 800 $^{kg}/_{hr}$ x (1-0.25) $^{kg}/_{kg\ dry\ stock}$ = 600 $^{kg}/_{hr}$

c_{water} = 4.187 $^{kJ}/_{kg-k}$ = 1 $^{kcal}/_{kg-k}$

L = 2270 $^{kJ}/_{kg}$ = 540 $^{kcal}/_{kg-k}$

Hence, $\dot{Q}$ = 600 $^{kg}/_{hr}$ x 1 x (100-30ºC) + 600 $^{kg}/_{hr}$ x 540 $^{kcal}/_{kg-k}$

$\dot{Q}$ = 366,000 $^{kcal}/_{hr}$

MSW: The amount of heat used to raise the temperature of MSW from 30ºC to 60ºC

From $\dot{Q} = \dot{m}_{msw}\, c_{msw}\, \Delta T$

And $\dot{Q}$ = rate of heat transfer

$\dot{m}_{msw}$ = MSW mass flow rate

ΔT = Temperature difference

c_{msw} = heat capacity

$\dot{m}_{msw}$ = 800 $^{kg}/_{hr}$

c_{msw} = 0.3$^{kcal}/_{kg\ dry\ stock}$

Hence, $\dot{Q}$ = 800$^{kg}/_{hr}$x 0.3 $^{kcal}/_{kg\ dry\ stock}$ x (60-30ºC)

$\dot{Q}$ = 7,200$^{kcal}/_{hr}$

Therefore, the total amount of heat used is 373,200 $^{kcal}/_{hr}$

Step 2: At the mixer: - Find mass flow rate of hot flue gas

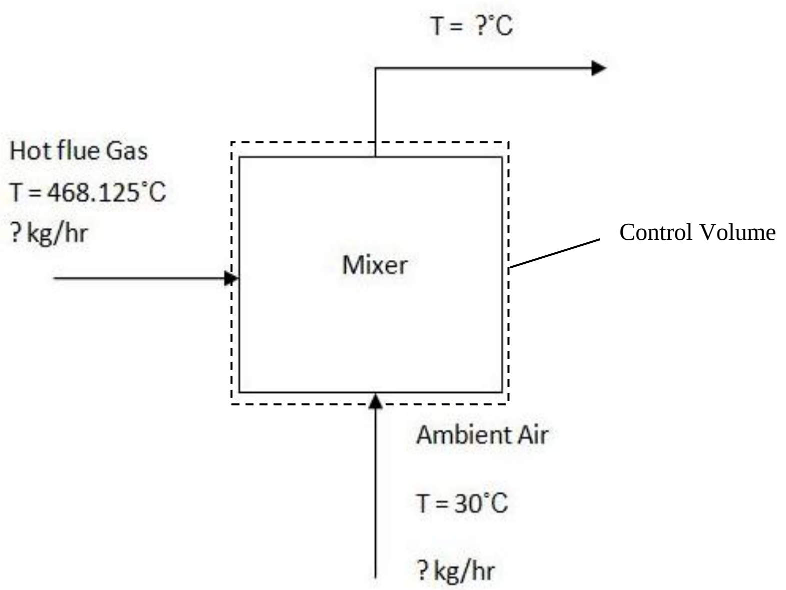


Figure 4.5: Control Volume: Mixer

Assumption: 1. Steady state

2. Control Volume

3. Steady flow

4. No heat loss

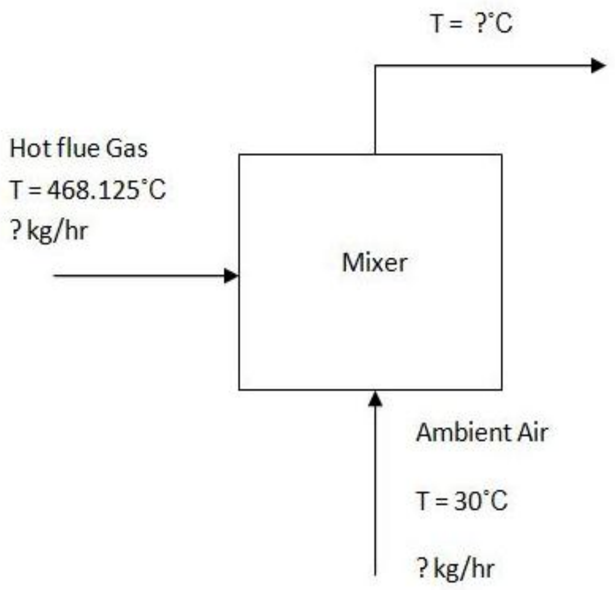


Figure 4.6: The unknown values; hot flue gas mass flow rate, air mass flow rate and mixed air temperature

<u>Ideal Gas Law</u>

An ideal gas is defined as the equation of state of a hypothetical ideal gas whereby all collisions are perfectly elastic and do not interact with each other (there aren't any intermolecular attractive forces between molecules or atoms).In such gases, any change in internal energy is accompanied by a change in temperature. One mole of an ideal gas at STP occupies 22.4 liters.

Ambient Air

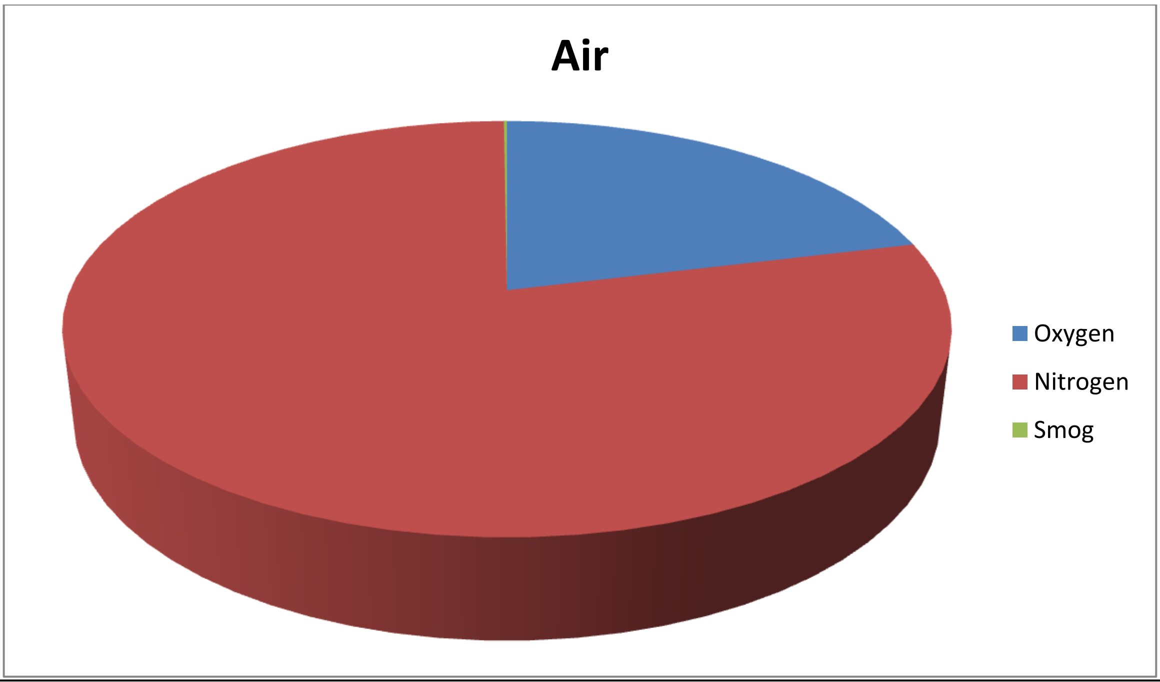


Figure 4.7: Ambient air composition; Oxygen 21%, Nitrogen 78% and Smog 0.00135%

Source: University of Colorado at Boulder, 2003

Basic Chemistry:

Mole:

The mole is a unit measurement in SI base unit usually used in chemistry and/or physic to define an amount of substance. A mole of a substance has mass in grams exactly equal to the substance's molecular or atomic weight. Thus, one can measure the number of moles in a pure substance by weighing it and comparing the result to its molecular or atomic weight.

Molecular Mass:

The molecular mass of a substance is the mass of 1 mol (equal to 1/12 the mass of one isotope of carbon-12). The most common units of molar mass is g/mol because the numerical value equals the average molecular mass in units of *u*. It differs from molar mass by taking into account the isotopic composition of a molecule rather than the average isotopic distribution of many molecules. As a result, molecular mass is a more precise number. Thus, it is more accurate to use molar mass on bulk samples. In other words, mass is appropriate most of the time except when dealing with single molecules.

Energy Balance and Mass Balance Concept

Energy balances states that the law implies that mass can neither be created nor destroyed. Thus, for any closed system, all transfers of matter and energy, both of which have mass, must remain constant over time as within the system mass cannot change quantity if it is not added or removed. By accounting for material entering and leaving a system, mass flows can be identified which might have been unknown, or difficult to measure without this technique. The exact conservation law used in the analysis of the system depends on the context of the problem but all revolve around mass conservation, i.e. that matter cannot disappear or be created spontaneously.

Energy Balance: Energy input = Energy output (from the first law of thermodynamics)

Hence, the quantity of mass is "conserved" over time and is widely used in many fields such as chemistry, mechanics, and fluid dynamics.

Assumption: 1. Isolated system

Data for calculation - Use 30˚C (ambient air temperature) as a reference for calculation

From $\dot{Q}_{input} = \dot{Q}_{output}$

$$(\dot{m}_1 C_p \Delta T)_{input} + (\dot{m}_2 C_p \Delta T)_{input} = (\dot{m}_1 C_p + \dot{m}_2 C_p) \Delta T_{output}$$

And $\dot{m}_1$ = Hot flue Gas flow rate

$\dot{m}_2$ = Ambient air flow rate

ΔT = Temperature difference

C_p = heat capacity

Energy Input: Hot flue gas ($\dot{m}_1$)

	mass %	Cp	Temp diff
CO2	0.1716794	0.334	438.125
H2O	0.1302987	0.404	438.125
N2	0.6979725	0.405	438.125
O2	0	0.3115	438.125
SO2	1.918E-05	0.5783	438.125
HCl	3.022E-05	0.3388	438.125

Table 4.1: The amount of heat of hot flue gas to be mixed in the mixer (see Appendix A4)

Energy Input: Ambient air ($\dot{m}_2$)

	mass %	Cp	Temp diff
O2	0.21	0.3115	0
N2	0.78	0.405	0
H2O	0.00135	0.404	0

Table 4.2: The amount of heat of ambient air to be mixed in the mixer (see Appendix A4)

Energy Output: ***Mixed air ($\dot{m}_1 + \dot{m}_2$)***

	mass %	**Cp**	**Temp diff**
CO2	m1+m2	0.334	ΔT_{output}
H2O	m1+m2	0.404	ΔT_{output}
N2	m1+m2	0.405	ΔT_{output}
O2	m1+m2	0.3115	ΔT_{output}
SO2	m1+m2	0.5783	ΔT_{output}
HCl	m1+m2	0.3388	ΔT_{output}

Table 4.3: The amount of heat of mixed air output 1

Hence, the equation will be:

$$172.0437\ \dot{m}_1 + 0 \text{ Kcal/hr} = (0.392682\ \dot{m}_1 + 0.38186\ \dot{m}_2)\ \Delta T_{output}$$

To find $\dot{m}_1$

From Step 1, the amount of energy that needed to input to dryer is 373,200 $kcal/_{hr}$

So, $(\dot{m}_1 C_p\Delta T)_{input} + (\dot{m}_2 C_p\Delta T)_{input} = (\dot{m}_1 C_p + \dot{m}_2 C_p)\ \Delta T_{output} = Q_{input\ to\ dryer}$

$$172.0437\ \dot{m}_1 + 0\ kcal/_{hr} = 373{,}200\ kcal/_{hr}$$

$$\dot{m}_1 = 2169.216\ Nm3/_{hr}$$

Convert $\dot{m}_1$ to ${kg}/{hr}$

The amount of hot flue gas to be mixed in the mixer is

	Nm3/hr	kg/hr
CO2	372.4097	731.519
H2O	282.6461	227.1264
N2	1514.053	1892.566
O2	0	0
SO2	0.041596	0.118846
HCl	0.065545	0.106803
	Total	**2851.437**

Table 4.4: The total amount of hot flue gas to be mixed in the mixer

In order to find $\dot{m}_2$, fluidize velocity in the dryer has to be considered.

Step 3: At the dryer: - Find the velocity of mixed air into the dryer

Data for calculation: - Equivalent of MSW particle size is 10 mm

- Density of MSW is 300 kg/m3

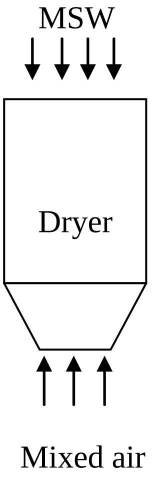


Figure 4.8: Mixed air flow

Check for fluidized velocity

From,

$$Re_{mf} = \left[(33.7)^2 + 0.0408 \frac{D_p^3 \rho_f (\rho_p - \rho_f) g}{\mu^2} \right]^{1/2} - 33.7$$

And Re_{mf} = Reasonable estimate of minimum fluidized velocity

D_p = Equivalent of MSW particle size

ρ_f = Density of mixed air

ρ_p = Density of MSW

g = gravity

μ = Viscosity of mixed air

Then, Re_{mf} = $\{(33.7)^2 + 0.0408[(0.01)^3(1)(300-1)9.8/(1.36x10^{-3})^2]\}^{1/2} - 33.7$

= $0.95\ m/s$

As a result, the calculated fluidize velocity is 0.95 m/s. It is the velocity of the mixed gas into the dryer in which the MSW would be blown upward (out of the dryer). Thus, a lower mixed gas velocity than fluidize velocity is needed. The assumed the mixed gas velocity is 0.475 m/s in order to make sure that the MSW flows in the downward direction while drying. (0.475 m/s = 0.95 m/s ÷ 2; assuming our safety factor as 2)

Step 4: At the dryer: - Find size of the dryer

With the space provided and the available of material in the market, sheet metal with the size of 2440 x 1220 x 10 mm is selected to build up the dryer.

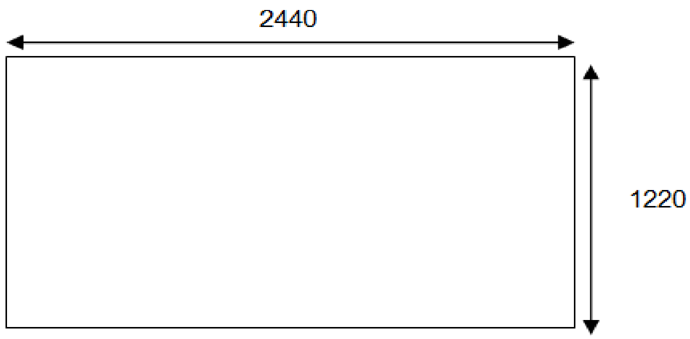


Figure 4.9: Size of sheet metal

Hence, the diameter of dryer can be selected to be 3 m by using four pieces of sheet metal connected to each other by welding (in order to minimize the material loss).

A cross-sectional area of the dryer is = ¶D^2/4 ; D = Diameter

= ¶ X $(3)^2$/4

= 7.07 m^2

And the velocity of hot gas is = volume flow rate /cross-sectional area

0.475 $^{m}/_{s}$ = volume flow rate ÷ 7.07 m^2

Hence, Volume flow rate = 3.35825 $^{m^3}/_{s}$

= 12,089.7 $^{m^3}/_{hr}$

Let's assume hot gas density is 1 $^{kg}/_{m^3}$,

Then, volume flow rate of hot gas inlet = 12,089.7 $^{m^3}/_{hr}$ x 1 $^{kg}/_{m^3}$

= 12,089.7 $^{kg}/_{hr}$

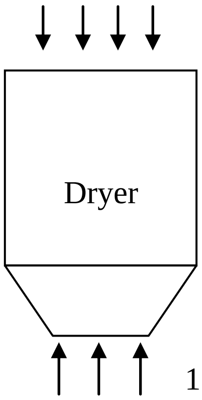


Figure 4.10: Mixed air flow rate

<u>Step 5:</u> At the mixer: - Find mass flow rate of ambient air

From the total mass flow that we need to input to dryer 12,089.7 $^{kg}/_{hr}$then,

Mass Balance: Mass flow input = Mass flow output
(from the first law of thermodynamics, steady state)

$\dot{m}_1 + \dot{m}_2$ = Total mass flow requirement

Substitute the value of mass input into the dryer into the mass balance equation,

$$2851.437\ {}^{kg}/_{hr} + \dot{m}_2 = 12{,}089.7\ {}^{kg}/_{hr}$$

$$\dot{m}_2 = 9238.263\ {}^{kg}/_{hr}$$

Convert $\dot{m}_2$ to ${}^{Nm^3}/_{hr}$

The amount of air at 30 ˚C to be mixed is

	kg/hr	**Nm3/hr**
O2	1940.035	1358.025
N2	7205.845	5764.676
H2O	12.47166	15.5255
	Total	**7138.226**

Table 4.5: The total amount of the ambient air

Step 6: **At the mixer: - Find temperature out of the mixer**

Substitute the value $\dot{m}_1$ and $\dot{m}_2$

	Nm3/hr	Cp	Temp diff
CO2	372.4097	0.334	ΔT_{output}
H2O	298.1716	0.404	ΔT_{output}
N2	7278.729	0.405	ΔT_{output}
O2	1358.025	0.3115	ΔT_{output}
SO2	0.041596	0.5783	ΔT_{output}
HCl	0.065545	0.3388	ΔT_{output}

Table 4.6: The amount of heat of mixed air output 2

From, $(\dot{m}_1 C_p\Delta T)_{input} + (\dot{m}_2 C_p\Delta T)_{input} = (\dot{m}_1 C_p + \dot{m}_2 C_p) \Delta T_{output}$

$$373{,}200 \ {}^{kcal}/_{hr} + 0 \text{ Kcal/hr} = 3615.8(\Delta T_{output})$$

$$\Delta T_{output} = 103.2 \ ^{\circ}C$$

Then, $T_{output} = 133.2 \ ^{\circ}C$

Therefore, the amount of hot gas used is $= \dot{m}_1 + \dot{m}_2 \ {}^{kg}/_{hr}$

$$= 2851.437 + 9238.263 \ {}^{kg}/_{hr}$$

$$= 12{,}089.7 \ {}^{kg}/_{hr}$$

The mass flow rate of hot flue gas, ambient air and mixed air are 2,851.437 ${}^{kg}/_{hr}$, 9,238.263 ${}^{kg}/_{hr}$ and 12,089.7 ${}^{kg}/_{hr}$, respectively. Also, the temperature of mixed air is 133.2°C

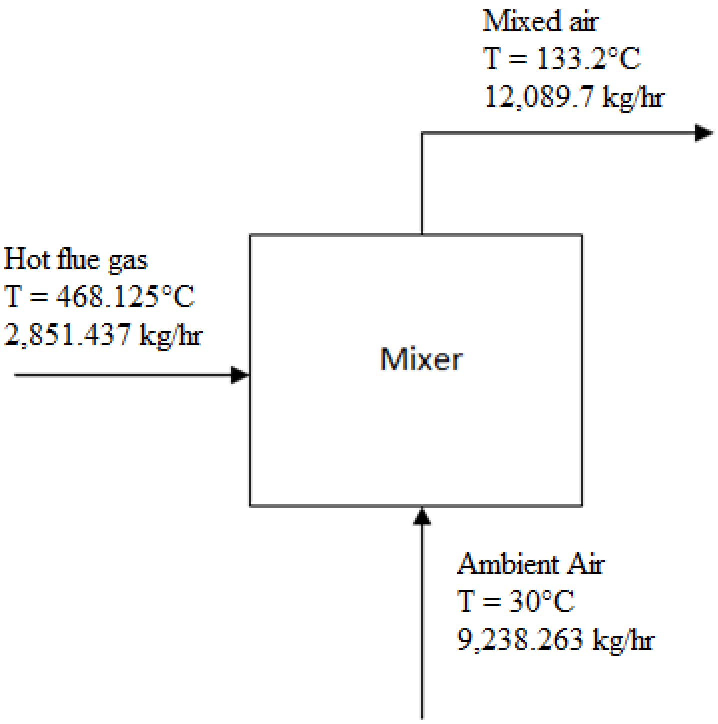


Figure 4.11: The mass flow rate of hot flue gas, ambient air and mixed air.

Step 7: At the dryer: - Find LTU and NTU for the dryer

Volumetric heat transfer coefficient in a dryer

This method of finding length of dryer should be used in both transfusion of water and heat. However, during the period that the drying rate is slow, the resistance of transfusion rate of water in the material is much more significant than others resistance. Moreover, the water in the material, in this case, has bond with the material. Hence, the propulsion of mass transfusion is not clear, so this method should not be used for calculating during the period that the drying rate is slow. The limitation of this method is not an impediment in this project. Since the dryer does not dry the material after the drying rate drop.

In this method, the length of dryer could be found by finding L.T.U. (length per transfer unit) and N.T.U. (number of transfer unit).

Hot gas mass flux, G = Amount of hot gas/Cross-sectional area

= $(12{,}089.7\ kg/_{hr}) / 7.07\ m^2$

G = $1{,}710\ kg/_{m^2 - hr}$

From, Length of the Transfer Unit (LTU) = $0.026 \times C_p \times G^{0.84} \times D$

And G = mass flux

C_p = Heat capacity

D = Diameter

Therefore, Length of the transfer unit (LTU) = $0.026 \times 0.24 \times (1{,}710)^{0.84} \times 3$

= 9.73 m

From, Number of transfer unit (N_t) = $(38 \times LTU)/ (C_p \times G^{0.84} \times D)$

And G = mass flux

C_p = Heat capacity

D = Diameter

Hence, Number of transfer unit (N_t) = $(38 \times 9.73)/ (0.24 \times (1{,}710)^{0.84} \times 3)$

= 0.988

From the total height of a dryer = N_t x LTU

Therefore, the total height of a dryer = 0.988 x 9.73

= 9.61 m

The dryer has a diameter of 3.0 m and 9.61 m in height.

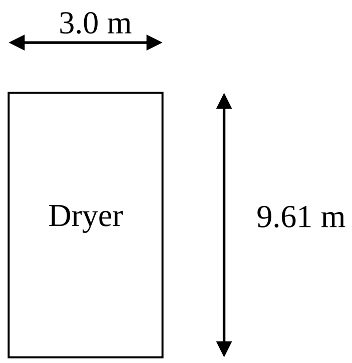


Figure 4.12: Dryer designed dimension

4.2 Financial calculation

4.2.1 Construction Cost

1. Dryer

- Material : sheet metal size 2440 x 1220 x 10 mm (density is 7800 kg/m^3)
- Size : height 9.61 m diameter 3 m
- Price of construction (120baht/kg) : 847,755 baht
- Type : Continuous Fluid Bed Dryer
- Insulator : Top insulator and trading 10 Fibertex B40s size 7500X1200 thickness 50 Price: 1,161X 10 = 11,610 baht
- Total: 1,083,697 baht

2. Mixer

- Material : sheet metal size 2440 x 1220 x 10 mm (density is 7800 kg/m^3)
- Size : Length 3 m diameter 1 m
- Price of construction (120baht/kg) : 88,216 baht
- Insulator : Top insulator and trading 10 Fibertex B40s size 7500X1200 thickness 50 Price: 1,161X1= 1,161 baht
- Total: 96,387 baht

3. Blower

- Blower 1 : Air control industries EV-BPR451D price = 45,000 baht
- Blower 2 : Air control industries EV-BPR501D price = 50,000 baht
- Total blower cost : 95,000 baht

4. Air damper (Butterfly valve)

- Material Ductile Iron
- Diameter 8”
- Price : 8,650 X 3 = 25,950 baht

5. Rotary damper
- 2 Rotary damper
- Price 20,000 x 2 = 40,000 baht

6. Pipe

- Diameter 20cm 20 m
- Price of construction(60baht/kg) = 120,562 baht
- Insulator per piece (1.2m) Price : 20X254 = 5,080 baht
- Total 120,562 baht

Total: Construction cost = 1,461,596 baht

4.2.2 Operating Cost

Blower: Consumption of Blower 1&2 = 1.5 kW + 2.2 kW = 3.7 kW

Average of the consumption is 80% of spec = 0.8 x 3.7 = 2.96 kW

Operating cost per hour: 1kW = 3 baht, hence 2.96kW = 8.88 baht/hr

Operating cost per day (10hr/day) = 10 x 8.88 = 88.8 baht/day

4.2.3 Maintenance Cost (Depreciation Cost)

1. Blower

   Life time of this blower is about 30,000 hr = 30,000/10 = 3,000 days

   So maintenance cost per day = cost of blower / working day

$$= \frac{45,000 + 50,000}{3,000}$$

= 31.67 baht /day

2. Damper

   Life time of this blower is about 30,000 hr = 30,000/10 = 3,000 days

   So maintenance cost per day = cost of blower / working day

$$= \frac{65,950}{3,000}$$

= 22 baht/day

Total maintenance cost = 31.67 + 22 = 53.67 baht /day

4.2.4 Profit after applying the fuel drying system

According to the reduction of moisture in MSW from 50% to 20% MC, as moisture content decreases, the lower heating value (LHV) of MSW is increased. At the same amount of output (400 kWe), it means that the MSW product input is reduced. (The lower the moisture content, the higher is the heating value)

The calculation for is as follow,

-Lower heating value of MSW at 20% MC = 3,501 kcal/kg
-Lower heating value of MSW at 50% MC = 2,652 kcal/kg

The reason why Lower Heating Values (LHV) are used to calculated here is because the dryer process is assumed to dry the total amount of water to vapor phase with no condensation of liquid phase (see Appendix A6).

The data of the MSW compositions is as follows (WB):
(After drying it to the moisture of 20% by the hot synthetic gas itself)

C	39.808	%
H	5.6	%
S	0.12	%
N	0.216	%
O	28.528	%
Cl	0.208	%
Moisture	20	%
Ash content	5.52	%

The data of the MSW compositions is as follows (WB):
(After drying it to the moisture of 50% by the hot synthetic gas itself)

C	32.34	%
H	4.55	%
S	0.098	%
N	0.133	%
O	23.18	%
Cl	0.169	%
Moisture	50	%
Ash content	4.49	%

From, Lower heating value is

$$LHV = 81C + 342.5\left(H - \frac{O}{8}\right) + 22.5S - 6(W + 9H)$$

Figure 4-9: Formula of LHV

Hence, LHV of MSW at 20% moisture content is

LHV(20% MC) $= 81(39.808) + 342.5(5.6 - \frac{28.528}{8}) + 22.5(0.12) – 6[20+9(5.6)]$

= 3,501 kcal/kg

And, LHV of MSW at 50% moisture content is

LHV(50% MC) $= 81(32.34) + 342.5(4.55 – \frac{23.18}{8}) + 22.5(0.098) – 6[50+9(4.55)]$

= 2,652 kcal/kg

-Lower heating value of MSW at 20% MC = 3,501 kcal/kg

-Lower heating value of MSW at 50% MC = 2,652 kcal/kg

Factory: 400 kWh

1 kWh = 859.8 Kcal (see Appendix A5)

Then, 400 kW = 343,920 kcal/hr

The amount of MSW to be used is:

At 20% MC: (343,920 kcal/hr) / (3501 kcal/kg) = 98.23 kg/hr

Efficiency of engine is 25%

So, (98.23 kg/hr) / 0.25 = 392.94 kg/hr

Efficiency of gasifier is 70%

So, (392.94 kg/hr) / 0.70 = 561.34kg/hr

At 50% MC: (343,920 kcal/hr) / (2,652 kcal/hr) = 129.68 kg/hr

Efficiency of engine is 25%

So, (129.68 kg/hr) / 0.25 = 518.73 kg/hr

Efficiency of gasifier is 70%

So, (518.73 kg/hr) / 0.70 = 741.05 kg/hr

Hence, the difference is 741.05 – 561.34 = 179.71 kg/hr

(The feed rate of MSW is reduced for 179.71 kg/hr)

Saved cost per day

The cost of MSW will be reduced for (MSW = 1.5 baht/kg) = 179.71 kg/hr x 1.5 baht /kg

= 269.57 baht /hr

= 269.57 baht /hr x 10 hr/day

= 2,695.7 baht /day

Total: profit after applying the Dryer is 2,695.7 baht /day

4.2.5 Time required for breakeven point

The construction cost of 1,461,596 baht will be borrowed from the Bank of Thailand who has an interest rate of 7.83% per annual (Bank of Thailand, June 2013). In order to find the period of loan payment to the bank, the annuity due formulas is used.

From, Annuity Due Formulas;

$$PV = P_{mt}\left[\frac{1-\frac{1}{(1+i)^{(N-1)}}}{i}\right] + P_{mt}$$

$$\text{Then, Time required for breakeven point} = \frac{-\ln\left[1+i\left(1-\frac{PV}{P_{mt}}\right)\right]}{\ln(1+i)} + 1$$

And	PV	=	Present value
	P_{mt}	=	Payment
	i	=	Interest rate
	N	=	Number of Periods
In this case;	PV	=	Construction cost (Amount of loan)
	P_{mt}	=	Profit after subtracting Operating cost and Maintenance cost
	i	=	Loan interest rate

$$\text{Then, Time required for breakeven point} = \frac{-\ln\left[1+(0.0783)\left(1-\frac{1,461,596}{932,184.45}\right)\right]}{\ln(1+0.0783)} + 1$$

= 1.6 years

= 585.24 days (approximately 586 days)

CHAPTER 5

PROJECT OUTCOMES

5.1 Engineering Part: Dryer & Mixer

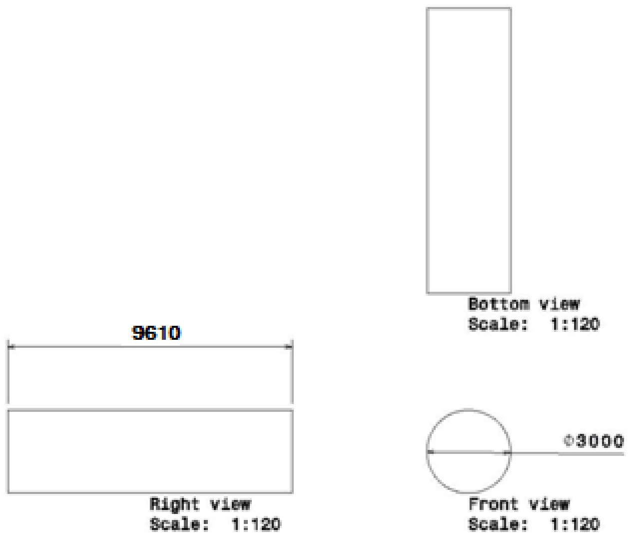


Figure 5.1: Dimension of dryer (mm)

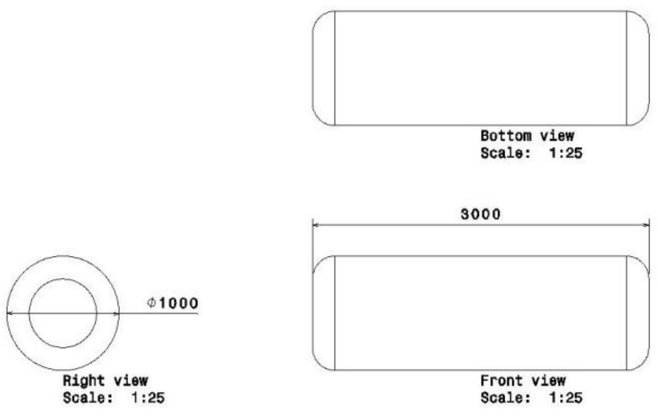


Figure 5.2: dimension of mixer (mm)

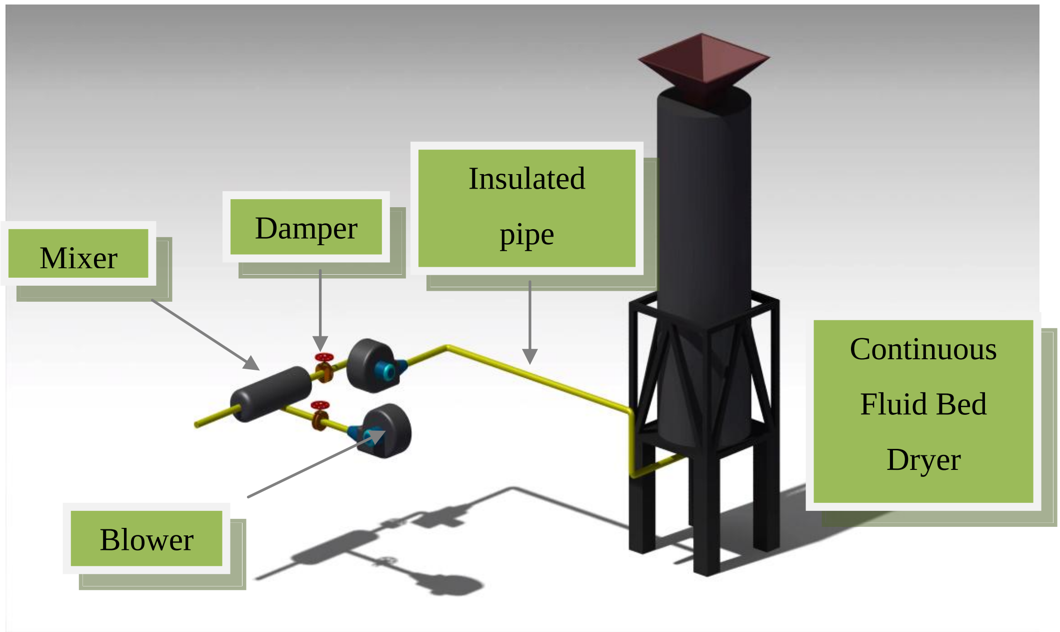


Figure 5.3: Overall 3D design; Dryer, Mixer, 2 Blowers, 2 Dampers

Figure 5.4: Simulation view with the power plant in 3D overview

5.2 Financial Part

- *Construction cost*

Dryer	1,083,697	baht
Mixer	96,387	baht
Blower	95,000	baht
Air damper (Butterfly valve)	25,950	baht
Rotary damper	40,000	baht
Insulated Pipe	120,562	baht
Total Construction cost	1,461,596	baht

- *Operating cost*

Blower	88.8	baht/day
Total Operating Cost	88.8	baht/day

- *Maintenance Cost*

Blower	31.67	baht /day
Damper	22	baht /day
Total Maintenance Cost	53.67	baht/day

- *Profit after applying the Dryer*

  Total profit after applying the Dryer 2,695.7 baht/day

- *Interest rate*

  Loan interest rate (Bank of Thailand, June 2013) 7.83% per annual

- *Time required for breakeven point*

  Time require for breakeven point is approximately 586 days

CHAPTER 6

DISCUSSION

Since the power plant used as the case study is a real pioneer plant, there are many other factors to consider. For example, the study doesn't include the problem of waste separation process, and etc. Hence, some values for calculation were obtained from literature in order to deviate from the exact values of the plant.

Furthermore, although there are many alternatives to design and implement the dryer process and equipments, due to the constrain of space available in the factory and the material available for the construction of the dryer and timing of implementation, not all the possible options were explored. However, design of the dryer is chosen based upon dryer decision matrix.

The calculation of using the hot flue gas from the internal gas engine to dry the MSW for reducing the moisture content at 50% to 20% was studied. In this calculation, the hot flue gas from the internal gas engine at 468.125˚C was partially taken to be mixed with the ambient air at 30˚C to get the mixed gas at the temperature. This mixed gas will be then used to dry the MSW to reduce the moisture content from 50% to 20% maximum.

The calculation started with the estimation of the amount of hot mixed gas to be used to reduce the MSW moisture content from 50% to 20% and heat up the MSW solid portion from 30˚C to 60˚C. Note, however that, the velocity of mixed air (0.475 m/s) can be increased to the value less than the minimum fluidized velocity 0.95 m/s. From the assumed velocity, mass flow rate of the mixed gas was found to be 12,089.7 kg/hr. After that, the temperature output of the mixed gas was found to be 133.2 ˚C given that the mass flow rate of the hot flue gas is 2,851.437 kg/hr and the mass flow rate of the ambient air is found to be at 9,238.263 kg/ hr.

Also, the diameter of dryer was designed to be 3.0 m and the total height of the dryer was provided from the formula with the LTU (Length of transfer unit) to be 9.73 m and the number of transfer unit to be 0.988 m. We can then get the total height of this fixed bed dryer at 9.61 m. In addition, the size of dryer, diameter and height can be modified but have to be trade-off, i.e. the diameter can be increased in order to reduce the height, or vice versa.

Lastly, adjustment or modification during operation with proper parameters as shown in Figure 4.11 is periodically required to achieve the effective outcomes as below:

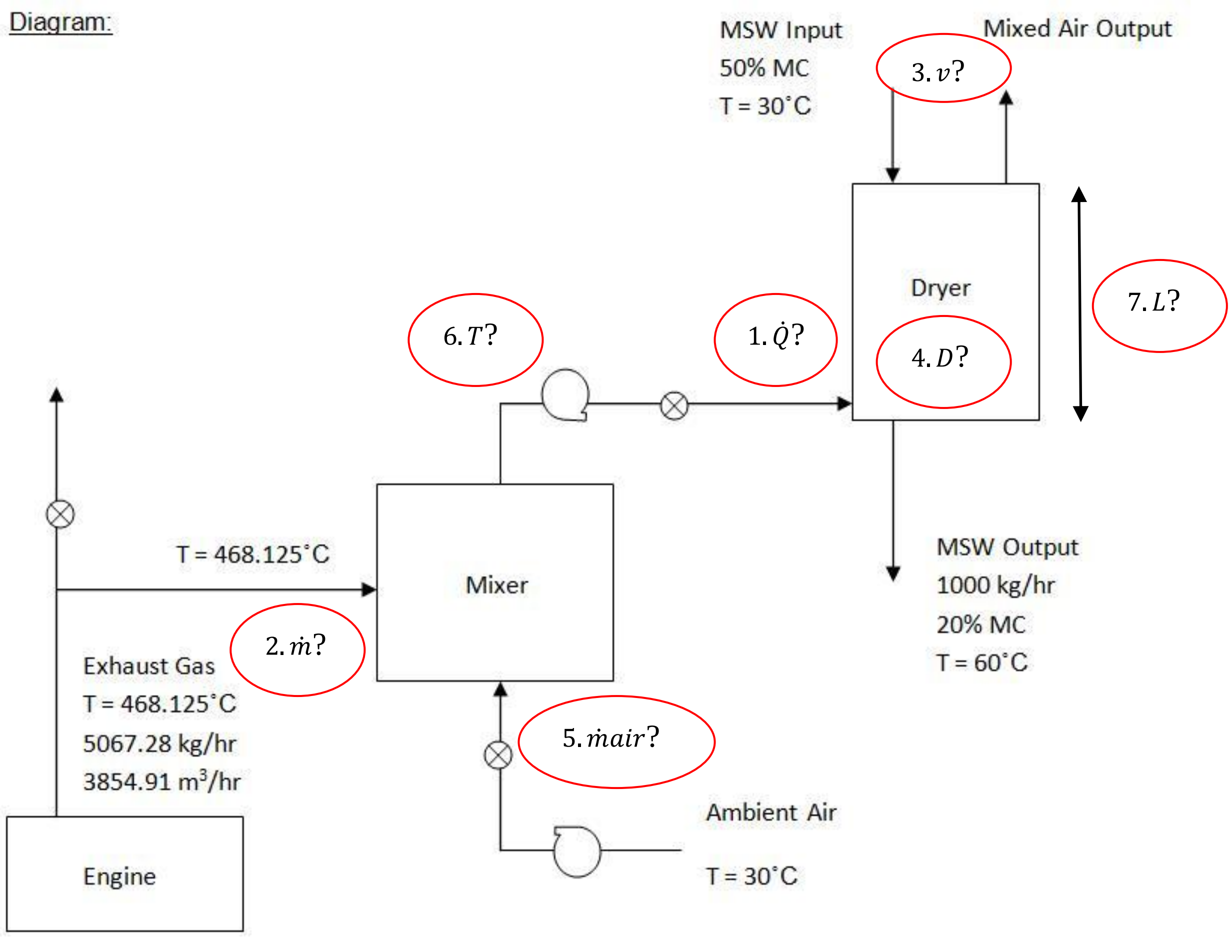


Figure 4.2: A diagram shows the drying system with finding values

1. At the dryer: - Find total amount of needed heat into the dryer = 373,200 $^{kcal}/_{hr}$
2. At the mixer: - Find mass flow rate of hot flue gas = 2,169.216 $^{Nm3}/_{hr}$
3. At the dryer: - Find the velocity of mixed air into the dryer = 0.475 $^{m}/_{s}$
4. At the dryer: - Find size of the dryer = Diameter 3.0 m
5. At the mixer: - Find mass flow rate of ambient air = 9,238.263 $^{kg}/_{hr}$
6. At the dryer: - Find temperature out of the mixer = 133.2°C
7. At the dryer: - Find LTU and NTU for the dryer = 9.73 m and 0.988 m

CHAPTER 7

CONCLUSION

Today, energy is essential necessity and waste is a major problem to society and the world. As stated earlier the energy consumption of the world has increased from 2011 to 2012 by 2.5% (Statistical Review of World Energy June 2012, BP plc). This means that the amount of coal, gas, and other fuels needed to produce electricity will need to be increased. Unless alternative solution such as better usage of existing fuel resources or alternative energy is found, non-renewable fuels are expected to run out in 2050 (Prof.Hameed Nezhad, 2009). Moreover, waste in the world is increasing at an exponential rate both due to increasing extravagant of human nature and ever growing population. World Health Organization (WHO) estimated that by 2050, the world population will be approximately 9 billion people. As for Thailand the energy consumption and waste is expected to increase by 549% and 350% respectively by 2050 (Shrestha et al., 2007). Thus, both energy and waste need to be properly managed.

Thus, my thesis is a crucial step in helping Samutsakorn power plant to become a part of the solution the world's problems. The outcome designed of the improved gasifier which dry moist MSW by recovered waste heat is not only commercially profitable but also environmentally friendly since the utilized fuels is biomass.

Also, the improved designed of gasifier with the dryer system will effectively generate the cost saved 2,695.7 baht per day. Thus, the breakeven point after implementing the improved designed of gasifier is 586 days with loan interest rate of 7.83% (Bank of Thailand, June 2013).

Finally, my objectives in designing a drying system which utilizes the hot fuel gas from the internal gas engine (recovered waste heat) to dry the MSW (reduce the moisture content) and improve the thermal efficiency of the existing gasifier, as stated in Chapter 1.2, have been achieved. Moreover, the design and calculation could be used as a guideline in practical operation of other power plants around the world.

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APPENDIX A1

DATA AND FIGURES OF THE POWER PLANT

1. OVERALL PROCESS

Figure A1-1: Waste Receiving

Figure A1-2: Feed Hopper

Figure A1-3: Trommel

Figure A1-4: Small size waste conveyor after screen

Figure A1-5: Large size waste (RDF) conveyor after screen

Figure A1-6: Plant Overview

Figure A1-7: Gasifier

Figure A1-8: Gas Cleaner

Figure A1-9: Gas Engine & Generator

Figure A1-10: Control Panel

Figure A1-11: Control Cabinet

Figure A1-12: Transformer & Grid Connection

Figure A1-13: Sediment Pond

Figure A1-14: Cooling Pond

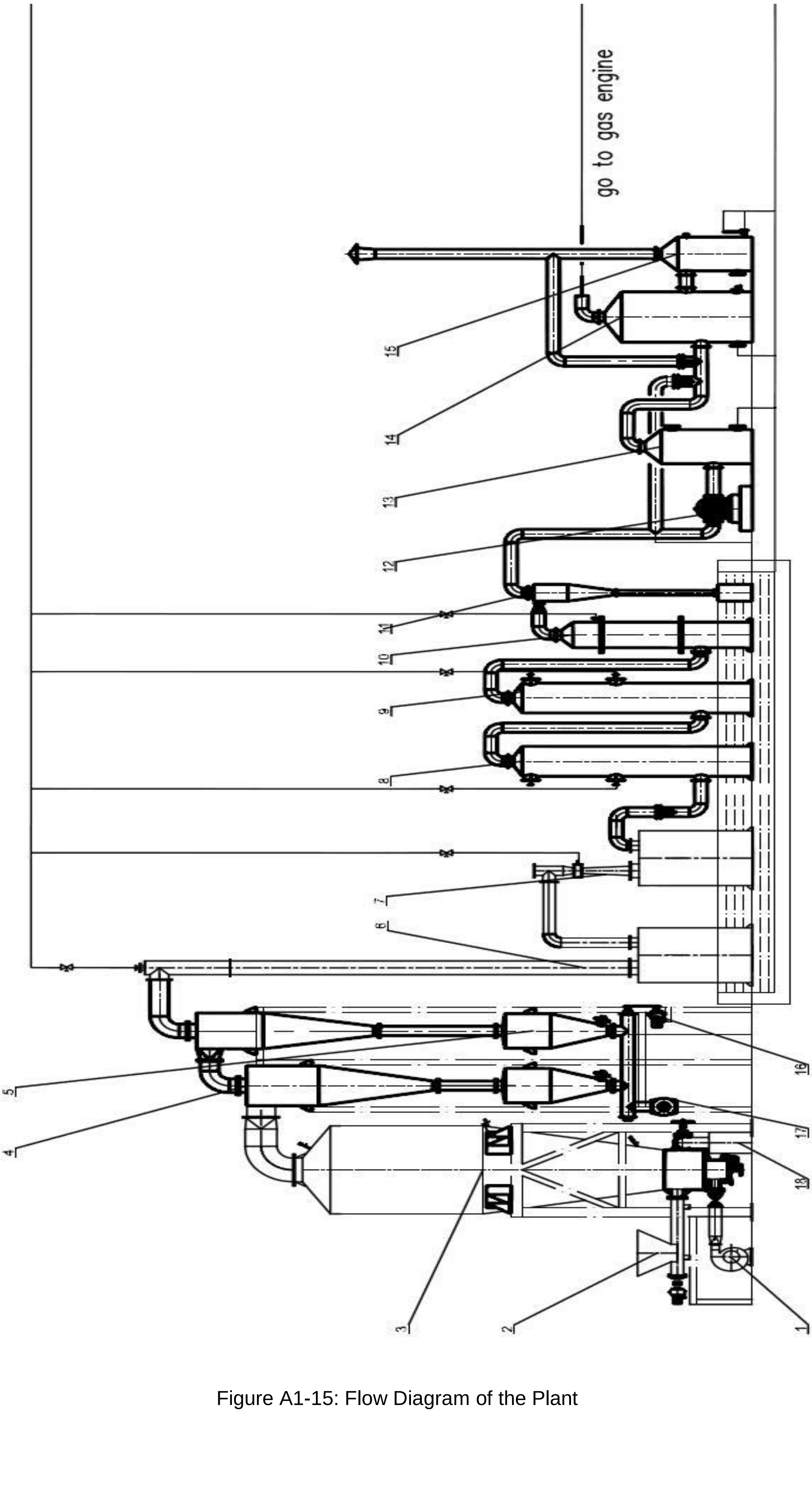


Figure A1-15: Flow Diagram of the Plant

According to Figure A1-15: Flow Diagram of the Plant, the meaning of each number is as follow,

1. Force Fan
2. Screw Feeder
3. Fluidized Bed Gasification Furnace
4. Cyclone Separator
5. Ash Box
6. Tube-type Dust Remover
7. Venturi Separator
8. Spray Tower 1
9. Spray Tower 2
10. Foam Tower
11. Circumvolving Liquid Separator
12. Roots Blower
13. Drop-Picker
14. Buffering Tank
15. Water Seal
16. Ash Screw Drainage
17. Drainage Blower
18. Safety Water Seal

2. GAS ENGINE GENERATOR

Figure A1-15: Gas Engine Generator

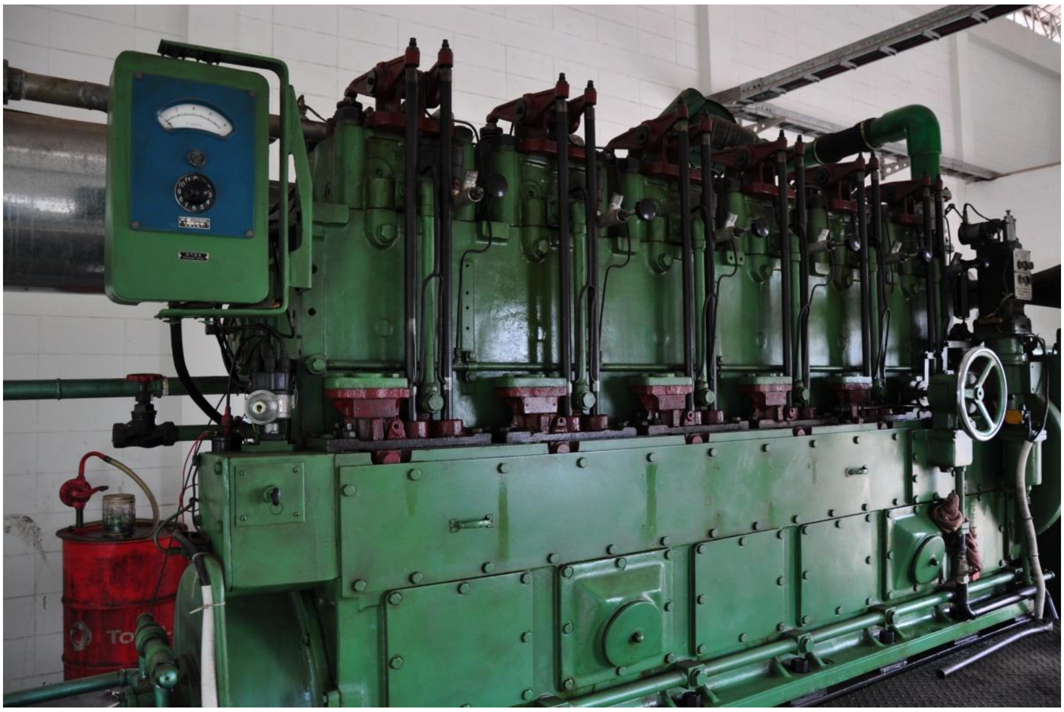


Figure A1-16: Gas Engine Generator with 6 Cylinders

3. WASTE

Figure A1-17: MSW before being chop

Figure A1-18: Waste Hack (Chopper)

Figure A1-19: Waste after being chop

Figure A1-20: Waste

Figure A1-21: Waste is being dry by sunlight

Figure A1-22: Waste after being dry is collected

Figure A1-23: Waste is kept in a storage house

Figure A1-24: A Storage House

APPENDIX A2

INFORMATION AND SPECIFICATION VALUE OF EQUIPMENTS

Blower: Centrifugal fan

Often called a "squirrel cage" (because of its similarity in appearance to exercise wheels for pet rodents), the centrifugal fan has a moving component (called an impeller) that consists of a central shaft about which a set of blades, or ribs, are positioned. Centrifugal fans blow air at right angles to the intake of the fan, and spin the air outwards to the outlet (by deflection and centrifugal force). The impeller rotates, causing air to enter the fan near the shaft and move perpendicularly from the shaft to the opening in the scroll-shaped fan casing. A centrifugal fan produces more pressure for a given air volume, and is used where this is desirable such as in leaf blowers, blow-dryers, air mattress inflators, inflatable structures, climate control, and various industrial purposes. They are typically noisier than comparable axial fans.

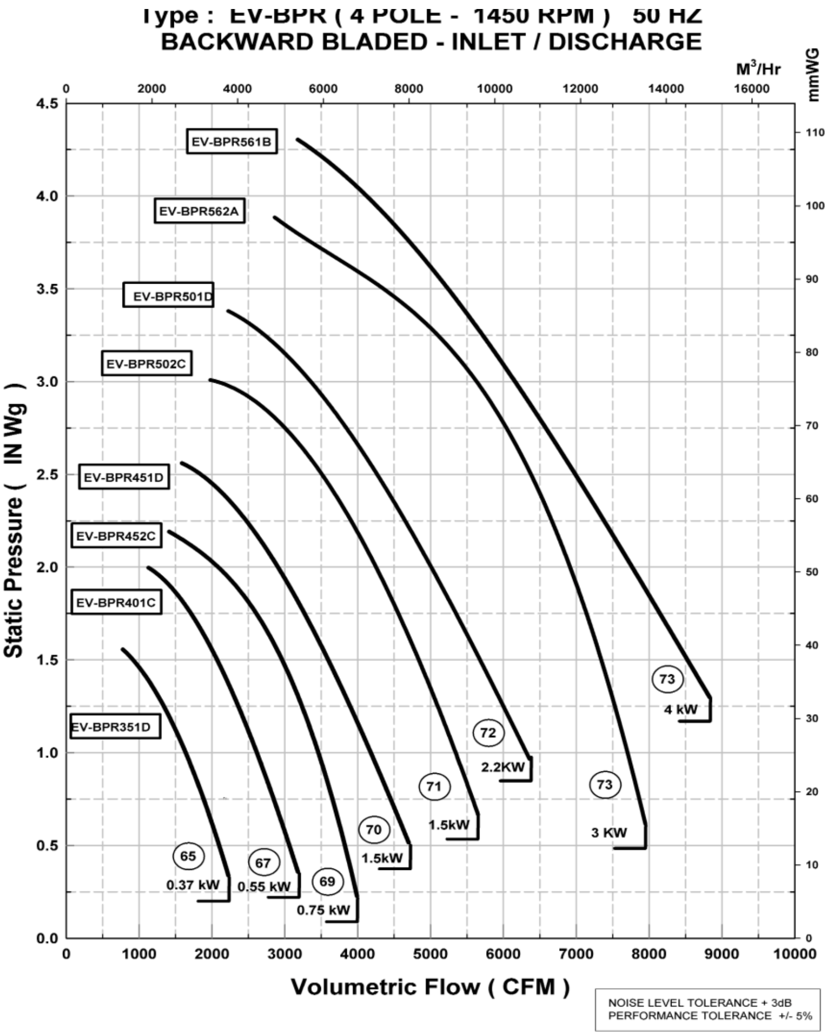


Figure A2-1: Graph between static pressure and volumetric flow of blowers

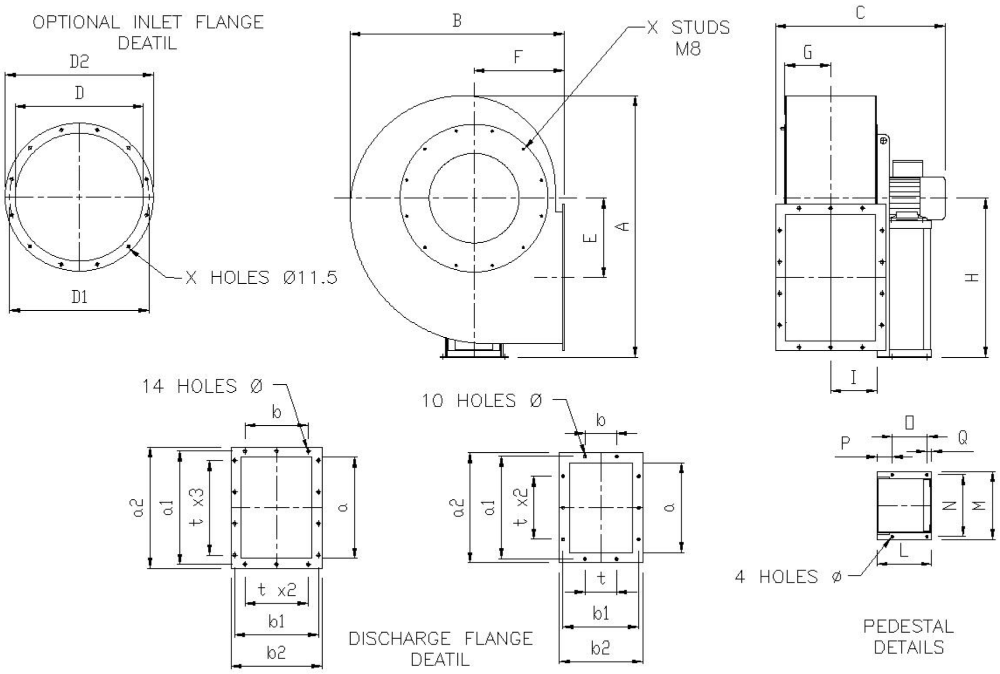


Figure A2-2: Dimension of blower

Type		Fan										Base								Inlet Flange				Discharge Flange									ApproxWeight
Fan	Motor	A	B	C	E	F	G	H	H1	H2	I	L	M	N	N1	O	P	Q	Ø	D	D1	D2	X	a	b	a1	b1	a2	b2	t	Qty	Ø	(Kgs)
BPR 351/D	71 B4	740	620	500	225	265	130	450	450	265	132	190	235	215	-	125	50	15	10	361	405	441	8	355	250	405	300	435	330	125	10	11.5	58
BPR 401/C	80 A4	830	695	560	250	300	146	500	500	300	148	190	235	215		125	50	15	10	405	448	485	8	400	280	448	332	480	360	125	14	11.5	69
BPR 452/C	80 A4	930	780	600	280	335	164	560	560	335	166	190	235	215		125	50	15	10	455	497	535	12	450	315	497	366	530	395	125	14	11.5	84
BPR 451/D	90 S4			635								215	270	245		137	60	18	10											125		11.5	90
BPR 502/C	90 L4	1040	850	675	315	355	184	630	630	355	186	215	270	245		137	60	18	10	505	551	585	12	500	355	551	405	580	435	125	14	11.5	110
BPR 501/D	100 LA4			745								260	332	300		200	35	25	12											125		11.5	119
BPR 562/A	100 LB4	1170	955	800	355	400	207	710	560	400	208	260	332	300		200	35	25	12	566	629	666	16	560	400	629	464	660	500	160	14	14	136
BPR 561/B	112 M4											260	332	300		200	35	25	12														147

Please note (1) - all drawings measurements are in millimeters (mm)
Please note (2) - above technical specifications are subject to change

Table A2-1: Dimension and specific size of blower

Figure A2-3: Blower

Air Damper

Air damper is a valve or plate that stops or regulates the flow of air inside a duct, chimney, VAV box, air handler, or other air handling equipment. A damper may be used to cut off central air conditioning (heating or cooling) to an unused room, or to regulate it for room-by-room temperature and climate control. Its operation can be manual or automatic. Manual dampers are turned by a handle on the outside of a duct. Automatic dampers are used to regulate airflow constantly and are operated by electric or pneumatic motors, in turn controlled by a thermostat or building automation system.

Figure A2-4: Air Damper, Butterfly valve: Model 10DJ

KITZ

Butterfly valves

Type		Butterfly Valves					
Body		Ductile Iron				Aluminum	
Disc		FCD450+EBP	SCS13A	FCD450+ENP	SCS13A	SCS14A	
Seat		NBR	NBR/EPDM	NBR	NBR/EPDM	EPDM	
Connection		10K				10K/150	
Model		10DJ	10DJU/E	G-10DJ	G-10DJU/E	10XJMEA	G-10XJMEA
							
2"	50A	2,500	2,925	4,710	4,930	2,170	3,215
2-1/2"	65A	2,630	3,240	4,845	5,215	2,460	3,425
3"	80A	3,190	3,750	5,340	5,760	2,880	4,140
4"	100A	3,815	4,620	5,810	6,345	3,475	5,140
5"	125A	5,040	6,345	7,290	8,440	4,530	6,770
6"	150A	5,695	7,310	7,930	9,425	5,180	7,390
8"	200A	8,650	11,020	11,570	13,690		12,300
10"	250A			17,160	18,970		20,180
12"	300A			20,590	25,870		26,430
14"	350A			44,350	51,740		
16"	400A			60,575	72,860		
18"	450A			73,750	88,225		

8”

Table A2-2: Air Damper specification information

Sheet Metal and Steel Pipe

Figure A2-5: Sheet metal

Figure A2-6: Steel Pipe

Standard sheet metal price calculation

Weight (kg) = Thickness(mm) x width(cm) x Length (cm) x 0.000785

Price of sheet metal = Weight x Price (baht/kg)

The latest up to date price is 30 baht/kg

APPENDIX A3

SPECIFIC INFORMATION OF MUNICIPAL SOLID WASTE (MSW) FROM LITERATURE

1. "Solid Waste Management in Asian Perspectives" by Prof. C. Visvanathan, Environmental Engineering and Management Program School of Environment, Resources and Development Asian Institute of Technology.

Increasing solid waste management problems and its disposal strikes environment and health hazards. This training material covers the essential elements of solid waste management in Asian context. Prevailing scenario of waste handling practices and disposal is exhibited along with its associated problems. Valuable case studies are also discussed. An integrated solid waste management in sustainable approach is presented as a response to necessary waste management strategy needs. Waste minimization in the form of proper waste segregation and utilization, the importance of pre-treatment of organic waste and combustible waste fraction does not only manage the waste but also generates products such as compost and renewable energy. Direct landfilling of commingled waste in Asian countries should be discouraged due to its high organic waste fraction which causes potential environmental emissions. The efforts of government to solve this problem from legal aspects through laws and regulations should be supported by an active participation of community, public and private agencies.

1.1 Introduction

Enormous amount of waste is generated daily and its management is a huge task. The prevailing scenario for solid waste final disposal is usually a matter of transporting the collected waste to the nearest available open space and dumping it. However, only a fraction of waste were properly collected and transported. Sometimes it is burnt to reduce its volume and to minimize attraction of animals and vermin and also to retrieve recyclable items. Solid waste management and disposal is an alarming problem encountered by many of the urban and industrial areas in developing economies in Asia. Waste generation has witnessed an increasing trend parallel to the development of industrialization, urbanization, and rapid growth of population. The problem has become one of the primary urban environmental issues. Despite the degradation of valuable land resources and creation of long-term environmental and human health problems, uncontrolled open dumping is still prevalent in most developing countries (ISWA and UNEP, 2002) which indeed desperately need an immediate action due to the associated harmful impacts. Moreover, in South and Southeast Asia, more than 90% of all landfills are non-engineered disposal abilities.

Aside of the concern on increasing waste generation, and inefficient collection and transportation infrastructure system, the composition of waste (high organic matter and high moisture content) and climatic condition were among the other factors that need to be considered in solid waste management. Moreover financial constraints and weak implementation of waste management policy with poor cooperation of government, public and private sector, educational institutions, and civil society complicates the issues.

1.2 State of Solid Waste Management and Practices in Developing Countries in Asia

In the past, managing solid waste was considered simply transporting waste to distant places for dumping and for the nature to take care. However, today, the increasing value of land and inadequate space, limited capacity of nature to handle unwanted emissions and residues pose alarming threats to human lives. Thus, solid waste management has become a matter of paramount concern.

1.2.1 Solid waste generation

The trend of solid waste generation in most Asian countries is increasing. The primary factors affecting waste quantity are population, urbanization, industrialization, and the changing lifestyle. For example in Thailand, solid waste generation has witnessed an increasing trend. In 1999, 13.8 million tons/day of waste was generated and increased Urban areas in Asia generate about 760,000 tones of MSW or approximately 2.7 million m3 per day. In 2025, this figure will increase to1.8 million tones of waste per day or5.2 million m3 of waste (World Bank,1999).Moreover, other related issues that affect solid waste generation are:

• In areas with a large number of tourists, the generation rate is even higher

• In big cities, the waste is more concentrated, and requires expensive removal or collection

• Waste composition is changing with rapid increase in the amount of paper, plastic, metal, and hazardous waste materials

• Poor urban waste disposal service results in even more litter and pollution of the local environment.

1.2.2 Solid waste composition

Solid waste composition can be affected by economic status and consumer pattern. Feedback on waste composition is important in evaluating the requirements or specifications for equipment need, treatment systems, and management programs and plans. Moreover, potential emissions (leach ate and landfill gas) from disposed solid waste can be linked with waste composition, specifically the amount of organic fraction present in waste. The composition of municipal solid waste (MSW) differs for different countries and regions. Moreover major portion of MSW generated in most developing Asian countries was dominated by biodegradable organic fractions composed of food wastes, yard wastes, and mixed paper. Food wastes dominate over the major portion of the waste generated in most developing countries in Asia like China, India, Sri Lakeland Thailand. In this regard, waste can be characterized as highly biodegrable with high moisture content in which the disposal management should consider this factor.

1.2.3 Solid waste collection and transport

Commonly, most poor cities in developing countries are deprived of proper waste collection services and only a fraction of generated waste is actually collected. Financial constraints and lack of technical expertise severely limit the effectiveness of solid waste collection and transportation. Inefficiency in collection system creates a main constraint on solid waste management capacity.

Typical scheme often observed in urban areas in Asia is the presence of primary collection service (house to house waste collection and transport to an intermediate collection point).Such primary collection often managed by community-based organizations and is often initiated by residents which desperately need a service wherein the residents are also willing to pay monthly collection fees.

In Thailand, the Bangkok Metropolis Administration (BMA) is responsible for the collection of solid waste and it operates the biggest single solid waste management system in Bangkok. The BMA primary solid waste collection system is consist of collection at households in various areas at accessible time to avoid traffic congestion to transfer station. The application of transfer stations is not widely practiced, but in some transfer points, the wastes collected by smaller vehicles are being transferred to larger trucks and from the compactor truck to a high density transport vehicles which improves transportation performance. The secondary or indirect waste transport collection places the waste into a large hauling truck, weigh, and transport in landfills.

Countless efforts in solid waste management has been undertaken in many countries in Asia but until now, the country still struggling on its collection and transportation schemes. Improving infrastructure and services establishment with the aim to improve waste collection and services needs to be focused. The problems that can be associated to insufficient and inefficient collection and transport are:

• Inappropriate collection techniques. Some systems are expensive to buy and maintain; some collection vehicles are too bulky to enter all parts of the town

• Inadequate planning on waste transport system and lack of vehicle/equipment and its maintenance that lead to complete breakdown of collection system

• Most municipalities do not have enough waste bins. In some municipalities, weak public cooperation on waste management system

• Ignorance on solid waste management leads to dumping in open spaces, along the roadsides, or in canals and rivers

• Dumping waste on vacant lots, canals or river could cause water pollution and would blocked drainage and cause flood when it rains

• Uncollected wastes often end up in drains, causing blockages which result in flooding.

Plastic bags litter along the road is a particular aesthetic nuisance and they cause the death of grazing animals which eat them

• Heavy refuse collection trucks can cause significant damage to the surfaces of roads that were not designed for such weights.

1.2.4 Solid waste disposal

In developing economies in Asia, the status of solid waste management is characterized by unsafe practices of open dumping and inefficient administration due to heavy governmental subsidies. However, economic and regulatory pressures are slowly driving towards the adaptation of timely and efficient solid waste management technique income Asian countries.

It appears that in most low-income countries, and many medium income countries in Asia, very little progress has been made in upgrading waste disposal operations, and open dumping remained as the dominant solid waste disposal system. For example in Sri Lanka, more than 80% of municipal solid waste is end up into open dumps.

Open dumps, where the waste is unloaded in piles, make very uneconomical use of the available space, allow free access to waste pickers, animals, and insects and often produce unpleasant odor and aesthetic nuisance. Such inadequate waste disposal creates severe environmental problems that affect health of humans and animals and cause serious economic and other welfare losses. The environmental degradation caused by common inadequate disposal of waste in Asia (open dumping and non-engineered landfill) can be expressed by:

• Contamination of surface and ground water through leach ate (water draining from beneath waste disposal sites) from inappropriately located or badly prepared landfill sites. The generation of lactates by percolating rainwater contain run-off of organic and inorganic compounds resulting in the contamination of soil, surface, and groundwater. Groundwater pollution originating from landfills may be at risk even after several centuries.

• Air pollution due to the presence of foul odor associated with open dumping and by burning of waste. Also, a poorly managed landfill sites produce methane gas which is both polluting and explosive and are nuisance for the people who live in surrounding area.

• Soil contamination through direct waste contact or leach ate and spreading of diseases by different vectors like birds, insects and rodents, or uncontrolled release of methane by anaerobic decomposition of waste.

• Insect infestation. Flies breed in some constituents of solid wastes, and flies are very effective vectors that spread disease. Mosquitoes breed in blocked drains and in rainwater that is retained in discarded cans, tires and other objects. Mosquitoes spread disease, including malaria and dengue. Rats find shelter and food in waste dumps. Rats consume and spoil food, spread disease, damage electrical cables and other materials and inflict unpleasant bites.

• Generally, MSW in Asia contains large fractions of organic matter which cause contamination to soil, water, and air upon decomposition. The decomposition of these wastes generates gases which impairs air quality in the immediate vicinity and, on a larger scale, contributes to the greenhouse effect and global warming.

• Risk in landfill stability. Stability of landfills was one of the major geotechnical tasks in landfill design and operation and has been a problem for years. The low density of waste reduced the surface flow of rainwater and evaporation, resulting in high rate of water infiltration. Besides, landfill leach ate decreased the shear strength of waste by mobilizing pore water pressure and flow pressure. Finally, this could trigger the possibility of landfill failure and lead to landslides as the landfill settles, festers, and slowly decomposes (Kosch and Ziehmann, 2004).

Due to many environmental drawbacks caused by open dumping or non-engineered landfills, the option to move into modern sanitary land filling is a better one, but still there would be possible potential problem, risk and contamination. Though, sanitary landfills could minimize emissions, it can only delay emissions. Understanding this problem is very important in handling and managing solid waste in future perspectives. This section provides necessary insights related to problems linked with direct disposal of solid waste in sanitary landfill.

• Modern sanitary landfills are designed with impervious liners, and leach ate collection, removal, and treatment systems to minimize the potential for groundwater contamination (Chanthikul et al., 2004). However, even modern landfills that employ state-of-the-art technologies such as liners and leach ate collection systems are quandary for if they are not leaking now; they would probably start leaking within a few decades of their closure (Tamm magi, 1999).

• Fugitive release of landfill gases occurs even in highly engineered system. In this regard, post closure monitoring is necessary and requires additional investment that would make direct land filling unattractive.

• Fires on disposal sites can cause major air pollution, causing illness and reducing visibility, making disposal sites dangerously unstable, causing explosions of cans, and possibly spreading to adjacent property.

• Natural degradation of solid waste in landfills occurs in a very slow process and may continue over scores for years and may require several decades for completion (Vieitez et al., 2000). Also, they added that waste degradation in landfills extends for periods of 20-40 years and it takes decades for the methane content to reach 50%. In this regard, landfills were known to create lasting detrimental environmental issues.

• Unreasonable standard of disposal site is due to the lack of training of workers on landfill site and insufficient financial and physical resources. As a result, some sites quickly degenerate into open dumps. It is crucial to maintain good operations behaving motivated and trained labors.

1.3 Conclusion

Proper solid waste management in developing economies in Asia is an important aspect to consider in minimizing further environmental contamination. Awareness on the problems and impacts associated with solid waste generation, collection and transport, and disposal must be promoted through campaign and education. The government should take an initiative to improve or modify the solid waste management system and create good monitoring system. Also, the public and private participation plays an important aspect for the success of the government solid waste management program. A community based solid waste management system could deliver positive impact towards proper waste collection in certain municipality and should be encouraged. Waste minimization through proper waste segregation of valuable items could not only help in reducing waste generation but also could generate extra income. Direct disposal of solid waste into open dumps or landfills should be discouraged. As already learned, the organic material contained in waste is the primary cause of potential emissions (leach ate and landfill gas) and aesthetic nuisance. Processing of organic fraction of waste (kitchen waste and yard waste) by composting or anaerobic digestion is sustainable options that produce reusable material such as compost or biogas. Inert fractions of waste can be therefore managed by sanitary landfill. Plastic and other combustible fraction in waste can be processed for RDF production which promotes "waste to energy" option. Waste should not be treated as a waste for it is able to sustain part of living needs. Also, should be managed appropriately in order to preserve the environment and resources.

2. "SOLID WASTE GENERATION IN THAILAND" BY PRESENTATION OF ENVIRONMENTAL MANAGEMENT, 2008, INDUSTRIAL WASTE MANAGEMENT VII, SONGKLANAKARINTR UNIVERSITY

Area	Standard generation rate (g/capita/d)
Bangkok	1,000
เทศบาลนคร/เทศบาลเมือง	800
เทศบาลตำบล	600
องค์การบริหารส่วนตำบล	400

Table A3-1: Municipal Solid Waste Management in Thailand

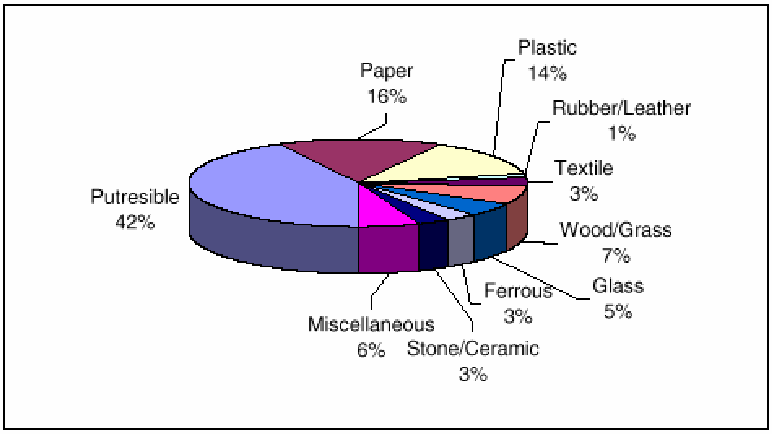


Figure A3-1: Chart shows composition of MSW in Thailand

3. "WASTE MANAGEMENT PRACTICES, MUNICIPAL, HAZARDOUS, AND INDUSTRIAL" BY JOHN PICHTEL, 2005 CRC PLACE, TAYLOR AND FRANCIS

Density and Moisture Content of MSW

Density is a useful parameter for the waste characterization as it provides information for predicting storage volume, including as-discarded at a residence or commercial facility, after compaction in a collection trunk and after compaction within a landfill cell.

The materials in MSW were crushed, waste density would sharply increase some compaction occurs during storage in piles, baling, and other size-reduction techniques also decrease irregularity and increase density (Liu and Liptak, 2000). MSW compacted in a landfill ranges in density from 300 to 900 kg/m3 (Sincero and Sincero, 1996; KielyShreddin, 1997).

Volume reduction has a significant impact on the cost of collection and hauling MSW. Collection trucks are space-limited; therefore, greater compaction capabilities will result in a greater density of MSW and more cost-effective hauling. High-pressure compaction using stationary balers can greatly

The density of MSW can be calculated on an as-compacted or as-discarded basis. The compaction ratio r is defined as the ratio of the as-compacted density ρc to the as-discarded density ρd and is given by

$$r = \rho_{c} / \rho_{d}$$

Waste Source	Component of Waste	Density (kg/m³)	Moisture Content (% by Wt)
Domestic	Food	290	70
	Paper products	70	5
	Plastic	60	2
	Glass	200	2
	Metals	200	2
	Clothing and textiles	60	10
	Ashes, dust	500	8
Municipal	Uncompacted	60–120	20
	Baled waste	470–900	—
	Compacted in collection truck	300–400	40
	Compacted in landfill	300–890	50

Adapted from Vesilind, P.A. et al., *Environmental Engineering*, 2nd ed., Butterworths, Boston, MA, 1998. Reproduced with kind permission of Elsevier Publishing.

Figure A3-2: Density and Moisture Content of MSW

APPENDIX A4

DATA OF INTERNAL GAS ENGINE AND EXHAUST GAS COMPOSITION

1. INTERNAL GAS ENGINE

Figure A4-1: 200GF119-M Gen-Set

Engine Model	6250M	B6250	B6250ML1	B6250MT
Gen-Set Model	180GF2	200GF120-M	200GF119-M	220M2GF2
Spec.				
Cylinder Number	6			
Bar X Stroke	250 X 300			
Rated Speed/ rpm	600	750		
Continuous Output/ kW	199	221	221	243
Fuel	Marsh Gas	Marsh Gas	Biomass Gas	Natural Gas
Rated Output/ kW	180	220	200	220
Rated Voltage/ V	400/230			
Rated Current/ A	325	361		397
Rated Frequency/ Hz	50			
Power Factor (lagging)	0.8			
Phases No. and Wiring	3 phases and 4 wires			
Exciting Method	Brushless			
Rotation Direction of Gen-Set	Clockwise from Generator side			
Cooling Method	Forced Open Water-Cooling			
Starting Method	Compressed Air (2.45~1.45MPa)			
Fuel Consumption/ MJ/kW·H	12.6	12	16.5	16.5
Gen-Set Size/ mm	5227x1350x2245	5170x1350x2500	5227x1350x2245	
Gen-Set Weight/ kg	12000			

Main Electric Performance of Gen-Set:
1. setting of the ideal gen-set not less than 95105% of the rated voltage
2. the performance index of voltage and frequency of the gen-set

Voltage				Frequency			
Stable Regulation %	Instant Regulation %	Recovery Time S	Fluctuation %	Stable Regulation %	Instant Regulation %	Recovery Time S	Fluctuation %
± 5	>25 / <20	5	1.5	8(0-8), adjustable	± 8	15	2

Note: 1. The frequency does not include the influence of the instant fire-off over the engine frequency
2. While calculating the stable voltage the variation from cold to hot stage is not included.

Table A4-1: Main Specification of Series 250 Biomass Gas Engine and Gen-Set

The technology of gas generator set is that of utilization of regenerated energy resources, which, by means of gasification technology, converts the waste of agriculture, such as rice husk, wood chip, straw, animal manure, household garbage, sewage, etc. into combustible gas, which, after the process of dust/tar removal, dewatering and cooling, goes into the gas engine for combustion and acting to drive the generation, thus converting the thermal energy into power.

2. SYNTHESIS GAS COMPOSITION

Refer to the give data from the plant as follow,

Gasifier of MSW fuel calculation

A basic model

Purpose: 1) To demonstrate the calculation of gasifier calculation for MSW solid waste as an example
2) To illustrate the material and energy balance of the gasifier

Information needed:

1) The characteristic of gasification process or gasifier to be used and also the purpose of synthetic gas to be used such as the feedstocks for production of other chemicals, the combustion for flue gas to produce steam from BFW, or the combustion of flue gas to produce electricity (IGCC) etc.
2) From the specified gasification process, we need to state the synthetic gas reference composition from the stated fuel used (in this case MSW) for drawing the process flow chart for the downstream process
3) The ultimate analysis, proximate analysis, heating value of fuel used for the calculation of the material and energy balance of the gasification process. This will need the heat flow requirement of the synthetic gas as well if we want to use it as an alternative fuel.

Criteria:

1) In case of no equilibrium constant of water gas shift reaction, methanation reaction and the methane reforming reaction, we will use the straight reaction (complete) instead assuming the hydrogen gas produced is enough for the synthetic gas component.

Calculation:

1) The material and energy balance of the gasifier

Picture:

1) Gasifier
2) The Internal Gas Engine

Figure A4-2: Gasifier of MSW fuel Calculation

Figure A4-3: Gasifier; 1 = MSW Feed, 2 = Fluidized Bed, 3 = Ash, 4 = Hot synthesis gas

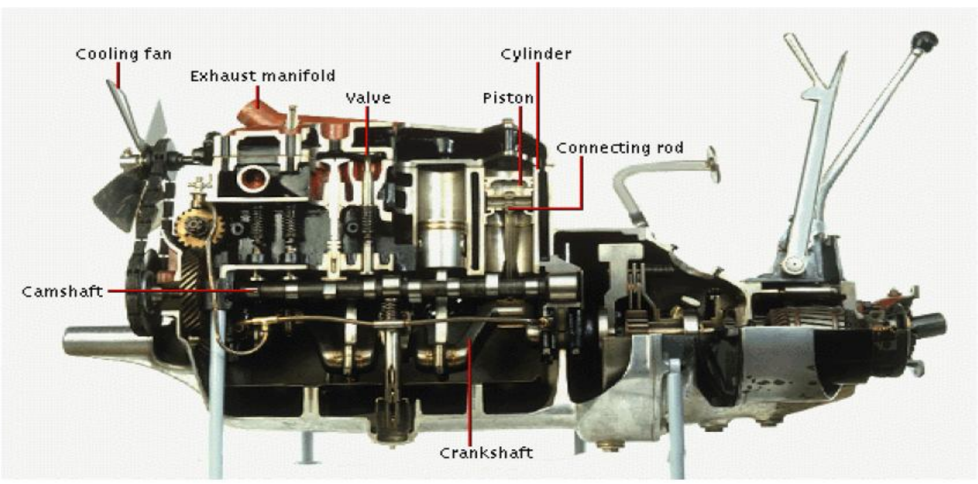


Figure A4-4: Internal Combustion Engine

Calculation details

Condition:

1) From the application of the gasifier, in this case, we will use the synthetic gas to produce the heat content supporting the electricity production with the internal gas engine to 400 kW (efficiency @ 25% so we have to produce 1600 kW)

2) Given the value of the heat content for the internal gas engine to produce electricity = **1376673.04** kcal/hr at the efficiency of 25%

3) The data of the MSW compositions is as follows (WB):
(After drying it to the moisture of 20% by the hot synthetic gas itself)

C	39.808	%
H	5.6	%
S	0.12	%
N	0.216	%
O	28.528	%
Cl	0.208	%
Moisture	20	%
Ash content	5.52	%
Heating value	2654	kcal/kg (after drying)

4) The data of the synthetic gas as reference is as follows:
(DB)

CO2 (mol%)	7.5	Note that this is only reference analysis
CO (mol%)	31	
H2 (mol%)	18.9	
CH4 (mol%)	2.1	
N2 (mol%)	40.5	

The moisture of this synthetic gas is 20 mol% (approx.)
We have to calculate for the synthetic gas composition and compare to this

Figure A4-4: Conditions of calculation

Calculation of Material balance:

1) The amount of MSW feed to the gasification at 20% safety factor = 622.4596 kg/hr
Assume that the efficiency of gasifier = 70%, then
the actual amount of MSW feed = 889.2279 kg/hr
21.34147 tons / day

2) The components of MSW feed

C	29.49865	kmol/hr
H	49.79676	kmol/hr
O	15.85493	kmol/hr
S	0.033346	kmol/hr
N	0.137195	kmol/hr
H2O	9.88031	kmol/hr
Cl	0.052101	kmol/hr

Figure A4-5: Calculation for Material balance

3) Calculate the complete combustion of MSW from stoichiometric balance

$C + O_2 \rightarrow CO_2$
$2H + 1/2O_2 \rightarrow H_2O$
$S + O_2 \rightarrow SO_2$

From the first reaction, we have		
O_2 consumed =	29.49865	kmol/hr
From the second reaction, we have		
O_2 consumed =	12.44919	kmol/hr
From the third reaction, we have		
O_2 consumed =	0.033346	kmol/hr
Total O_2 consumed according to stoichiometric balance	**41.98119**	kmol/hr
From O component in MSW, we have		
O_2 generated =	7.927467	kmol/hr
Net O_2 consumed for MSW	**34.05372**	kmol/hr
drawn from air	762.8034	Nm3/hr
N_2 from drawn air =	2869.594	Nm3/hr
	128.1069	kmol/hr
Total air drawn (DB)	3632.397	Nm3/hr
	162.1606	kmol/hr

Consider that the moisture of MSW is high and we need less H_2O for water gas shift reaction and steam reforming reaction; then we have to add less air (up to 21.4%) for combustion

Figure A4-6: Stoichiometric balancing

4) Calculate the amount of air fed to the gasifier at 21.4% of stoichiometric air consumption (DB)

O_2 drawn inside for gasification process =	163.2399342	Nm3/hr	7.287497	kmol/hr
N_2 drawn inside for gasification process =	614.0930859	Nm3/hr	27.41487	kmol/hr
Moisture in air at 50% relative humidity at 30 C = 0.00135 g H_2O / g dry air				
Amount of moisture in air =	1.351101956	kg/hr	0.075061	kmol/hr
			34.77743	kmol/hr

Figure A4-7: Calculate the amount of air fed to the gasifier at 21.4% of stoichiometric air consumption on Dry Basis (DB)

5) N_2 balance

From total N_2 input = total N_2 output

N_2 input to gasifier:		
N_2 from air fed at 21.4% of stoichiometric balance =	27.41487	kmol/hr
N_2 from fuel fed Nitrogen forming to N_2 =	0.068598	kmol/hr
Total N_2 input	27.48347	kmol/hr

Figure A4- 8: Nitrogen balancing

6) Iterative calculation:

6.1) Start up Tar formation and combustion

From some literature from China, the tar content will make up to 10%		
of synthetic gas calorific value or =	137667.3	kcal/hr
Literature showed the heating value of tar =	30000	kcal/kg
Tar output =	4.58891	kg/hr
Select the type of tar to be aromatic $C_8H_{13}O_2$ (MW = 141), then		
amount of kmol/hr of tar =	0.032545	kmol/hr
C (kmol/hr) in tar =	0.260364	kmol/hr
H (kmol/hr) in tar =	0.423091	kmol/hr
O (kmol/hr) in tar =	0.065091	kmol/hr
Let's start up with C react with tar and then part of C to CO_2 =	29.49865	kmol/hr
0.05 kmol/hr of C reacted with O_2; then C left =	29.44865	kmol/hr
Amount of C (kmol/hr) left from tar formation =	29.18829	kmol/hr
O_2 used for CO_2 formation in this stage =	0.05	kmol/hr
($C + O_2 \rightarrow CO_2$)		
CO_2 occurred =	0.05	kmol/hr
O_2 in air left out now =	7.237497	kmol/hr
This oxygen will react with H to form H_2O and S to form SO_2 and therefore (depleted)		
S (kmol/hr) consumed ($S+O_2 \rightarrow SO_2$)	0.033346	kmol/hr
SO_2 occurred =	0.033346	kmol/hr
O_2 in air left out now =	7.204151	kmol/hr
H (kmol/hr) consumed ($2H + 1/2O_2 \rightarrow H_2O$) and O_2 in air depleted =	28.8166	kmol/hr
H (kmol/hr) consumed for HCl	0.052101	kmol/hr
H_2O occurred =	14.4083	kmol/hr

6.2) Look back at fuel feed, then we get

C left from tar and CO_2 formation =	29.18829	kmol/hr
H left from tar, H_2O and HCl formation =	20.50497	kmol/hr
Overall H_2O from feed and formation at this 1st stage =	24.28861	kmol/hr

Figure A4-9: Calculation details

6.3) From the reaction of

$C + O \rightarrow CO$
$2H + 1/2O_2 \rightarrow H_2O$
$C + H_2O \leftrightarrow CO + H_2$
$CO + H_2O \leftrightarrow CO_2 + H_2$
$C + 2H_2 \leftrightarrow CH_4$

We start from the reaction of O in fuel feed to be consumed for H2O formation by depleting H =	10.25248	kmol/hr
H2O occurred =	10.25248	kmol/hr
Then total H2O existed =	34.5411	kmol/hr
O from fuel feed left =	5.537359	kmol/hr
O reacted with C to form CO =	5.537359	kmol/hr
(O from fuel feed depleted)		
CO occurred =	5.537359	kmol/hr
C consumed =	5.537359	kmol/hr
C left =	23.65093	kmol/hr

6.4) Based on the ratio of CO:CO2 = 4.13:1, we can iteratively calculate from CO = 1.302827 kmol/hr to have CO2 = 0.315 kmol/hr and every CO = 4.13 kmol/hr occurred there will be CO2 1 kmol/hr occurred

With this we have number of times to have CO and CO2 occurred =	4.548915	times
Round up to	4.2	times
Then, the CO kmol/hr will be	22.88336	kmol/hr
The CO2 occurred will be	4.515	kmol/hr
C left =	2.104932	kmol/hr
H2O consumed =	22.176	kmol/hr
H2O left =	12.3651	kmol/hr
H2 occurred =	22.176	kmol/hr

6.5) C left = 2.104932 kmol/hr react with 2H2 --> CH4

H2 consumed =	4.209863	kmol/hr
H2 left =	17.96614	kmol/hr
CH4 occurred =	2.104932	kmol/hr

Figure A4-10: Calculation details

7) Summary:

		% (WB)	% (DB)
CO2 (kmol/hr)	4.565	5.218598222	6.083792
CO (kmol/hr)	22.88336	26.15970593	30.49673
H2 (kmol/hr)	17.96614	20.53845544	23.94353
CH4 (kmol/hr)	2.104932	2.406307239	2.80525
N2 (kmol/hr)	27.48347	31.41843912	36.62732
H2O (kmol/hr)	12.44016	14.22128886	0
Tar (kmol/hr)	0.032545	0.037205189	0.043373
SO2 (kmol/hr)	0.033346	0.038120399	0.04444
HCl (kmol/hr)	0.052101	0.059560887	0.069436
Total (kmol/hr)	87.4756	100	100

Figure A4-11: Syngas output from gasifier

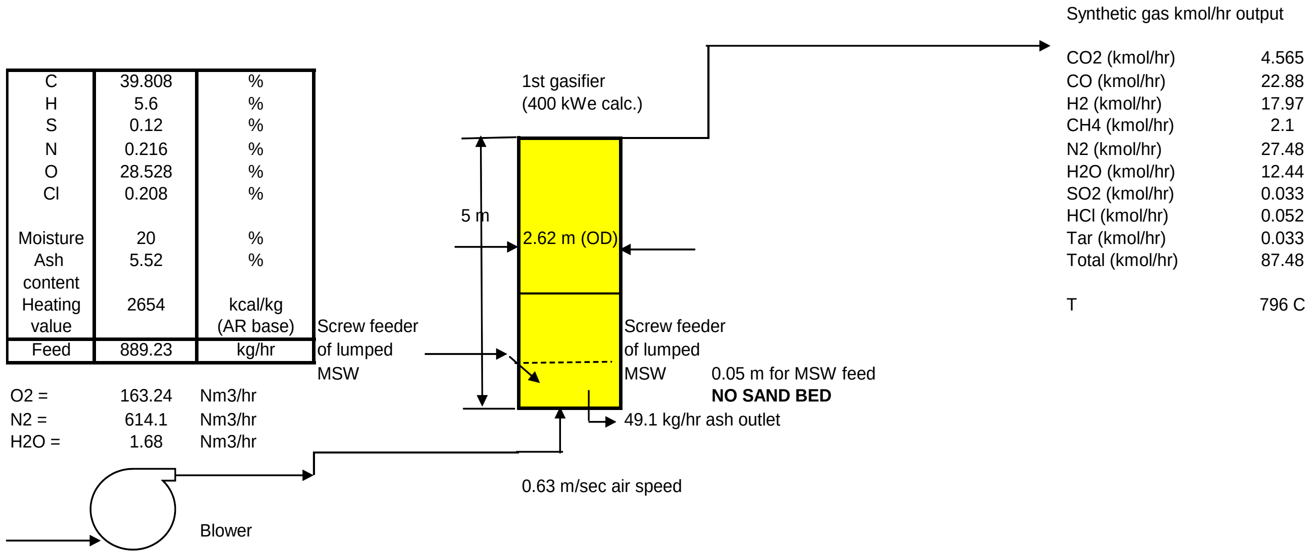


Figure A4-12: Block Diagram of 400 KWe, MSW Process

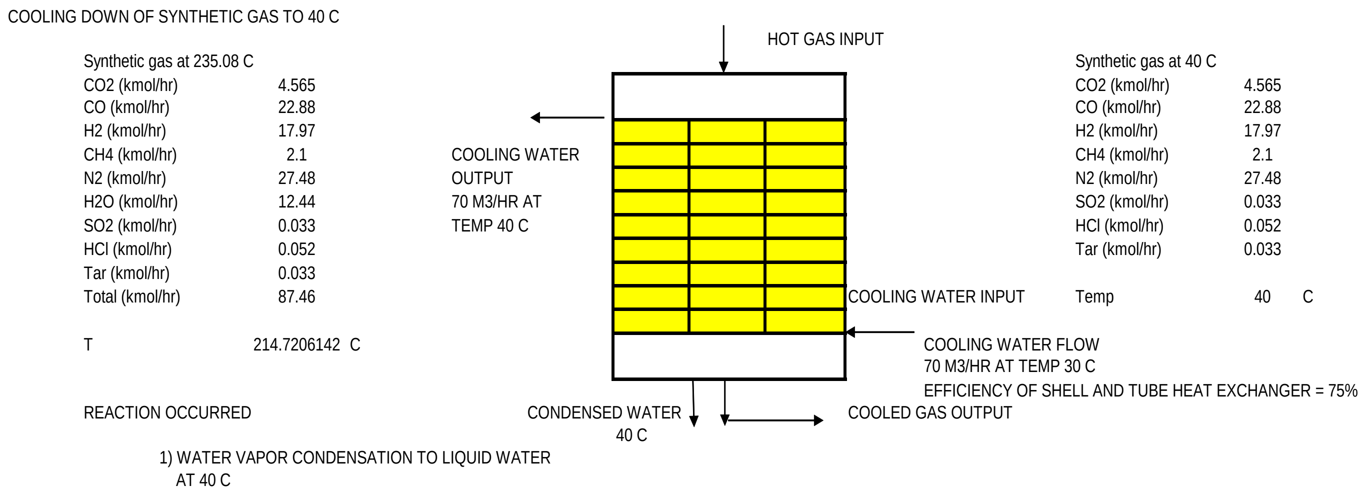
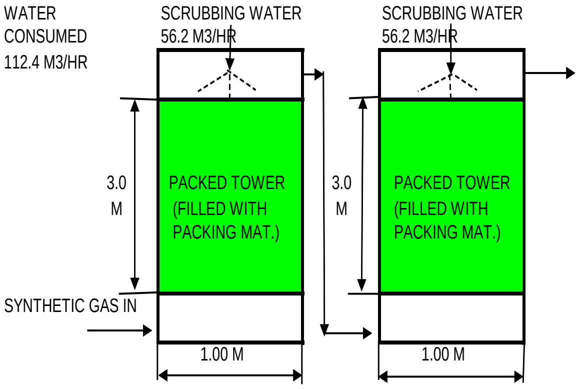


Figure A4-13: Cooling down of synthesis gas

ACID GAS SCRUBBER (SO2 AND HCL)

Synthetic gas at 40 C	
CO2 (kmol/hr)	4.565
CO (kmol/hr)	22.88
H2 (kmol/hr)	17.97
CH4 (kmol/hr)	2.1
N2 (kmol/hr)	27.48
SO2 (kmol/hr)	0.033
HCl (kmol/hr)	0.052



Synthetic gas at 40 C	
CO2 (kmol/hr)	4.565
CO (kmol/hr)	22.88
H2 (kmol/hr)	17.97
CH4 (kmol/hr)	2.1
N2 (kmol/hr)	27.48
SO2 (kmol/hr)	0.0033
HCl (kmol/hr)	0.0052

LOW ENOUGH TO CAUSE NO PROBLEM
FOR SO2 AND HCL

Tar is then, reduced by using wet ESP or catalytic reactor to convert tar to H_2 and CO

Figure A4-14: Acid gas scrubber

Synthetic gas at 40 C	
CO_2 (kmol/hr)	4.565
CO (kmol/hr)	22.88
H_2 (kmol/hr)	17.97
CH_4 (kmol/hr)	2.1
N_2 (kmol/hr)	27.48
SO_2 (kmol/hr)	0.0033
HCl (kmol/hr)	0.0052

Air at 30 C (0% excess)	
O_2 (kmol/hr)	24.625
N_2 (kmol/hr)	92.6369
H_2O (kmol/hr)	0.253638
Total	117.5155

INTERNAL GAS ENGINE

Flue gas output Material balance:	
CO_2 (kmol/hr)	29.545
H_2O (kmol/hr)	22.42364
N_2 (kmol/hr)	120.1169
O_2 (kmol/hr)	0
SO_2 (kmol/hr)	0.0033
HCl (kmol/hr)	0.0052

Energy balance:
INPUT:

GAS	Nm3/hr	Cp	Temp diff.	kcal/hr
CO_2	102.256	0.334	10	341.535
CO	512.512	0.516	10	2644.562
H_2	402.528	0.316	10	1271.988
CH_4	47.04	0.6	10	282.24
N_2	615.552	0.405	10	2492.986
SO_2	0.07392	0.5783	10	0.427479
HCl	0.11648	0.3388	10	0.394634
	1680.078			
AIR				
O_2	551.6	0.3115	0	0
N_2	2075.067	0.405	0	0
H_2O	5.68148	0.404	0	0
TOTAL				7034.133

REACTION OCCURRED:
HEAT RELEASED:

	$CO + 1/2\ O_2 \rightarrow CO_2$	(283000 kJ/kmol)	
	$H_2 + 1/2O_2 \rightarrow H_2O$	(242000 kJ/kmol)	
	$CH_4 + 2O_2 \rightarrow CO_2 + 2\ H_2O$	(803000 kJ/kmol)	
			12510080 kJ/hr
			2989981 kcal/hr
TOTAL			2997015 kcal/hr

OUTPUT:

OUTPUT OF ENERGY TO ENGINE =	344168.3 kcal/hr
OUTPUT OF FLUE GAS:	2652847 kcal/hr

	Nm3/hr	Cp	Temp. diff	kcal/hr
CO_2	661.808	0.334	1752.5	387379.4
H_2O	502.2895	0.404	1752.5	355626
N_2	2690.619	0.405	1752.5	1909700
O_2	0	0.3115	1752.5	0
SO_2	0.07392	0.5783	1752.5	74.91576
HCl	0.11648	0.3388	1752.5	69.15965
				2652850

TEMP FLUE GAS OUTPUT = 1782.5 C
(without cooling by cooling water)

TEMP FLUE GAS OUTPUT AFTER COOLING WITH WATER AND LUBRICATION 468.125 C Based on 25% efficiency and constant Cp

	Nm3/hr	Cp	Temp. diff	kcal/hr	kg/hr
CO_2	661.808	0.334	438.125	96844.85	1299.98
H_2O	502.2895	0.404	438.125	88906.49	403.6255
N_2	2690.619	0.405	438.125	477425.1	3363.273
O_2	0	0.3115	438.125	0	0
SO_2	0.07392	0.5783	438.125	18.72894	0.2112
HCl	0.11648	0.3388	438.125	17.28991	0.1898
				663212.4	5067.28

Difference in energy = 1989637 kcal/hr

Amount of water to be used without lubrication = 30609.8 kg/hr
(Temp. not exceeding 100 C) 30.6098 m3/hr
0.510163 m3/min
(0.60 m3/min)

Figure A4-14: Synthetic gas firing in internal gas engine

APPENDIX A5

ENERGY UNIT CONVERSION

CONVERSION US · UK · METRIC · SI UNITS
FOR THERMAL ENGINEERS
BASICS | GRUNDLÆGGENDE

Heat Content & Energy
1 kJ | kN·m = 0,9478 Btu
1 kJ | kN·m = 0,2388 Kcal
1 Btu = 1,055 kJ
1 Btu = 0,2520 Kcal
1 kcal = 4,187 kJ
1 kcal = 3,968 Btu
1 kWh = 3600 kJ
1 kWh = 859,8 Kcal

Heat Load | Power
1 kW = 3412 Btu/h
1 kW = 859,8 Kcal/h
1 Btu/h = 2,931·10-4 kW
1 Btu/h = 0,2520 Kcal/h
1 kcal/h = 1,163·10-3 kW
1 kcal/h = 3,968 Btu/h
1 Boiler HP = 9,81 kW

1 Joule (J) is the MKS unit of energy, equal to the force of one Newton acting through one meter.

1 Watt is the power of a Joule of energy per second

Power = Current x Voltage (P = I V)

1 Watt is the power from a current of 1 Ampere flowing through 1 Volt.

1 kilowatt is a thousand Watts.

1 kilowatt-hour is the energy of one kilowatt power flowing for one hour. (E = P t).

1 kilowatt-hour (kWh) = 3.6 x 106 J = 3.6 million Joules

1 calorie of heat is the amount needed to raise 1 gram of water 1 degree Centigrade.

1 calorie (cal) = 4.184 J

(The Calories in food ratings are actually kilocalories.)

A BTU (British thermal unit) is the amount of heat necessary to raise one pound of water by 1 degree Fahrenheit (F).

1 British Thermal Unit (BTU) = 1055 J (The Mechanical Equivalent of Heat Relation)

1 BTU = 252 cal = 1.055 kJ

1 Quad = 1015 BTU (World energy usage is about 300 Quads/year, US is about 100 Quads/year in 1996.)

1 therm = 100,000 BTU

1,000 kWh = 3.41 million BTU

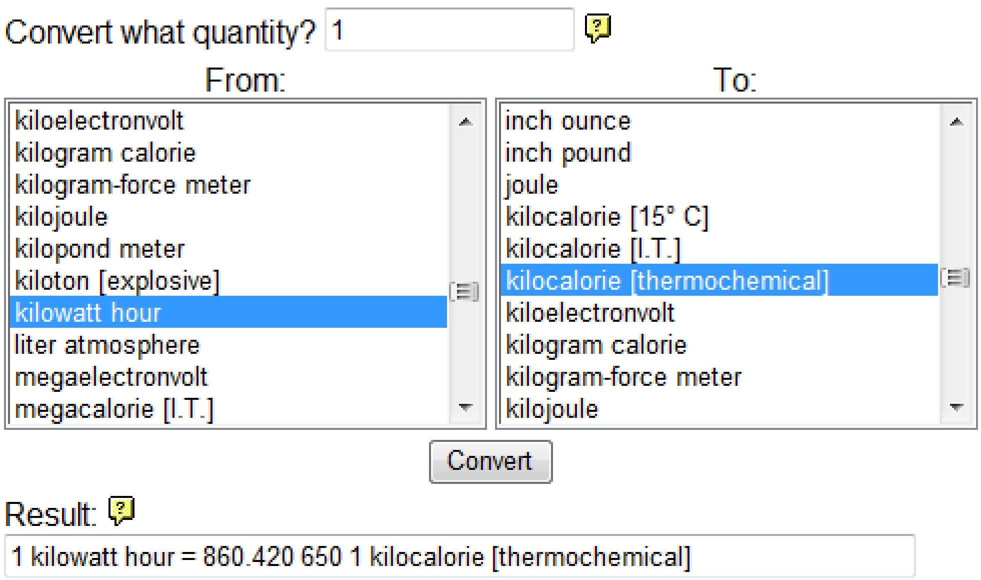


Figure A5-1: Unit conversion (from http://www.onlineconversion.com/energy.htm)

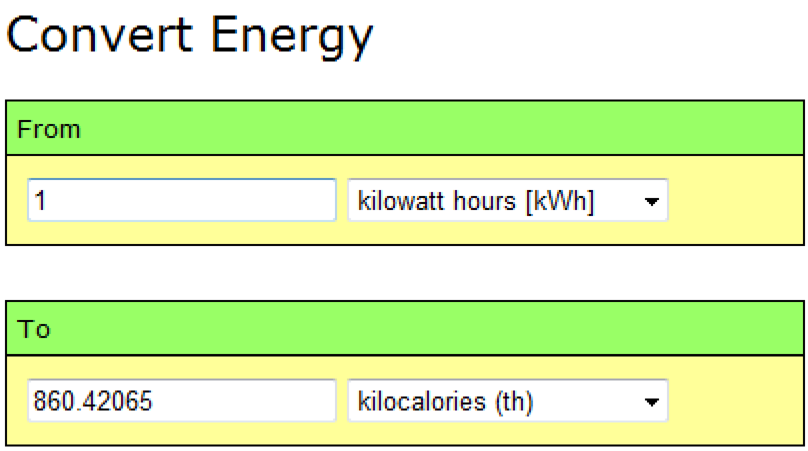


Figure A5-2: Unit conversion (from http://www.digitaldutch.com/unitconverter/energy.htm)

APPENDIX A6

HEATING VALUE

1. INTRODUCTION

For fuels where the precise fuel composition is not known, the enthalpy of the reactants cannot be determined from the enthalpies of formation of the reactant species. The heating value of the fuel is then measured directly

The heating value QHV or calorific value of a fuel is the magnitude of the heat of reaction at constant pressure or at constant volume at standard temperature [usually 25ºC] for the complete combustion of unit mass of fuel

The complete combustion means that all carbon is converted to CO2,, all hydrogen is converted to H2O, and any sulfur present is converted to SO2

In term of higher heating value QHHV is used when the H2O formed is all condensed to the liquid phase; in term of lower heating value QLHV is used when the H2O formed is all in the vapor phase

2. HOW TO MEASURE QUANTITIES AND HEATING VALUES

Fuels are measured for trading purposes and to monitor processes which produce or use them. The units of measurement employed at the point of measurement of the fuel flow are those which are the best suited to its physical state (solid, liquid or gas) and require the simplest measuring instruments. These units are termed the natural units for the fuel (the term physical unit is also used). Typical examples are mass units for solid fuels (kilograms or tones) and volume units for liquids and gases (liters or cubic meters). There are some exceptions, of course; fuel wood, for instance, is often measured in cubic meters or in a volume unit employed locally.

Electrical energy is measured in an energy unit, kilowatt-hour (kWh). Quantities of heat in steam flows are calculated from measurements of the pressure and temperature of the steam and may be expressed in calories or joules. Apart from the measurements to derive the heat content of steam, heat flows are rarely measured but inferred from the fuel used to produce them.

It is also common to convert liquids measured in liters or gallons to tones. This enables the total quantity of different liquid products to be calculated. Conversion from volume to mass requires the densities of the liquids.

Once it is expressed in its natural unit, a fuel quantity may be converted into another unit. There are several reasons for doing so: comparing fuel quantities, estimating efficiency, etc. The most usual unit is an energy unit because the heat-raising potential of the fuel is often the reason for its purchase or use. Use of energy units also permits the summing of the energy content of different fuels in different physical states.

The conversion of a fuel quantity from natural units or some intermediate unit (such as mass) into energy units requires a conversion factor which expresses the heat obtained from one unit of the fuel. This conversion factor is termed the calorific value or heating value of the fuel. Typical expression of the values would be 26gigajoule/tone (GJ/t) for a coal or 35.6 mega joule/cubic meter (MJ/m3) for a gas. In this Manual the term" calorific value" will be used although "heating value" is also in widespread use.

The calorific value of a fuel is obtained by measurement in a laboratory specializing in fuel quality determination. Major fuel producers (mining companies, refineries, etc.) will measure the calorific value and other qualities of the fuels they produce. The actual methods used to measure calorific values are not important for this Manual but the presence of water in fuel combustion will influence calorific value and this is discussed below.

3. THE DIFFERENCE BETWEEN GROSS AND NET CALORIFIC VALUE

Most fuels are mixtures of carbon and hydrogen and these are the main heating agents. There may be other elements which do not contribute, or contribute only slightly, to the calorific value of the fuel. Both the carbon and the hydrogen combine with oxygen during combustion and the reactions provide the heat. When the hydrogen combines with oxygen, it forms water in a gaseous or vapor state at the high temperature of the combustion. The water is therefore almost always carried away with the other products of combustion in the exhaust gases from the apparatus in which the combustion takes place (boiler, engine, furnace, etc.).

When the exhaust gases cool, the water will condense into a liquid state and release heat, known as latent heat, which is wasted in the atmosphere. The heating value of a fuel may, therefore, be expressed as a gross value or a net value. The gross value includes all of the heat released from the fuel, including any carried away in the water formed during combustion. The net value excludes the latent heat of the water formed during combustion. It is important when obtaining a calorific value to check whether it is net or gross. The differences between net and gross are typically about 5% to 6% of the gross value for solid and liquid fuels, and about 10% for natural gas.

There are a few fuels which contain no, or very little, hydrogen (for example blast furnace gas, high-temperature cokes and some petroleum cokes). In these cases there will be negligible differences between net and gross calorific values.

The derivation of net calorific values for solid fuels is further complicated because they often contain water trapped within the fuel in addition to the water which will be formed from the hydrogen they contain. The reduction in net calorific value as a result of the additional water is uncertain because the dampness of the fuel may vary according to weather and storage conditions.

In summary, the net calorific value of a fuel is the total heat produced by burning it, minus the heat needed to evaporate the water present in the fuel or produced during its combustion. Major users of solid fuels, such as power stations, should be able to provide net calorific values based on the monitoring of the electricity generation.

APPENDIX A7

MATRIX DECISION

1. Making Difficult Decisions: The Weighted Criteria Decision Matrix

As business professionals, we are constantly being asked to make decisions. How much staffing will be required to meet our needs next year? What is the best investment for improving capacity? What new products or services should we be developing to best serve our customers? Some of these decisions are considered "no brainers" and can be quickly made. Others, however, are more complex and need careful review before a final decision can be made. One tool that can be used to help in the decision-making process is called the Weighted Criteria Decision Matrix (or Decision Matrix for short).

2. How it works

Suppose you and your spouse have decided to go on a vacation. You have narrowed your options down to four destinations – Hawaii, Las Vegas, Niagara Falls, and a Caribbean Cruise. You both agree that all of your options are good. So how do you select the best one?

Using the Decision Matrix, you would:

1. List each of the options/alternatives to consider along the columns of your matrix.

2. Brainstorm and identify the top criteria for your evaluation and list them along the rows of your matrix. What are the important factors to consider when making the decision?

3. Assign a "Criteria Weight" to each criterion that you have listed. The most important criteria would get the higher "weighting" as jointly determined, in this case, by you and your wife.

4. For each alternative, assign a "score" based upon how well it satisfies the criteria (high score = highly satisfies criteria).

5. Multiply each score by its criteria weight and total the values for each alternative. This would be your "Weighted Score."

6. The option with the highest weighted score would be considered the "best" alternative based upon your criteria weighting and scores. In our example, the Caribbean Cruise would be the best option.

❷	❸	❶ Score *			
Criteria	**Criteria Weight ***	**Hawaii**	**Las Vegas**	**Niagara Falls**	**Caribbean Cruise**
Expense	10	3 ❹	8	9	5
Romantic Potential	10	10	3	7	9
Things To Do	6	8	6	6	10
Travel Time	4	7	3	2	4
Shopping Potential	3	3	7	5	9
Relaxation Potential	8	10	4	6	8
Weather	7	10	7	5	9
	❺ **Weighted Score:**	**365**	**260**	**302**	**370** ❻

**1 = Low / 10 = High*

Figure A7-1: How to construct a decision matrix

3. Benefits of Using the Decision Matrix

1. It provides a framework for identifying the options to consider and important criteria for making a decision.

2. It can be used by teams to reach consensus around decisions (using voting techniques).

3. It allows people to make decisions using both quantitative (measurable) and qualitative (subjective) information.

4. It documents the thinking that was used to make the final decision. What factors were considered? How well does the final selection meet the needs of the stakeholders? What would have to change to reach a different conclusion?

APPENDIX A8

MINIMUM FLUIDIZED VELOCITY

by the Presentation of the University of Texas at Austin, Unit Operation ChE 354

1. Fixed and Fluidized Beds

Low Velocity: Fluid does not impart enough drag to overcome gravity and particles do not move, called Fixed Bed.

High Velocity: At high enough velocities fluid drag plus buoyancy overcomes the gravity force and the bed expands, called Fluidized Bed.

2. Minimum Fluidization

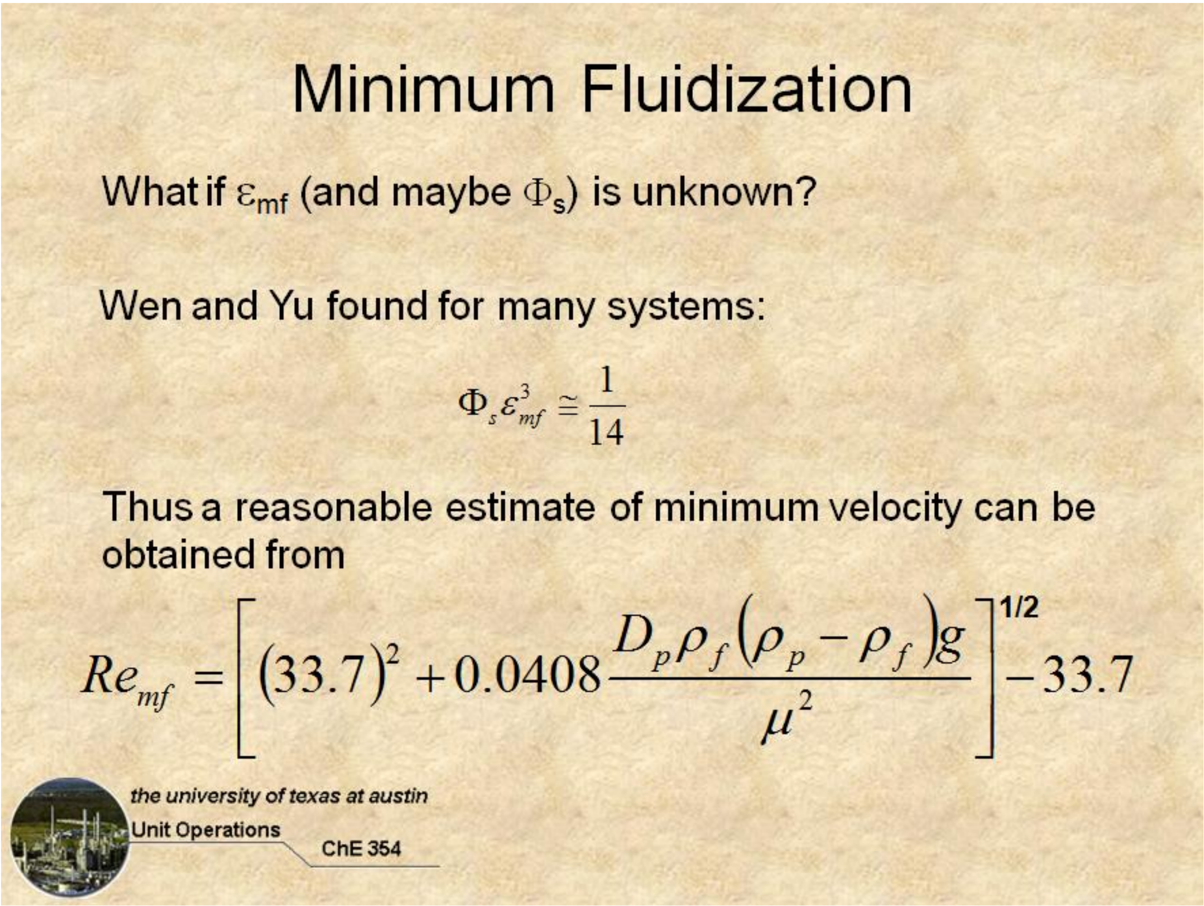


Figure A8-1: Minimum Fluidized Velocity

APPENDIX A9

THE EXAMPLE OF AVAILABLE DRYER ON MARKET

Sukup Tower Dryer Specifications

	U1012	U1212	U1512	U1812	U2012	U2412
Bu/Hr. 20% - 15%*	1000	1200	1500	1800	2000	2400
Bu/Hr. 25%-15%*	600	720	900	1080	1200	1440
Heat Holding Bu.	615	737	915	1113	1275	1521
Cool Holding Bu.	215	288	305	400	434	481
Total Holding Bu.	1299	1494	1689	1982	2178	2471
Drying Airflow (CFM)	48,000	62,300	77,800	85,600	94,600	110,300
Burner Cap. (BTUx1000)	11,000	13,457	16,805	18,490	20,434	23,825
Ave. Heat (BTUx1000)	6500	7738	9663	10,632	11,749	13,699
Blower HP	50 hp Axial	60	75	75	100	100
AC Drive Metering HP	3/4	1 ½	1 ½	1 ½	1 ½	1 ½
Grain Column	12.75"	12.75"	12.75"	12.75"	12.75"	12.75"
Tower Diameter	12'0"	12'0"	12'0"	12'0"	12'0"	12'0"
Overall Height	48'	54'	61'	71'	78'	88'

	U2518	U3018	U3518	U4018	U4718	U5024	U6024	U7024
Bu/Hr. 20% - 15%*	2500	3000	3500	4000	4700	5000	6000	7000
Bu/Hr. 25%-15%*	1500	1800	2100	2400	2820	3000	3600	4200
Heat Holding Bu.	1472	1925	2208	2642	2941	3469	4026	4436
Cool Holding Bu.	642	642	812	831	1136	1238	1295	1499
Total Holding Bu.	3090	3543	3996	4449	5053	6336	6950	7564
Drying Airflow (CFM)	128,550	148,200	174,300	206,400	226,200	275,100	296,100	343,500
Burner Cap. (BTUx1000)	27,767	32,011	37,649	44,582	48,859	59,422	63,958	74,196
Ave. Heat (BTUx1000)	15,966	18,406	21,648	25,635	28,094	34,167	36,776	42,663
Blower HP	(3) 40	(3) 50	(3) 60	(3) 75	(3) 75	(3)100	(3) 100	(3)125
AC Drive Metering HP	2	2	2	2	2	3	3	3
Grain Column	12.75"	12.75"	12.75"	12.75"	12.75"	12.75"	12.75"	12.75"
Tower Diameter	18'0"	18'0"	18'0"	18'0"	18'0"	24'0"	24'0"	24'0"
Overall Height	68'	78'	88'	98'	111'	100'	110'	120'

Sukup Manufacturing Co provides this information to assist you in choosing the optimal equipment for your situation. Many factors, such as grain variety, maturity levels, grain cleanliness, weather conditions and operation/management, can affect the performance of your tower dryer and results may vary. This information is calculated and is not a guarantee of product specifications or performance. Based on these factors, Sukup specifications should only be used as estimates, and not as a warranty, express or implied, of how a particular Sukup unit will perform under your operating conditions. Because we are continually improving Sukup products, changes may occur that may not be reflected in the specifications.

*BU/Hr (bushels per hour) listed are wet bushels, No. 2 shelled yellow corn at listed moisture content and are estimates based on drying principles, field results and/or computer simulation.

Figure A9-1: Tower Dryer Specifications

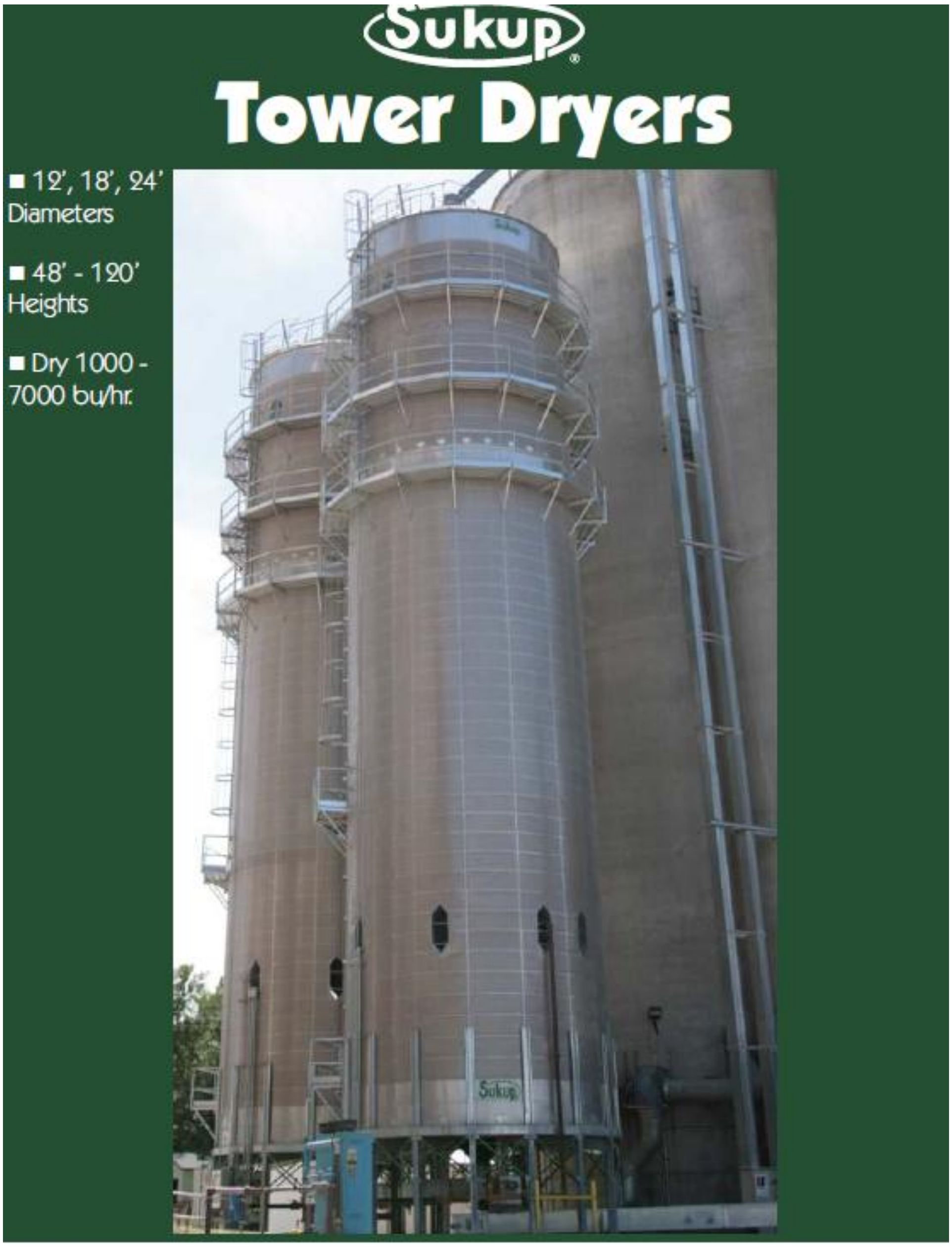


Figure A9-2: One of the tower