Techno Economic Evaluation of MSW Gasification for Power Generation

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***Abstract*— Energy recovery from biomass and municipal solid waste (MSW) by gasification technology has attracted significant interest because it satisfies a key requirement of environmental sustainability by producing near zero emissions. Though it is not a new technology, studies on its integrated process simulation and analysis are limited, in particular for (MSW) gasification. This paper develops a gasification process by using the Advanced System for Process Engineering (Aspen) Plus software for evaluation of its technology performance. Using the develop model.computational model was developed on the basis of Gibbs free energy minimization. The model of gasification process the effect of operating conditions, gasification temperature, air to fuel ratio and moisture content. Gasification temperature and air to fuel ratio affect the synthesis gas produce while moisture content only gave minimal change toward the gas composition. By using pilot scale downdraft gasifier, tar was collected and analysed. Cleaner gas collected after flow through series of filter bed consists of sawdust and activated carbon. In terms of economic, all the calculation and result was based from small scale of 10 tonne/day MSW plant. The operation of this plant can generate RM 1.124 million of revenue per year with payback period of 6.85. The rate of return of investment (ROROI) is positive at 6.31% per annum and cumulative cash flow is positive.**

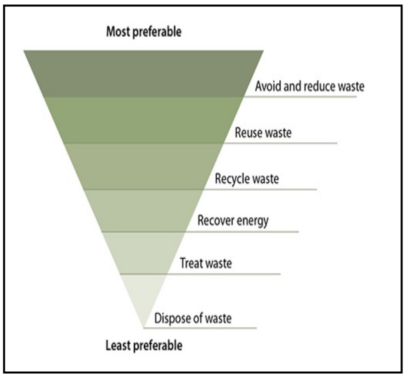
***Keywords*— MSW, techno economic, Aspen Plus**

I. INTRODUCTION

Solid waste management (SWM) is one of the major threatening environmental issues in the world especially in developing countries. The biggest fraction of the solid waste generation is municipal solid waste (MSW). MSW can be defined as type of solid waste generated from community, commercial and agricultural operations. This includes wastes from households, offices, stores and other non-manufacturing.As a developing country, Malaysia population continue to increase from year to year. According to the Department Of Statistic Malaysia (2016), as of 2016, Malaysia's population is 31.7 million with a growth rate of 1.5% per year. These indicate that there will be an increase in the generation of MSW from year to year.

By the year of 2025, Malaysia will generate 1.4 kg of MSW per person in day (Badgie *et al.,*2015). By assuming that, the population of Malaysia at that time is around 36.5 million, this will cause of 5103.7 tonne of MSW generation per day. A step need to be taken for handling this serious problem. Integrated solid waste management (ISWM) refers to the strategic approach to sustainable management of solid wastes covering all sources and all aspects. It covers generation, segregation, transfer, sorting, treatment, recovery and disposal in an integrated manner, with an emphasis on maximizing resource use efficiency. Many governments around the world have implements this strategy in handling their waste, including the MSW. They emphasis on the reduction of the waste and reuse it whenever possible. A recycle culture is being teach to the citizen to create awareness toward the environment. Waste prevention and minimisation also include under the ISWM.

Fig. 1.Waste Hierarchy



Malaysia initiates privatization in 1993, to facilitate handling of MSW through on integrated management system. Company such as Alam Flora Sdn Bhd is one of few companies that involve in this sector (Abas and Wee, 2014.)

Energy recovery which is in this case, waste to energy ,WTE is also one of the method to deal with the MSW. Incineration and gasification are example of the WTE. In developed country such as Japan, they have adopted the incineration method since 1960. According to the Japan Ministry of Environment, in the fiscal year 2009, there were 1243 incineration facilities in Japan, incinerating garbage using several methods such as stoker furnaces, fluidized bed furnaces and gasification fusion resource furnaces with the objective of ash recycling .

Malaysia also applied to this technique with the built of 4 small scale incinerator across the country. However, various issues arise as the incinerator is say to use unproven technology which concern the citizen. On top of that, the incinerator is still not in operation since 2014. For example, the Tioman incinerator has a capacity of 15 tonnes per day, at a cost of RM520.70 per tonne [Ying *et al*, 2014]. The MSW disposal in peak tourist seasons is between six to eight tonne while on daily disposal is about 4 tonne. This put a burden on the local authority to think for other MSW treatment on such an island. Furthermore, the government is now built the country first mega incinerator in Kepong that will be able to turn 1000 tonnes of waste to energy every day (Pathma,2014) Hopefully, these facilities can become a benchmark for the future.

Waste to energy(WTE) method which is gasification process is developed after technology around the world. The ability to produce a synthesis gas that able to run the turbine is exciting since it can be utilized as fuel for power generation. According to Power

House Energy Group USA, it WTE gasification plant in Nashviller ,Tennessee can produce up to 36,000 MW per hour of electricity which is sufficient to provide for 350 average homes. This is the result of 64 tonne/day of refuse derive fuel (RDF) put into it downdraft gasifier. Therefore, it is not impossible for Malaysia to have a WTE gasification plant.

In Malaysia, the use of landfills as an approach to handle the MSW generations is being employed to the low cost and the vast land the nation have. However, in the future, the land that is available to be used as landfills will be reduced while the populations is increasing. Figure 2 show the percentage component of MSW generated in Kuala Lumpur.

Sources	Residential high income (%)	Residential medium income (%)	Residential low income (%)	Commercial (%)	Institutional (%)
Food/organic	30.84	38.42	54.04	41.48	22.36
Mix paper	9.75	7.22	6.37	8.92	11.27
Newsprint	6.05	7.76	3.72	7.13	4.31
High grade paper	-	1.02	-	0.35	-
Corrugated paper	1.37	1.75	1.53	2.19	1.12
Plastic (rigid)	3.85	3.57	1.90	3.56	3.56
Plastic (film)	21.62	14.75	8.91	12.79	11.82
Plastic (foam)	0.74	1.72	0.85	0.83	4.12
Pampers	6.49	7.58	5.83	3.80	1.69
Textile	1.43	3.55	5.47	1.91	4.65
Rubber/leather	0.48	1.78	1.46	0.80	2.07
Wood	5.83	1.39	0.86	0.96	9.84
Yard	6.12	1.12	2.03	5.75	0.87
Glass (clear)	1.58	2.07	1.21	2.90	0.28
Glass (colored)	1.17	2.02	0.09	1.82	0.24
Ferrous	1.93	3.05	2.25	2.47	3.75
Non-ferrous	0.17	0.00	0.18	0.55	1.55
Aluminum	0.34	0.08	0.39	0.25	0.04
Batteries/hazards	0.22	0.18	-	0.29	0.06
Fine	-	0.71	2.66	0.00	0.39
Other organic	0.02	0.00	-	1.26	1.00
Other inorganic	-	0.27	0.25	-	8.05
Others	-	-	-	-	6.97
Total	100.00	100.00	100.00	100.00	100.00

Fig. 2. Average Composition Weight Percentage of Components in MSW generated By Various Sources in Kuala Lumpur

Therefore, the use of other options such as incineration and gasification is a must to prepare for the future. Despite that the incineration technology is a wise choice if it is design and run properly, the public still concern on the product of the incineration. The biggest problem is the dioxins that were removed by filters and held in fly ash. The problem of ash disposal became a problem when it was discovered that a toxic mix of ash from incinerators had been used as path material for allotments around Newcastle upon Tyne in United Kingdom (D.Waller,2001)

Gasification is considered as clean option compared to incineration in terms of environmental friendly and energy efficiency. It produce low quantity of pollutants while only need minimum pollution control equipment. The flexibility of gasification in utilize wide range of fuel is exciting. It can utilize lower price feedstock such as coal and MSW into something valuable. However, the gasification plant for power generation is more difficult to design and operate compare to conventional power plant. The fuel that need to have low moisture content before using it as feed for gasifier while hydrogen-rich syn gas might be explosive and difficult to handle. The synthesis gas produced from gasification is capable to power a turbine for electric generation purposes. In order to imply these technology in Malaysia, a deep evaluation in terms of technology and economic must be done. The evaluation of gasification from technological and economic perspective will provide a knowledge and view on the utilization of gasification in real scenario. Formation of tar and gas composition will be the main objective in evaluating the technological part of gasification. The gas composition varied by changing process conditions such as air to fuel ratio, gasification temperature and moisture content. In economic aspect, gasification is evaluated by assessing if the operating the MSW gasification plant can generate revenue and the capital recovered in plant operation time.

II. METHODOLOGY

A. Tar formation

MSW that will be put into the reactor will be weighed first during the experiment to know the composition of the MSW. The type of gasifier use is pilot scale downdraft gasifier with inductive draft air. There is gas filter separately connected for the smale scale downdraft gasifier to filter out the particulate matter out from the gasifier. There is also a flare connected to the gasifier to burn excess gas. All the opening at the gasifier must be tight close to ensure the temperature can achieve 800°C. The point where the sample is taken must be before and after the filtration process to know how much tar is remove from the sample. Figure 3 show the arrangement of experiment for the pilot scale gasification. Generally, biomass gasification undergoes the following steps in a gasifier:

1. The biomass particle decomposes quickly to form char, gaseous products and tar
2. Reactions between the gaseous products
3. Tar cracking and char gasification
4. During gasification of biomass, the following reactions are take place.

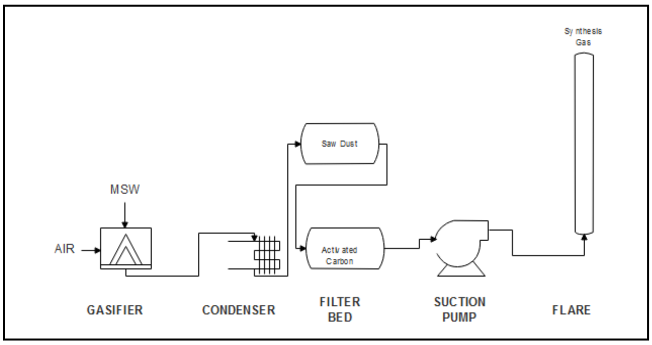


Fig. 3:Process flow diagram of pilot scale downdraft gasifier

Several reactions involve in gasification to produce synthesis gas.

Basic Combustion Reaction

$$C + 1/2O_2 \rightarrow CO \quad (1)$$

$$C + O_2 \rightarrow CO_2 \quad (2)$$

Boudouard Reaction

$$C + CO_2 \rightarrow 2CO \quad (3)$$

Water Gas Shif tReaction

$$C + H_2O \rightarrow CO + H_2 \quad (4)$$

Methanation Reaction

$$C + 2H_2 \rightarrow CH_4 \quad (5)$$

Shift Conversion

$$CO + H_2O \rightarrow Co_2 + H_2 \quad (6)$$

Steam Reforming Of Methane

$$CH_4+H_2O \rightarrow CO+3H_2 \quad (7)$$

B. Analysis of synthesis gas (syn gas) composition

A simulation by using process simulation tool, Aspen Plus will investigate the important parameter for the gasification such as temperature, moisture content and the air-fuel ratio. This simulation intent to know what is the change in parameter effect toward the composition of gas produce from the gasification. Aspen Plus is choose due to it capability to simulate solid handling with accurate heat and mass balances based on property method choose. Proximate and ultimate analysis is based on the MSW composition in Malaysia to relate it with the MSW used in pilot scale gasification for tar formation.

The property method use is Peng-Robinson equation of state with Boston Mathias modifications (PR-BM) Calculator block is used to enter FORTRAN Statement. Two FORTRAN subroutines have been used in the simulation. First is used to specify the conversion of MSW to form water in the RStoic block because the value of conversion was entered temporarily in the block. Second FORTRAN statement is used first to convert the ultimate analysis from dry to wet basis and secondly to calculate the yield istribution of MSW in the RYield block. The parameter used for the simulation is stated in table. Table 2,3 and 4 explained regarding the information and paramete use in simulate gasification process.

Table 2: Proximate Analysis Of MSW (wt% dry basis).

Element	Value (%)
Moisture Content	50
Fixed Carbon	8.33
Volatile Matter	83.93
Ash	7.74

Table 3:Ultimate Analysis of MSW (wt% dry basis).

Element	Value (%)
Carbon	50.77
Hydrogen	8.1
Oxygen	33.29
Nitrogen	0.01

Table 4:Parameter for MSW gasification simulation.

	Gasifier	Air	MSW
Temperature (°C)	200-800	25	25
Pressure (Bar)	1 Bar		
Mass Flow Rate (kg/hr)		0.01	10

The gasification process simulated by using Aspen Plus consists of several blocks which is:

1. Drying block
2. Decompose block
3. Gasification block
4. Separation block

Aspen Plus simulates the process through a sequence based on how the equipment model is placed. The simulation sheet is shown on the figure 4 while the model used is represented on table 5.

Table 5:Aspen Block in gasification simulation

Operation	Aspen Plus Model	Function
Drying	RStoic	Converts a portion of coal to form water. Requires only extent of reaction to be known. MSW→ 0.0555084 H2O
	Flash 2	Rstoic has single outlet stream so Flash2 is used to separate dried MSW from moist nitrogen.
Gasification	Ryield	Decomposes the MSW into its constituent elements based on ultimate analysis
	Rgibbs	Simulates gasification of dry MSW. Models chemical equilibrium by minimizing Gibbs free energy.
Separation	Ssplit	Separates combustion gases from ash.

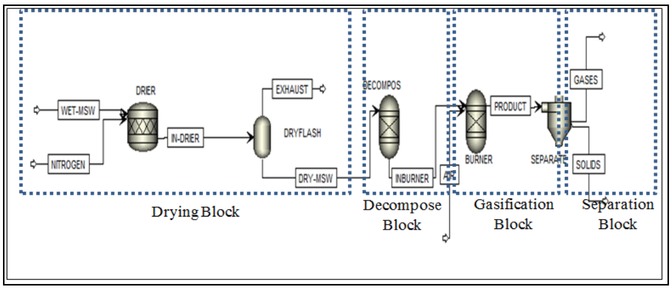


Fig. 4. Aspen Plus gasification flowsheet

C. Economic Evaluation

The economic model was calculated based on the initial estimation of accounting item from the sale of the generated energy such as total plant costs, total operating costs, taxation and direct revenues. All economic point of evaluation has been focused to time value of money adjustment.

The future costs and revenues have been discounted to current worth based on a fixed discount rate of 6% per year. This is required to evaluate investment options that might add to costs and revenues in different time points alongside their estimated life. According to the current national fiscal imposition in Malaysia, taxation is set at 28 %. Local taxation coefficient has not been applied because specific localization has not been foreseen for the plant.

D. Revenue Generation

Calculation of revenue is important to evaluate for the if the operating bring profit for the operator

Revenue = electric generated x 24 hour x 330 days x tariff rate

E. Profitability Analysis

Profitability analysis of the gasification plant determine by calculating several factor.

1. Payback period (PBP)
2. Rate of return on investment (ROROI)
3. Cumulative cash position (CCP)
4. Cumulative cash ratio (CCR)

This analysis will give a clear indicator whether the operation of gasification plant is feasible or not.

III. RESULTS AND DISCUSSION

A. Tar Formation

Tar formation is the main problem of gasification. The comparison was made based on 2 samples that collected at different location of the gasifier to solve the tar formation or syn gas produces

i. Bottom of the pipe that connect the gasifier to the condenser
ii. Bottom of the 2nd filter bed (activated carbon)

In order to measure the tar yield under different reaction conditions, it was collected in two bubblers where a mixture of methanol and chloroform was used for dissolving tar. One bubbler was kept at room temperature, while the other one was kept at dry ice temperature. The condensed water and readily condensable tar was collected in the first bubbler and light tar was condensed under dry ice condition in the second bubbler.

The tar was defined as the amount of left over organic materials when the tar mixed solvent mixture was dried at 35oC for 4 hours. According to this, the tar yield was calculated and summarized in Table 4.3. For each measurement, approximately 3g of solution out of 70g were taken on and placed upon aluminium tray and the tray was put in an oven at 35oC for 4 h.

Under this temperature, all the solvent is evaporated, while the heavier organic compounds (tar) were remained on the tray. From the initial and final weight of the tray with and without the sample, the tar yield was calculated. The following equations were used to calculate the total tar, tar yield and tar concentration in product gas. Before proceeded to tar analysis, the solution was filtered to remove contains of huge particles

$$\text{Total tar per gram feedstock, X} = \frac{\text{wt of tar in 1 g solution}}{\text{wt of total feedstock fed}} \text{ x wt of total solution} \quad (6)$$

Figure 5 and 6 show the tar formation after gasification. The solution that is initially colourless has turned into dark grey after passing raw gas. Therefore this is an early indicator for the present of tar after gasification.

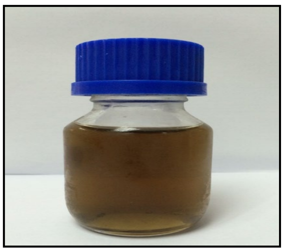


Fig. 5:Tar formation before filter bed

After the raw gas flow through condenser and two filter beds consist of sawdust and activated carbon. Another sample is taken. This is to know the effectiveness of the type of material use as a filter to trap the tar.

Fig. 6: Tar formation after filter bed

After the raw gas flow through condenser and two filter beds consist of sawdust and activated carbon. Another sample is taken. This is to know the effectiveness of the type of material use as a filter to trap the tar.

By referring to the figure 6, the after effects of filter beds show the solution that is clear. This is an indicator that the saw dust and activated carbon can be used to eliminate tar and purify syn gas produced. Total concentration of tar remove shown in table 11.

Table 11: Tar concentration

	Before Filter	After Filter Bed
Tar concentration (mg/m^3)	191.07	23.19

Total tar removal from raw gases is 88% by calculating using following equation.

$$\text{Tar removal} = [\frac{191.07 - 23.19}{191.07}] \text{ x } 100\% = 88\% \quad (7)$$

Therefore, the use of sawdust and activated carbon is effective as gas cleaning agent.

B. Analysis of Synthesis Gas Composition

B(i). Effect of the temperature toward synthesis gas composition

The gasifier temperature was one of the most important factors on syngas production from MSW gasification. It affected the equilibrium of the reaction of the chemical reactions (Cimini *et al.*, 2005).The simulation was run by varying the temperature from 200°C to 1200°C with constant MSW inlet and air mass flow rate. This is to investigate the change in gas composition when temperatures increased. Early study predicted at the highest percentage of syn gas will be produce when the temperature reach 700°C and above.

At lower temperature, water in terms of water vapour dominate the composition of the gas since there is moisture content retained after drying process. Methane,(CH_4)also present at the lower temperature. Nitrogen monoxide, (NO) and nitrogen dioxide,(NO_2) does not present at the lower temperature however as the temperature increase, a trace of this component presented which resulted in lower nitrogen composition, N_2.

Carbon dioxide, (CO_2) which is usually the main product of combustion show highest percentage of gas composition at temperature 500°C and continue to decrease as temperature higher. This is completely opposite compare to carbon monoxide which dramatically increases in composition as the temperature past 500°C. Hydrogen that is the main component that made up syn gas show highest percentage of composition when gasification is at temperature of 700°C and slowly decline as the temperature increases. All the data regarding the effect of temperature toward gasification process is put in Table 12 and Figure 7.

Table 12: Gas Composition

Temperature, °C	**Gas Composition,%**								
	H_2O	N_2	O_2	H_2	CO	CO_2	CH_4	NO	NO_2
200	53	19.7	0	0.4	0	14.5	12.4	0	0
300	46.2	19.5	trace	2.6	0	17.4	14.2	0	0
400	38.8	18.8	trace	9.4	0.4	19.5	13.2	trace	0
500	29.1	17.4	trace	21.2	2.8	20.2	9.3	trace	trace
600	17.5	15.2	trace	33.4	12	17	4.8	trace	trace
700	13.9	13.8	trace	39.6	20.3	11.7	0.7	trace	trace
800	15	13.6	trace	39.1	22.7	9.6	0	trace	trace
900	16.3	13.6	trace	37.8	24	8.2	0	trace	trace
1000	17.3	13.6	trace	36.8	25	7.2	0	trace	trace
1100	18.1	13.6	trace	36	25.8	6.4	0	trace	trace
1200	18.8	13.6	trace	35.4	26.5	5.7	0	trace	trace

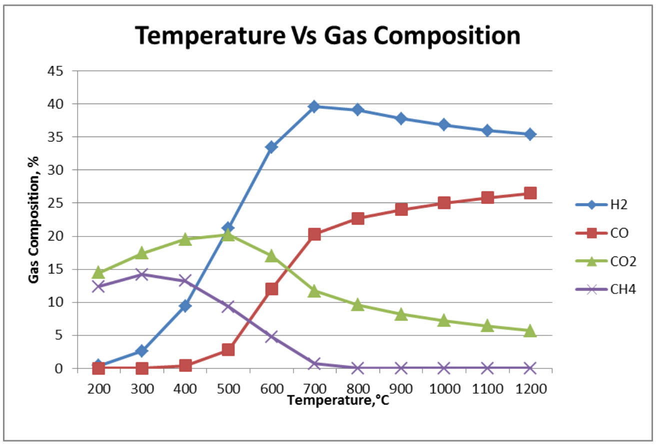
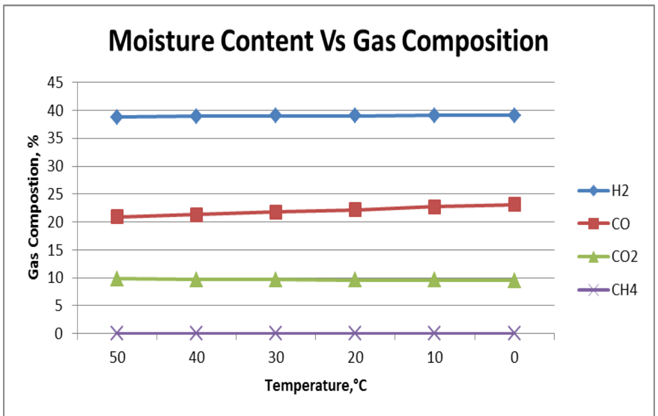


Fig. 7:Graph of gasification temperature versus gas composition

B(ii) Effect of the moisture content toward synthesis gas composition

The moisture content of MSW in Malaysia is high since it made up majorly of food wastes. Although any level of moisture content in MSW is not a problem for gasification but in real scenario, it takes a lot of energy to reduce the moisture content to acceptable. However, for this simulation, parameter been investigate is only about the effect of early moisture content toward syn gas produce. Table 13 and figure 8 show the data collected.



Moisture Content	Gas Composition,%								
	H_2O	N_2	O_2	H_2	CO	CO_2	CH_4	NO	NO_2
50	16.6	13.9	trace	38.8	20.9	9.8	0.00001	trace	trace
40	16.2	13.8	trace	38.9	21.3	9.7	0.00001	trace	trace
30	15.8	13.8	trace	39	21.8	9.7	0.00002	trace	trace
20	15.4	13.7	trace	39	22.2	9.6	0.0003	trace	trace
10	15	13.6	trace	39.1	22.7	9.6	0.0004	trace	trace
0	14.7	13.6	trace	39.1	23.1	9.5	0.001	trace	trace

Table 13: Gas Composition

Fig. 8: Graph of moisture content versus gas composition

Only slight changes detected on every composition of gas regardless of the initial moisture content. Therefore, moisture content does not affect the gas composition

B(iii) *Effect of Air to Fuel Ratio (AFR) toward gas composition*

Since the gasification is a partial combustion process. The amount of feed air into the system will produce more CO_2 than CO which will reduce the energy content of the syn gas. The amounts of air produce varying according to the value of air fuel ratio. The air fuel ratio will ranges from 1 to 0.01.

The H_2 and CO that made up the syn gas show increasing trend in volume of gas produce as the AFR decrease. Therefore, syn gas produce is inversely proportional to the air fuel ratio Figure 17 show the data collected from the simulation. CO_2 volumes decrease the air fuel ratio (AFR) decrease since less oxygen available for complete combustion.

Table 14: Gas Composition

Air Fuel Ratio (AFR)	Gas Composition,%								
	H2O	N2	O2	H2	CO	CO2	CH4	NO	NO2
1	23.6	54.1	trace	5.1	2.8	14.3	0	trace	trace
0.9	23.1	51.9	trace	7	3.9	14.1	0	trace	trace
0.8	22.6	49.4	trace	9.2	5.1	13.8	0	trace	trace
0.7	22	46.6	trace	11.5	6.4	13.5	0	trace	trace
0.6	21.3	43.5	trace	14.1	7.9	13.1	0	trace	trace
0.5	20.5	40	trace	17	9.6	12.7	0	trace	trace
0.4	19.7	36.1	trace	20.3	11.6	12.3	0	trace	trace
0.3	18.8	31.7	trace	24.1	13.7	11.7	0	trace	trace
0.2	17.7	26.5	trace	28.4	16.3	11.1	0	trace	trace
0.1	16.5	20.6	trace	33.3	19.2	10.4	0	trace	trace

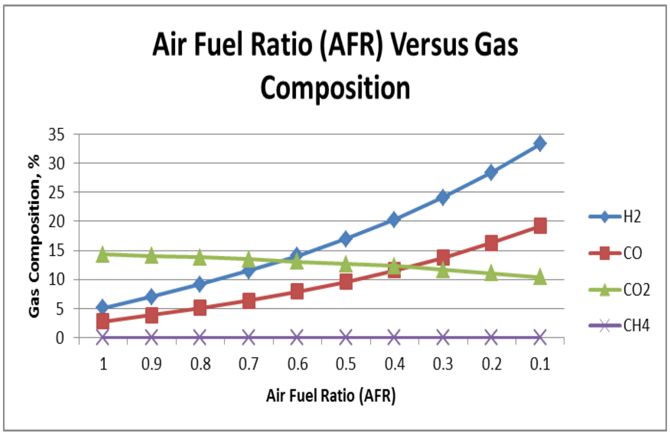


Fig. 9: Graph of Air Fuel Ratio (AFR) versus gas composition

C. *Economic Evaluation*

This part will be discussed on the economic feasibility for the installation of a power generating MSW gasifier for electricity For the purpose of this economic evaluation, the mass flow rate set for MSW is 10 tonne/day which is when simulated in Aspen Plus, capable of generating up to 262.83 kW of electricity. Most cost information was provided and obtained generally (Choy *et al.*,2015) . The total cost of the major plant equipment items which include the delivery cost is RM 1 million. The total direct cost of the plant that includes continuous-emission-monitoring (CEM) unit is RM 3.5 million. The CEM installed at the end of process line to monitor the quality of the gas emission does not exceed the government standard.

The indirect-cost items that are incurred in the construction of a plant are:

a) Engineering and supervision
b) Construction expense
c) Contractor's fee
d) Contingency

The total indirect plant cost of the MSW gasification process is RM 1.4 million. Hence, the fixed-capital investment of the MSW gasification plant is RM 5.5 million which is equal to the sum of the direct plant cost plus indirect plant cost and shown in table 15.

Table 15: Summary of total capital investment (TCI)

	Percent (%)	RM
Delivered-Equipment Cost		1000000
Direct Cost (Include Equipment cost)	63.64	3500000
Indirect Cost	25.45	1400000
Working Capital		550000
EIA and HAZOP	10.91	600000
Total Capital Investment	100	5500000

The total production cost is generally divided into the categories of manufacturing costs and general expenses. The manufacturing costs are divided into two groups which are fixed operating costs and variable operating costs. Fixed operating costs doesn't change as time pass by or change in production rate occur as long the capacity does not over the design production rates. Variable operating costs (VOC) is highly depend on the product and manufacturing process. This include item such as

a) Raw materials
b) Utilities
c) Miscellaneous operating materials
d) Shipping and packaging

The raw materials need is MSW, lime powder, and ammonium anyhydrous. Lime poweder ($CaOH_2$) is used for wet scrubbing to remove sulphur dioxide emission while ammonium anyhydrous used for selective catalytic reduction to convert NO_x gases into nitrogen and water.

Water is used for the steam generation for the generation by using steam turbine Potable water usage for the daily plant activities also included as the volume of water needed for operation of plant. The price for every meter cube usage of water is RM 2.00 as stated for the industry use by Syarikat Air Selangor (SYABAS). Electricity for the plant is supply by utility company, Tenaga Nasional Berhad (TNB) with industrial tariff rate of RM0.35 per kWh. The electricity is need to drive all the motor at plant and for daily usage. The value and cost for table 15,16,17 is after conversion (Choy *et al.*,2015)

Table 16:Variable operating cost

Variable Operating Cost	RM/Year
Utilities	225560
Raw Material	12643.2
Miscellaneous Materials	13000
Total	251203.2

Table 17:Total Production Cost

	Percent (%)	RM/Year
Fixed Operating Cost	81.09	405750
Variable Operating Cost	16.12	248003.2
General Expense	2.79	13500
Total Production Cost	100	667253.2

D. *Revenue generated*

For an electricity generation system, typically, 1 kg municipal solid waste can produce 0.4–0.6 kWh of electricity by the combustion process (Niessen,1995). Therefore, 10 tonnes per day of MSW can generate approximately 5000 kWh per day (208 kW) and the annual electricity generation is 1,650,000 kWh,

Based on our analysis of MSW in Malaysia and simulation by using Aspen Plus, 1 kg of MSW can generate 0.63 kWh. The margin of difference with literature is only 5%. The total generation of electricity that can be produced by using 10 tonnes of Malaysia MSW and plant operation of 330 days is 2081609 kWh per year. According to TNB, the tariff rate for selling the electricity for residential area is RM 0.54 per kWh. Therefore the revenue that will be generated will be RM 1124068.35 per year

E. *Profitability Analysis*

For the profitability analysis for the gasification plant. Few assumptions have been made.

a) The plant life is 10 year
b) The taxation rate for Malaysia is 25%
c) No discount rate
d) Total capital investment (TCI) divided into two years
e) The land price is RM 500,000

The total cumulative cash at the end of plant operation is RM 2.73 million. The time taken for all of the capital to recover or known as payback period is 6.8 years

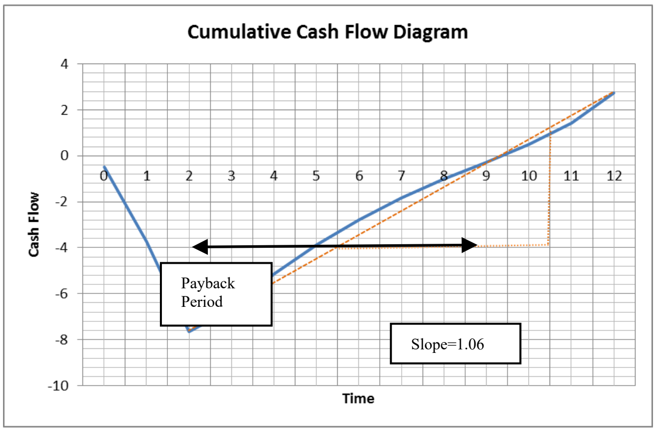


Fig.10:Cumulative Cash Flow Diagram

By 8th year of operation is the point where gasification plant will recover all the capital.

$$ROROI = \left(\frac{Slope}{FCI} - \frac{1}{n}\right)100\% = 6.31\% \quad (8)$$

ROROI is amount of return of an investment relative to the investment costs. This gasification show positive gain of an investment. This ROROI is important in comparing different kind of activities such when comparing between incineration and gasification technology to deal with MSW. The cumulative cash ratio is 1.36. Cumulative cash ratio act as early prediction if the project potentially profitable or not. Project with CCR greater than 1 is considered potentially profitable while ratios less than unity cannot be profitable. Therefore this project is profitable

IV. Conclusion

Tar formation that is the main issues of gasification solved with installation of saw dust and activated carbon as filter at pilot scale downdraft gasifier to reduce the NOx gas produce and tar. Thus, cleaner syn gas produced at the end of process line with less tar. In addition, filter beds do reduce the moisture of the gas produced. Physical examinations of the beds prove the inference as the bed is wet after that gasification.

Comparing tar contents before and after filter resulting in positive result. Tar contents reduce dramatically by 87.9%. The colour of the solution that is the medium for tar collection also becomes clear from dark brown.

Analysis of the parameter for the gasification on the temperature effect show that high volume of syn gas produce when temperature of gasification reaches 700°C onward The volume of H_2 decrease beyond 700°C but the volume of CO increase which counter the effect of H2 reduction. The moisture content give significant effect of the volume of syn gas produce at same temperature of gasification but perhaps it might affect the total energy need to reduce the moisture content to acceptable level. As for the air fuel ratio (AFR), high AFR will produce more CO2 while low AFR resulted in higher syn gas production.

Operating 10 tonnes/day gasification plant will generate RM 1.124 million of revenue per year with 330 working days. Payback period (PBD) which is the time taken to recover all the capital is 6.8 years from total of 10 years operation of plant. and cumulated cash flow is positive (+) with CCR ratio of 1.36.The value is an indicator that this project is profitable. The rate of return of investment (ROROI) is 6.31% per annum which is consider positive

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