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Waste Power Generation Analysis Using Landfill Gas

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Abstract: Landfill (Final Disposal Place) annually generates Landfill Gas (LFG) emissions which are the greenhouse gas emissions resulting from the decomposition of natural microorganisms in the landfill. To reduce these emissions into the atmosphere, it is necessary to review the implementation of Waste to Energy (WtE) Power Plant by using landfill gas (LFG) of Bandung waste city. The things that will be seen from this research is the operational time of the plant and the power that can be generated from the plant. The method that will be used is to simulate by using LandGEM software to know the modeling of LFG emission of Bandung City's waste by giving input data in the waste acceptance per year and Ebsilon Professional to know the electric power generated and the improvement of efficiency and power to determine the suitable system. From this research it is found that for mass flow rate 1.5 kg / s, the operational time of generation in real condition is 8 years and in new condition is 25 years. The maximum power value that WtE power plant can achieve by using this LFG is 10,584 MW with estimated electric generation cost is 498,36 (IDR)/KWh.

Keyword: LFG, Power Generated, Rankine Cycle.

INTRODUCTION

WtE power plant is a powerhouse that uses waste city as its fuel. WtE power plant uses solid waste (Municipal Solid Waste / MSW). There are several methods in processing of MSW like thermo-chemical, bio-chemical, and chemical. Thermochemical method is a method that uses heat in its waste processing to convert to mechanical energy and then to electrical energy by generator. For bio-chemical methods using microorganisms / bacteria in waste processing and for chemical methods using acids and alcohols in the waste processing [1].

Development of WtE power plant in Indonesia itself is still relatively slow. In 2011 to 2013, the power generated by WtE power plant remains the same / that is equal to 26 MW and in 2014 to 2015 get increase to 36 MW [2]. When compared with other countries, Indonesia is still very lagging behind. As in Singapore, they have produced 128 MW of electric power on 2015 [1]. Another example is the Indian state that has produced 274 MW of electric power by 2016 [1]. Therefore, it is necessary to develop the WtE power plant in Indonesia.

In fact, the use of WtE power plant has deficiencies in certain methods. In the combustion method, one of the drawbacks is the exhaust gas produced. The byproduct of this inceneration process is a toxic gas consisting of CO_2, NO, and dioxin / furans, and others [3]. Dioxin / dibenzo-p-dioxins is a toxic gas derived from the production waste gas, the bleaching process on paper pulp and in the combustion process for WtE power plant. Dioxin itself can damage hormones in the human body can even cause cancer. [3]

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In addition, the landfill can produce greenhouse gas emissions in the form of LFG (Landfill Gas). LFG is a natural byproduct of the decomposition of organic matter under anaerobic conditions (without oxygen). LFG contains about 50 to 55 percent methane and 45 to 50 percent carbon dioxide, with less than 1 percent of non-methane organic compounds (NMOCs) and trace amounts of inorganic compounds. Methane is a powerful greenhouse gas 28 to 36 times more effective than carbon dioxide in trapping heat in the atmosphere over a 100-year period. [4]

Therefore, it needs another method of waste treatment for environmentally friendly WtE power plant that use LFG in it's power generation process such as using landfill gas power generation. Landfill gas power generation is one of the technologies in WtE power generation that uses decomposing gases on waste which then the gas is burned so it can be used to heat the working fluid. The advantages of this landfill gas power generation are cheaper and suitable for countries that use centralized landfills such as Indonesia. [1], [3], [5].

LFG METHOD FOR WASTE TO ENERGY POWER GENERATION

LFG is a natural byproduct of the decomposition of organic matter under anaerobic conditions (without oxygen). LFG contains about 50 to 55 percent methane and 45 to 50 percent carbon dioxide, with less than 1 percent of non-methane organic compounds (NMOCs) and trace amounts of inorganic compounds. Methane is a powerful greenhouse gas 28 to 36 times more effective than carbon dioxide in trapping heat in the atmosphere over a 100-year period. [4]

When MSW is deposited in a landfill, the MSW is decomposed aerobically (with oxygen) with a small amount of methane produced. Furthermore, with a year's time, anaerobic conditions will form and methane-producing bacteria will form and will decompose waste and will produce methane. [4]

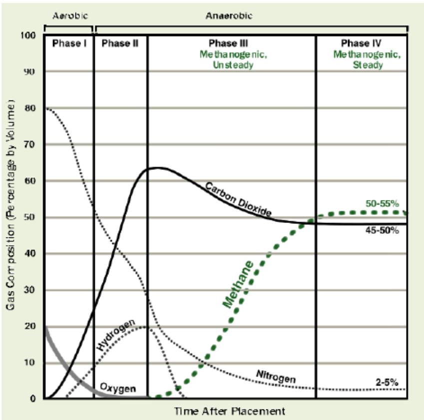

Fig. 1: Changes in LFG composition after waste dumping [4]

The figure above explain about the change composition og gas emissions produced by the natural microorganisms in the waste in the landfill. The phase of changing gas composition is divided into four phases, there are

- Phase 1 : is a phase where the work is aerobic bacteria. These bacteria work by consuming oxygen when breaking the molecular chains of carbohydrates, proteins and fats found in organic waste. The byproduct of this process is carbon dioxide. Phase 1 will continue until the oxygen is depleted [4]
- Phase 2 :This phase begins to use an anaerobic process that does not require oxygen. Bacteria alter the materials produced from aerobic bacteria into acetic, lactic and formic acid and alcohols such as methanol and ethanol. When the acid mixes with the existing moisture and nitrogen is consumed by the bacteria, then carbon dioxide and hydrogen are produced [4]
- Phase 3 :Anaerobic bacteria consume organic acids produced from phase 2 and form acetate. This process causes the Final Disposal Place to be a more neutral environment in which methane-producing bacteria will emerge by consuming carbon dioxide and acetate [4]
- Phase 4 :The composition and production rate of LFG will be relatively constant. LFG usually consists of 50-55% methane, 45-50% carbon dioxide and 2-5% other gases. Production of LFG in phase 4 will usually last for 20 years. [4]

LFG collection usually begins when a part of the landfill (so-called "cell") is closed for the addition of a dump. The collection system can be either vertical ditch or horizontal ditch. [4]

The most commonly used method of collecting LFG is by digging vertical wells and connecting well heads with LFG gas collection piping system which will carry LFG gas to the gas storage using a blower or vacuum system. Another type of gas collection system is using a horizontal system where the pipe will be laid horizontally in the well. This horizontal system is used for in deep landfill or active cell receiving waste. This system can also be combined between vertical wells and horizontal wells. The choice of this system depends on the characteristics of the landfill to be used. [4]

For controlling the emission, there are component such as flare and gas storage. Flare is a tool for powering and burning LFG. Flares are a component of any energy recovery option as they may be needed to control LFG emissions during startup and downtime of the energy recovery system and to control gases that exceed the capacity of energy conversion equipment. In addition, flare is a cost-effective way to gradually increase the size of energy generation systems in active landfills. As more waste is placed in the landfill and the gas collection system is expanded, the flare is used to control the excess gas between system upgrades and energy conversion [4]. Another way is to make gas storage. This gas storage will store the excess LFG so that when the downtime occurs then the gas storage results can be used so that the mass flow rate that will enter into the generation system can be maintained.

LFG MODELLING

In the fermentation process, LFG emission modeling in landfill can be modeled using LandGEM software. LandGEM is an excel microsoft based software developed by EPA. LandGEM itself uses a first-order decay equation in estimating the amount of LFG and methane produced by a landfill. [4]

$$Q_{CH4} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} kL_0 (\frac{M_i}{10}) e^{-kt_{ij}} \qquad (3.1)$$

With:

Q_{CH4}	=	Estimated methane generation flow rate (in cubic meters [m3] per year)
i	=	1-year time increment
n	=	(year of the calculation) – (initial year of waste acceptance)
j	=	0.1-year time increment
K	=	methane generation rate (1/year)
L_0	=	potential methane generation capacity (m3 per Mg or cubic feet per ton)
M_i	=	mass of solid waste disposed in the ith year (Mg or ton)
t_{ij}	=	Age of the jth section of waste mass disposed in the i_{th} year (decimal years)

In LFG gas modeling, the gas produced by the landfill is not fully utilized. There are gases that are lost due to this collection process so that in modeling it is necessary to pay attention to the efficiency of collection. The collection efficiency is a measure of the ability of the gas collection system to capture the LFG produced in the landfill. The estimated LFG production generated by the model is multiplied by the collection efficiency to estimate the recoverable LFG volume for combustion or use in LFG energy projects. The efficiency of LFG collection by landfills with vertical wells and / or horizontal wells covering 100% of the waste area produced has an efficiency ranging from 50% - 95%. In this research, the collecting efficiency value to be used is 80%. [4]

In LFG modeling that a landfill can be generated, the user needs the characteristics of a landfill in the form

- Landfill name
- Landfill open year
- Landfill closure year
- Landfill capacity (optional)
- Landfill waste acceptance rate (ton/year)

Furthermore, in modeling, users also need the characteristics of the existing waste in the landfill. Waste characteristic is required

- Methane generation rate (k)
- Methane generation rate capacity (Lo)
- NMOC Concentration

- Methane concentration

The rate of methane yield (k) is the rate of methane that can be produced by the landfill annually. The rate is significantly affected by weather conditions in the landfill area. The more humid / high rainfall in the landfill, the higher the kila. Because the landfill to be studied in this study is found in Bandung, Indonesia, the k value used is 0.3 where the k value is the average value in the tropics. [6]

The potential capacity of methane produced is the methane value that can be generated from a landfill. This value depends on the composition of the landfill. The more organic waste, the higher the Lo will be. In this study, the value of L_0 used is the default value where this value represents the average potential capacity of methane generated by 40 landfill. [4], [7]

NMOC concentration value (Nonmethane Organic Compound Concentration) is a residual gas which is the result of waste fermentation waste. This gas does not react and the value used for this NMOC uses the default value by CAA of 4000 ppm. For methane value in gas LFG also use default value that is 50% volume of LFG gas.

By using waste acceptance input per year by PD Kebersihan Bandung (the table below) City, the gas flow rate of LFG produced is as follows

Table 1: Waste acceptence of Sarimukti landfill

Year	Total Waste Acceptance (Ton)
2006	165.375
2007	328.764
2008	354.638
2009	326.088
2010	323.640
2011	347.027
2012	375.656
2013	382.071
2014	310.256
2015	316.130
2016	371.416
2017	401.933

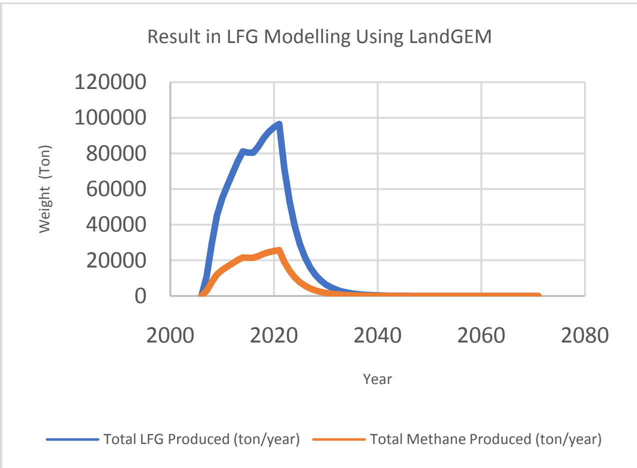

Fig. 2: Result in LFG Modelling

It can be seen that the maximum value of methane income occurs in 2021 where in 2021 it is the closing year of landfillSarimukti as described in the methodology section. From this data, it can be seen the design of the fuel flow rate as well as the calculation of the operation time of the generation.

Calculation and Simulation of LFG Power Generation

Existing Condition

Power Plant Operational Time

In the generation process, there are times when the gas flow rate generated by the landfill will be greater than the rate of gas to be used in the generation. Therefore, if the resulting LFG rate is greater than the rate of use, the excess gas will be stored in a gas storage tank. This gas storage tank will then add the required gas in the generation process so that when gas production rates are lower, the gas storage reserves will be used to extend the operational life of the WtE power plant.

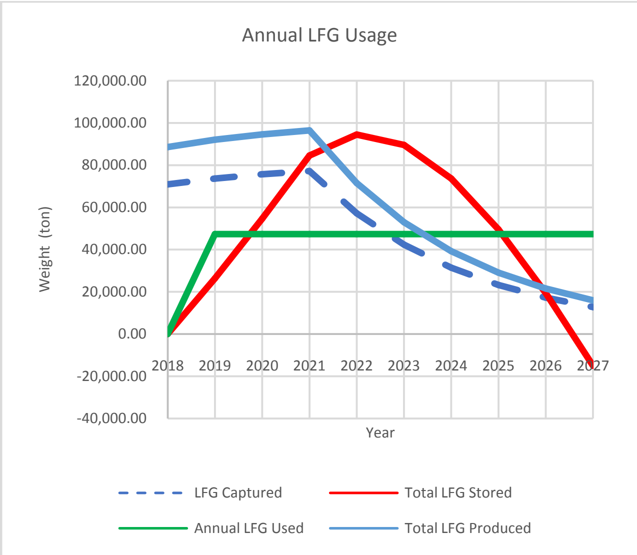

Fig. 3: WtE power plant operational time using gas storage

From the picture above can be seen that the use of gas starts in 2019 with a rate of 47.310 tons / year. The use of this gas will remain constant until 2026 until the stored gas is depleted. Thus, by using a rate of 47.310 tons / year, then the operational time of this WtE Power Plant will be for seven years.

Another way to control the LFG flow rate is by using flare. Flare is a component to burn the excess LFG to be used so that the resulting LFG gas is not directly discharged into the atmosphere. Under the same conditions as gas storage media, the operational time of WtE Power Plant at a rate of 47.310 ton / year can be illustrated in the figure below

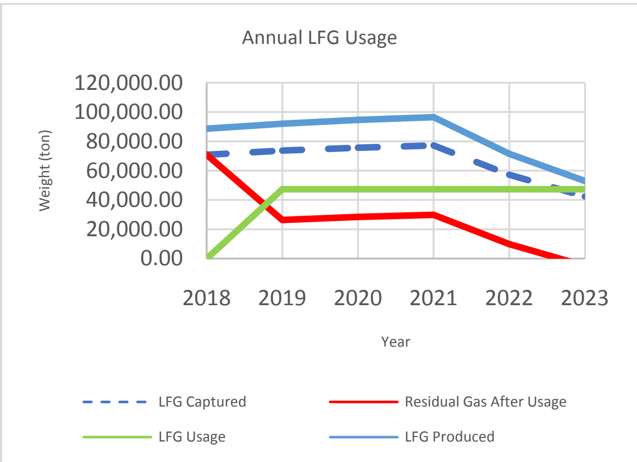

Fig. 4: WtE power plant operational time using flare

WtEpower plant operating time is in 2019 so that LFG gas extraction will begin in 2019. LFG usage rate will be set at 1,5 kg / s or 47.310 ton / year. The use of this gas will remain constant until 2026 until the stored gas is depleted. Thus, by using a rate of 47,310.00 tons / year, then the operational time of this WtE power plant will be for years for using gas storage tank and 4 years for using flare

Power Generation Design and Electrical Power Output Using Simple Rankine Cycle

With this mass flow rate (47.310 ton/year) sand using simperankine cycle, we will estimate the power generated by this power generation.

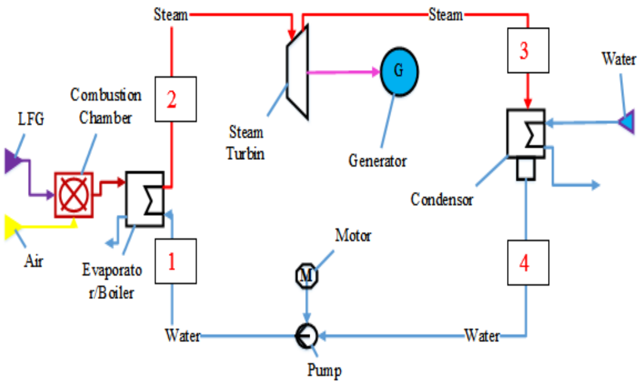

Fig. 5:LFG power generation modelling with simple rankine cycle

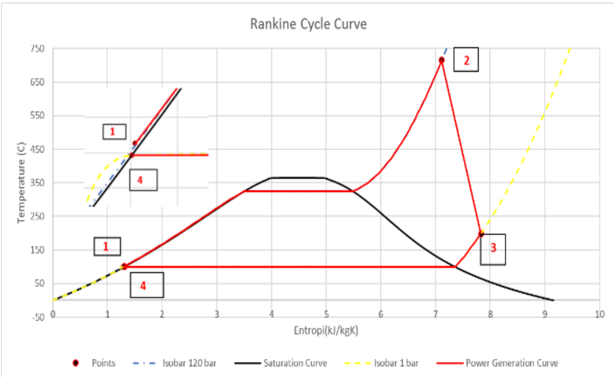

Fig. 6:Simple rankine cycle curve in Waste to Energy power generation

Table 2: Simulation result for WtE with simple rankine cycle

Simulation Data and result	**Value**
Inlet pressure turbin (bar)	120
Working fluid mass flow (kg/s)	7
Inlet pressure condensor (bar)	1
Combustion temperature (°C)	1074,365
Efficiency (%)	16,925
Electrical power output (MW)	5,843

From the picture above can be seen that the generation of waste power using a simple rankine cycle has a low efficiency of 16.925% with a power that can be generated of 5.843 MW. The resulting power is quite small and with a relatively short operational time, the WtEpower generation with LFG fuel is not in accordance with the expected so that when building a new landfill then should be followed by WtE power plant planning and development so that the operational time of WtEpower generation can be improved again. In addition, it is necessary to increase efficiency by comparison and addition of cycles such as brayton and ORC cycles.

Effects of Changes in Components Parameters

In this simulation, the only modified parameters are the amount of fuel mass coming into the power generation system, while other parameters are constant such as vapor inflection, component efficiency, and so on. However, since the addition of fuel mass flow requires the addition of air that needs to be burned, the mass flow rate of air will also be changed. The graph below shows the simulation results based on 10 types of fuel mass flow rate values. The value of % fuel mass flow rate is 100% if the fuel entering the plant is worth 2,33 kg / s (maximum value of LFG production in one year).

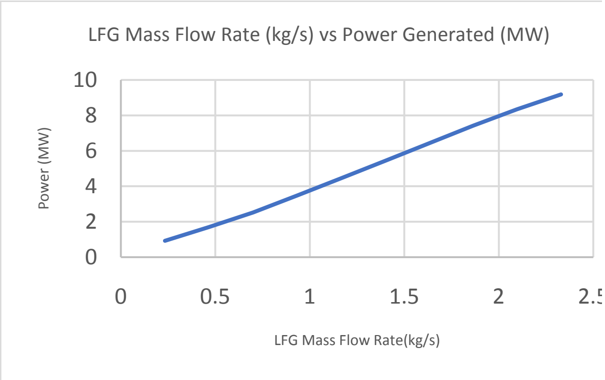

Fig7: Fuel mass flow rate vs Generated power output

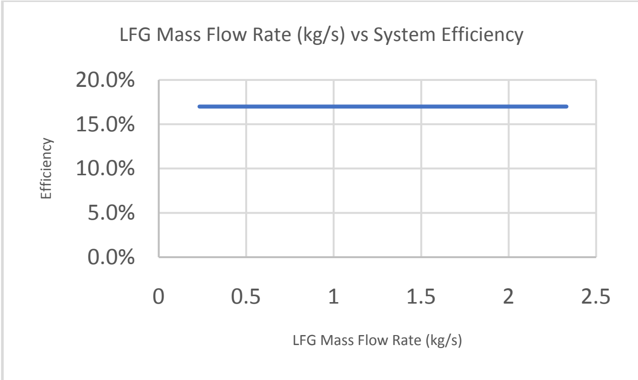

Fig 8: Fuel mass flow rate vs system efficiency

From these figure above we know that the fuel mass flow rate have a proportional correlation with output power and don't have a correlation with system efficiency.

Another effect of changes in component parameters that we want to analyze are inlet pressure turbin. In this simulation, the parameters are changed only the vapor pressure entering the turbine, while other parameters are constant. The graph below shows the simulation results based on 10 types of steam pressure values on turbine inputs with a range of values from 10% to 100%. The% turbine input pressure value is 100% if the turbine input vapor pressure is 120 bar. The value of mass flow rate of fuel and working fluid is maintained at 1,5 kg / s and 7 kg / s.

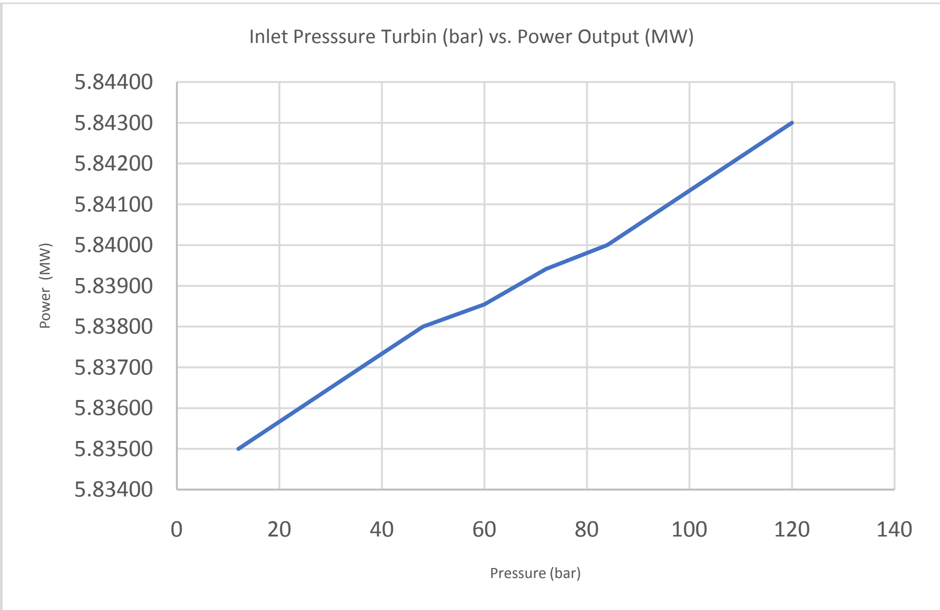

Fig. 9: Inlet pressure turbin vs Generated power output

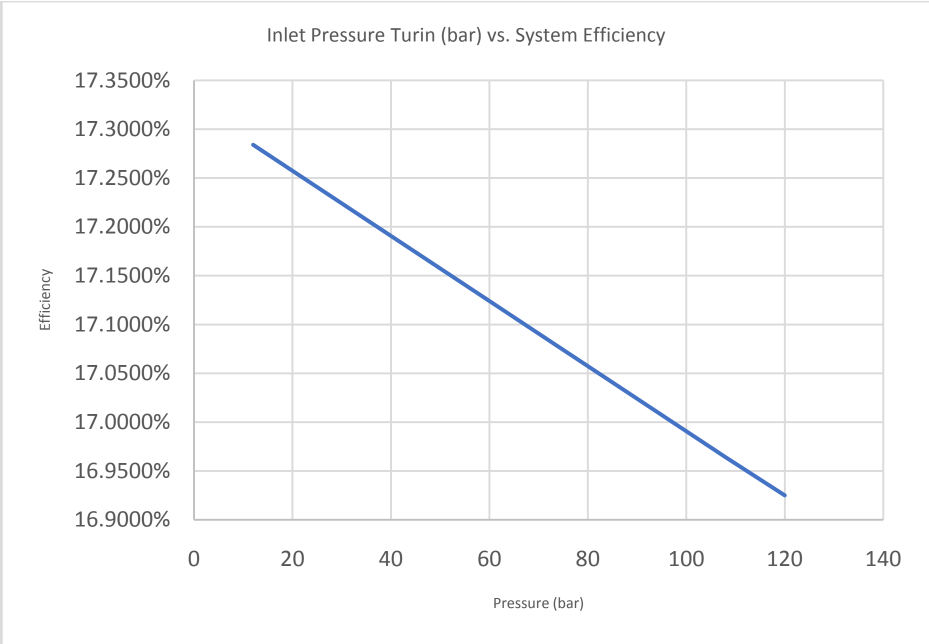

Fig. 10: Inlet pressure turbin vs system efficiency

From the picture above can be seen that inlet pressure turbin has proportional correlation with power output and inversely proportional correlation with system efficiency. Another thing can be seen from the pictures above is the higher the pressure then the efficiency of the system decreased but decreased efficiency is not too significant. This happens because even though the output power increases but the increase in output power can not compensate for the required power of the motor to pump the working fluid to reach 120 bar.

Another effect of changes in component parameters that we want to analyze are inlet pressure condensor. In this simulation, the parameters changed only the vapor pressure that goes into the condenser, while other parameters are constant. The graph below shows the simulation results based on 10 types of vapor pressure values at input to condensate with a range of values from 10% to 100%. The turbine input value% value is 100% if the turbine input vapor pressure is 10 bar. The value of mass flow rate of fuel and working fluid is maintained at 1.5 kg / s and 7 kg / s.

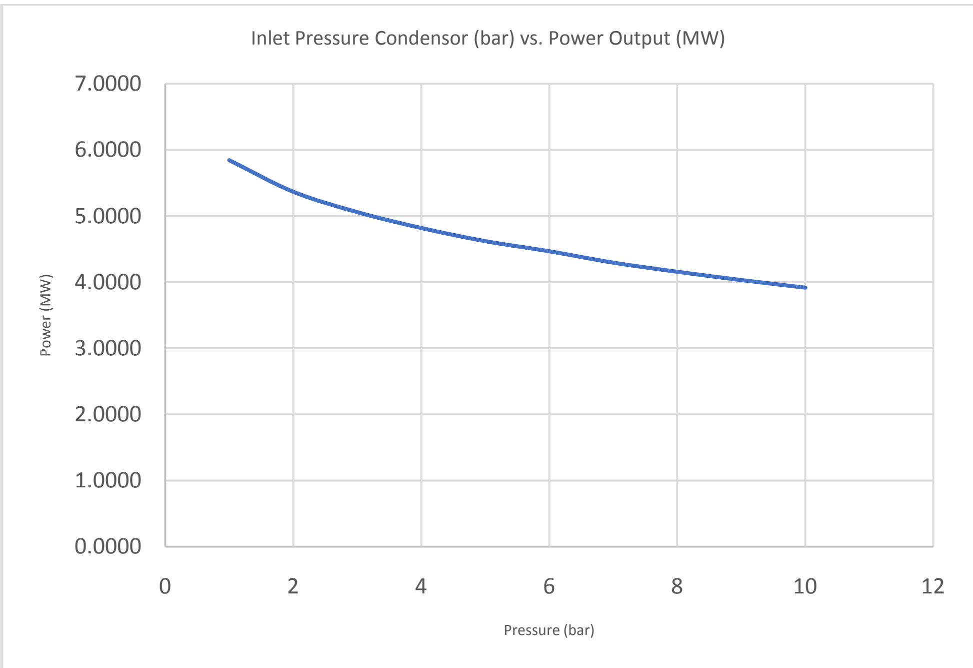

Fig. 11: Inlet pressure condensor vs Generated power output

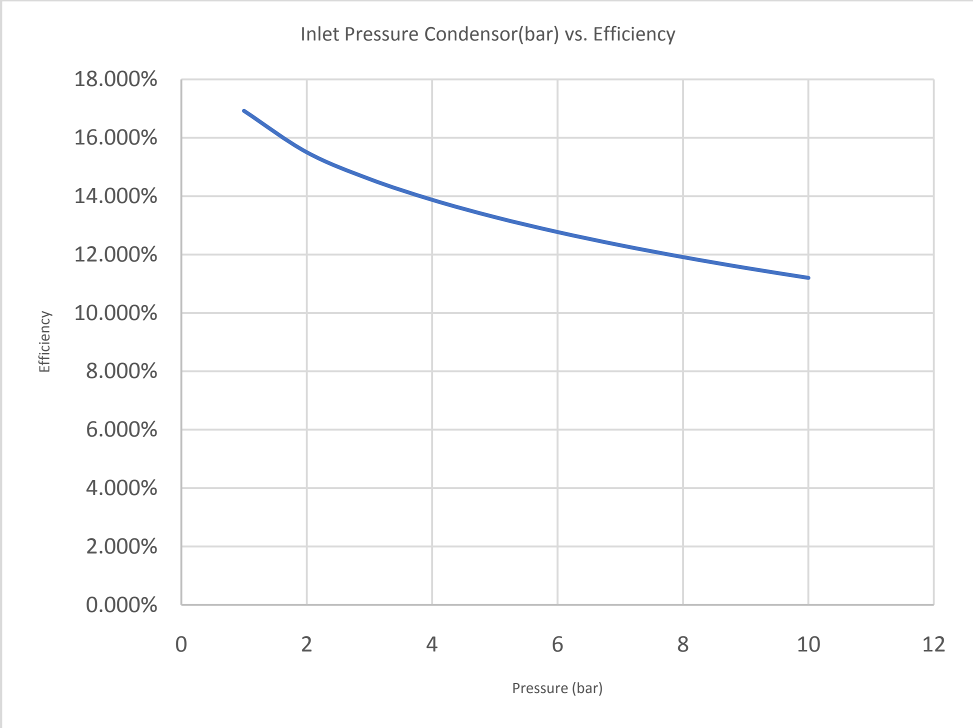

Fig 12: Inlet pressure condensor vs system efficiency

From these figure above we know that the inlet pressure condensor have a inversely proportional correlation with output power system efficiency.

Prediction for New Landfill Condition

The new condition of the waste power generation to be designed is the planning of WtE power generation to be built in conjunction with the opening of the landfill. In this planning, the landfill age will be the same as the previous landfill which is fifteen years with the amount of waste that will enter into the landfill will be predicted with the increase of population. landfill is assumed to be opened in 2022 after the Sarimuktilandfill infiltration with the operational time of the landfill to be planned is fifteen years. The fuel mass flow rate as well as the rate of air entry is equal to that of the existing conditions.

Waste Acceptance Prediction

Assuming that the average amount of waste generated by residents of Bandung City remains so that the predicted acceptance of waste by new landfill as follows.

Table 3: Average ton waste a person can produce

Year	Total population	Waste total (ton)	Weight of waste a person can produce (ton/person)
2007	2.329.918	328.764,00	0,141105395
2008	2.374.198	354.638,00	0,149371704
2009	2.417.288	326.088,00	0,134898283
2010	2.394.873	323.640,00	0,13513869
2011	2.429.176	347.027,00	0,142857907
2012	2.444.617	375.656,00	0,153666607
2013	2.458.503	382.070,58	0,155407815
2014	2.470.802	310.256,44	0,125569123
2015	2.481.469	316.130,38	0,127396466
2016	2.490.622	371.416,00	0,149125801
Average			0,141453779

By keep this waste a person can produce still, we can calculate the waste acceptance by using forecast on Bandung's population

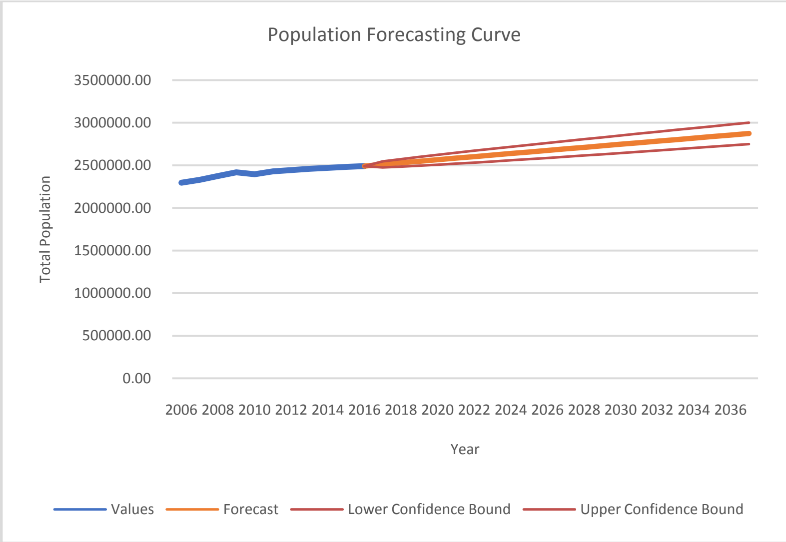

Fig. 13: Population forecasting curve

By knowing the average waste generated by the population of Bandung city per year, it will be forecasting the population until 2037 by doing linear forecasting on the number of residents Bandung city with a 95% confidence interval and using its average data. The result of waste estimation as follow

Table 4:Result of prediction of waste to be received by new landfill

Year	Total population	Waste Estimation (ton)
2022	2.602.508,45	368.134,65
2023	2.620.683,08	370.705,53
2024	2.638.857,72	373.276,40
2025	2.657.032,35	375.847,27
2026	2.675.206,99	378.418,14
2027	2.693.381,62	380.989,01
2028	2.711.556,26	383.559,88
2029	2.729.730,89	386.130,75
2030	2.747.905,53	388.701,62
2031	2.766.080,16	391.272,49
2032	2.784.254,80	393.843,36
2033	2.802.429,43	396.414,23
2034	2.820.604,06	398.985,10
2035	2.838.778,70	401.555,97
2036	2.856.953,33	404.126,85
2037	2.875.127,97	406.697,72

Waste Modelling Using LandGEM

By forecasting the weight of waste that will be received by the new landfill annually, then it can be modeled LFG emissions generated by the new landfill. This new landfill condition will be equated with the Final Disposal Place Sarimukti where the operational time of this Final Disposal Place is for fifteen years so that in 2037, the acceptance of waste by this new TPA will stop causing the decrease of LFG production after 2037.

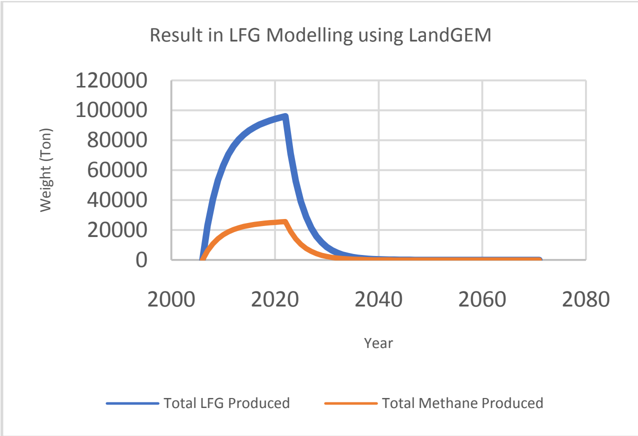

Fig 14: Landfill emission modelling result using LandGEM

Power Plant Operational Time

The WtEsystem to be built will start working in 2024 with a mass flow rate equal to when the real time is 1,5 kg / s. This system will be built in conjunction with the start of the landfill operating time but during the initial two years, no generation will be generated because the stored gas is insufficient so that the operation of the plant begins in 2024 with the first two years of LFG gas collection only.

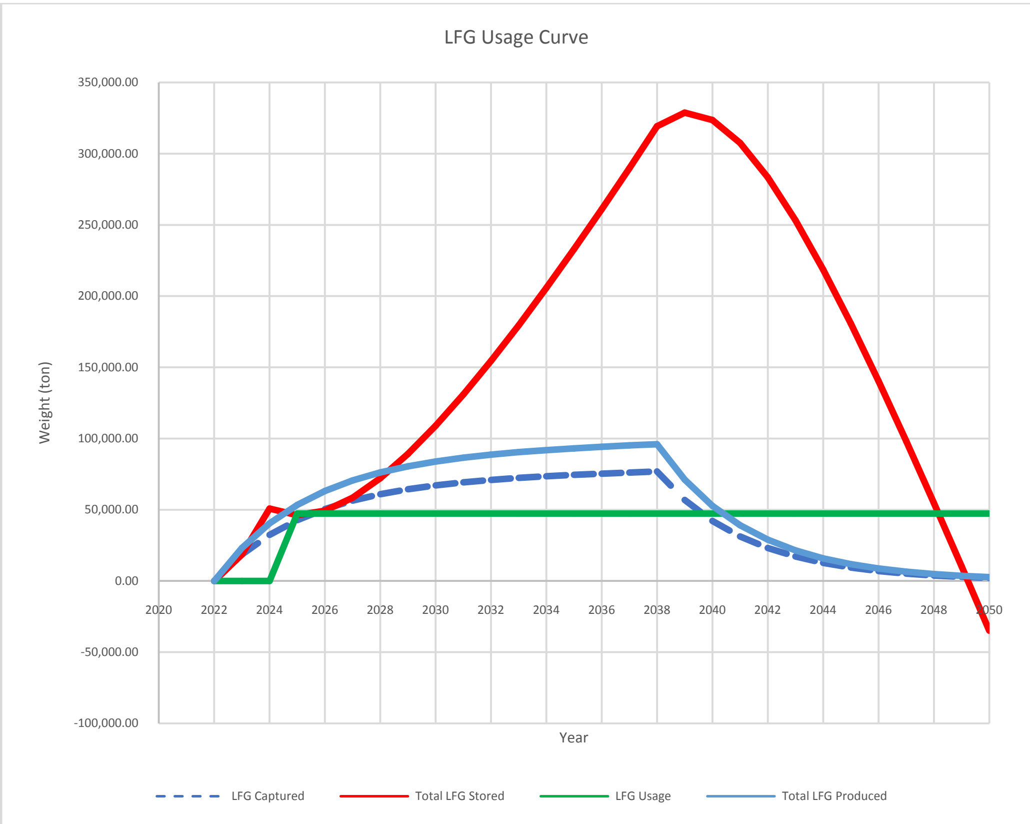

Fig. 15:WtE power plant operational time using gas storage

It can be seen from the graph above that the gas will begin to be stored in 2022 then it will be used in 2024 which will cause a decrease in the total gas stored. The total stored gas will then be discharged in 2048 which causes the operational time of this generation to be for 25 years.

Another way to control the LFG flow rate is by using flare. Flare is a component to burn the excess LFG to be used so that the resulting LFG gas is not directly discharged into the atmosphere. Under the same conditions as gas storage media, the operational time of WtE power plant at a rate of 1,5 kg/s can be illustrated in the figure below.

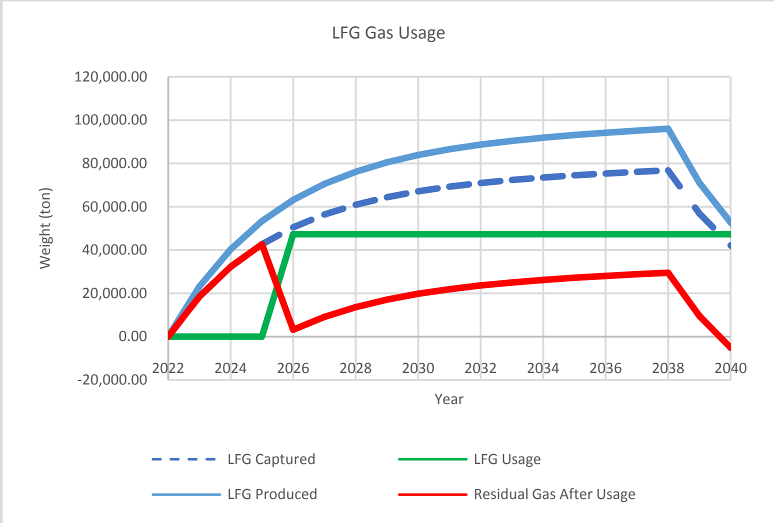

Fig16:WtE power plant operational time using gas storage

From the picture above can be seen that the excess gas that will be burned so there is no gas storage. The generation process will stop in 2039 because the residual gas after the reduction of usage will be minus value which causes the operational time of the plant is 14 years.

Power Generation Improvement Design and Simulation Result

System optimization is done by adding and changing cycles. For the first system use a simple cycle of Rankine combined with ORC. For the second system use a simple Brayton cycle. For a third system using the brayton and simple Rankine cycle combine and for the fourth cycle using a combination of Brayton cycle, simple Rankine and ORC.

For using the simple rankine cycle and ORC, the simulation result and design as follow.

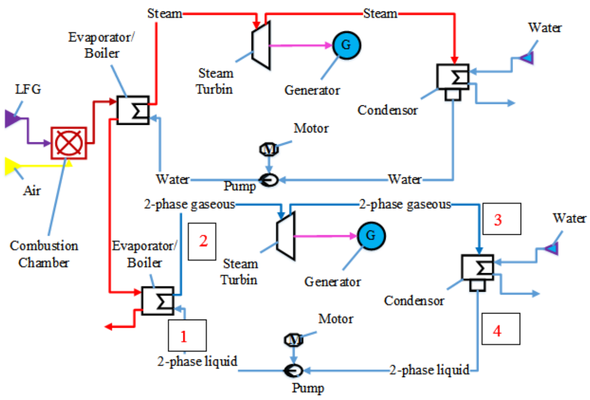

Fig. 17: Simple rankine cycle and ORC power generation design

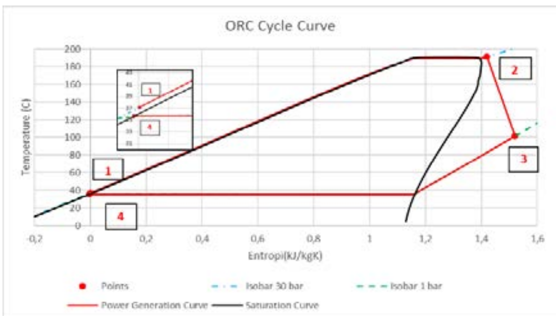

Fig. 18: ORC cycle curve

Because the simple rankine cycle remain same as before (section A.2) then the curve cyle of ORC as follow

Because the gas output after using in simple rankine cycle still have high temperature, then we use this exhaust gas to heat the rankine fluid which is pentane. The result of this simulation as follow

Table 5: Simulation data and result for ORC

Simulation data and result for ORC	**Value**
Turbin inlet pressure (bar)	30
Working fluid mass flow rate (kg/s)	12
Condensor inlet pressure (bar)	1
Evaporation temperature (°C)	345,672
Total system efficiency (%)	19,668%
Total electrical power output (MW)	6,86 MW

From the above simulation results can be seen that there is a significant increase between efficiency and power generated. In efficiency there was an increase of 19.668% and the addition of power on the ORC cycle side of 1.017 MW.

Another cycle that we will design is brayton cycle. The brayton cycle design that will be simulated as follow.

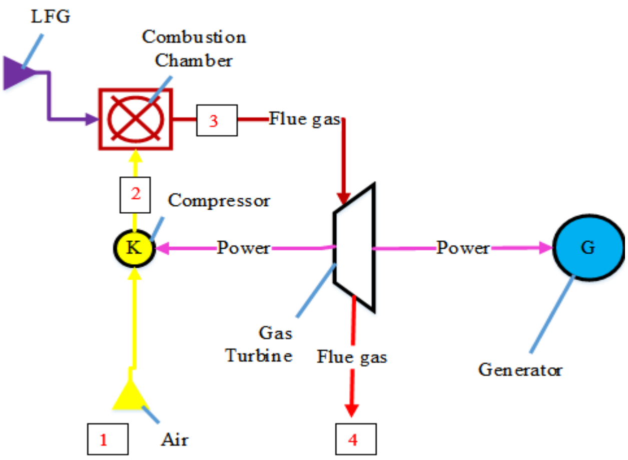

Fig. 19: The Brayton cycle and simulation

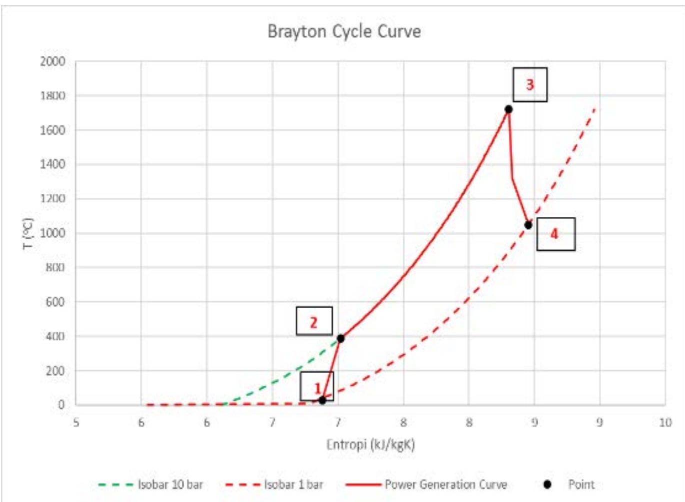

Fig. 20: Result of brayton cycle simulation in curve

Table 6: simulation result and data for brayton cycle

Simulation data and result	Value
Turbin inlet pressure (bar)	10
Working fluid mass flow rate (kg/s)	27,3
Efficiency (%)	15,098%
Power output(MW)	6,393 MW

The power generated using this system is 6,393 MW with an efficiency of 15,098%. The power generated is quite good but the efficiency of the use of this brayton cycle is still very low as in generating gas in general. Therefore, to improve this efficiency will be used combine cycle power generation by combining brayton cycle with simple rankine and / or ORC.

Because the heat from gas turbine exhaust are still high, we can use this heat to generate power using simple rankine cycle which design as follow.

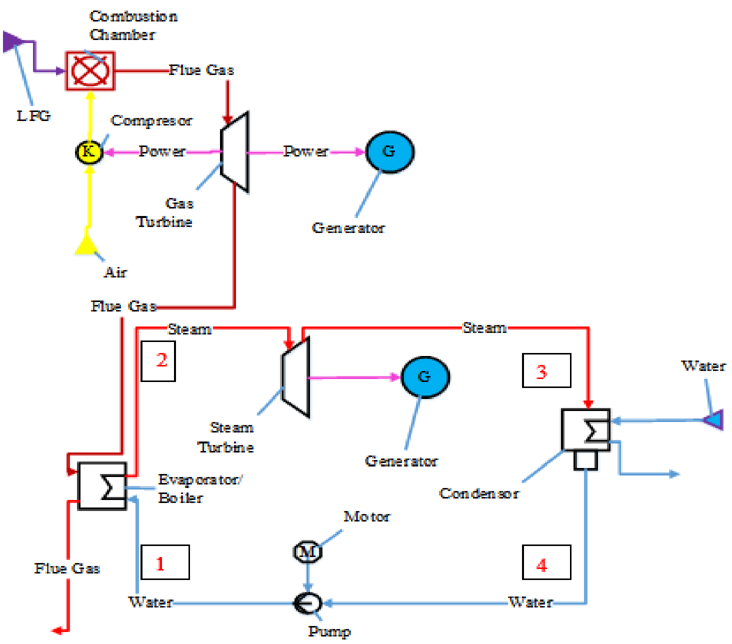

Fig. 191: Combine cycle using brayton and simple rankine cycle

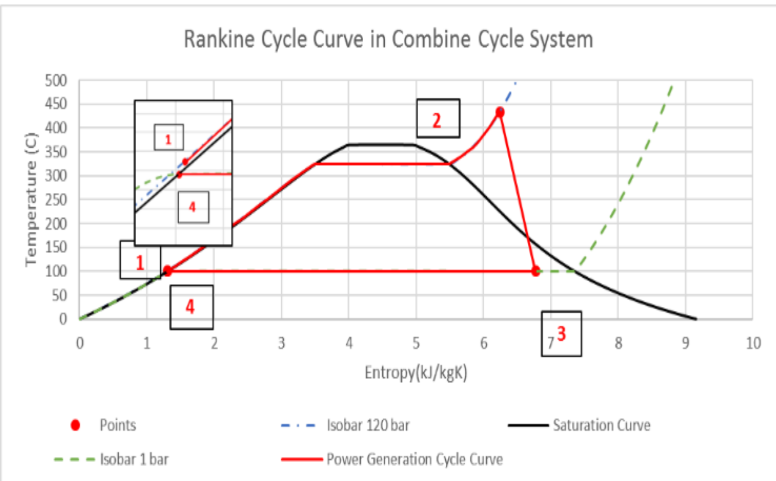

Fig. 202: ORC curve cycle

Because the curve cycle and simulation data of brayton remain the same, we will use the rankine cyle as follow.

Table 7: Simulation data for rankine cycle and system result

Simulation data for rankine cycle and Result	**Value**
Inlet pressure turbin(bar)	120
Working fluid mass flow rate (kg/s)	6
Condenser inlet pressure (bar)	1
Inlet evaporator temperature (°C)	767,182
Efficiency total system (%)	23,397%
Total electrical power output(MW)	10,017MW

This system has a power value of 10,017 MW with an efficiency of 23,397% with the power generated is 10.017 MW. The resulting power is good but since the discharge temperature after this cycle is still high enough, the ORC generation cycle is used to utilize this wasted heat.

The system design for using combine cycle that use brayton, simple rankine cycle and ORC are draw in picture below.

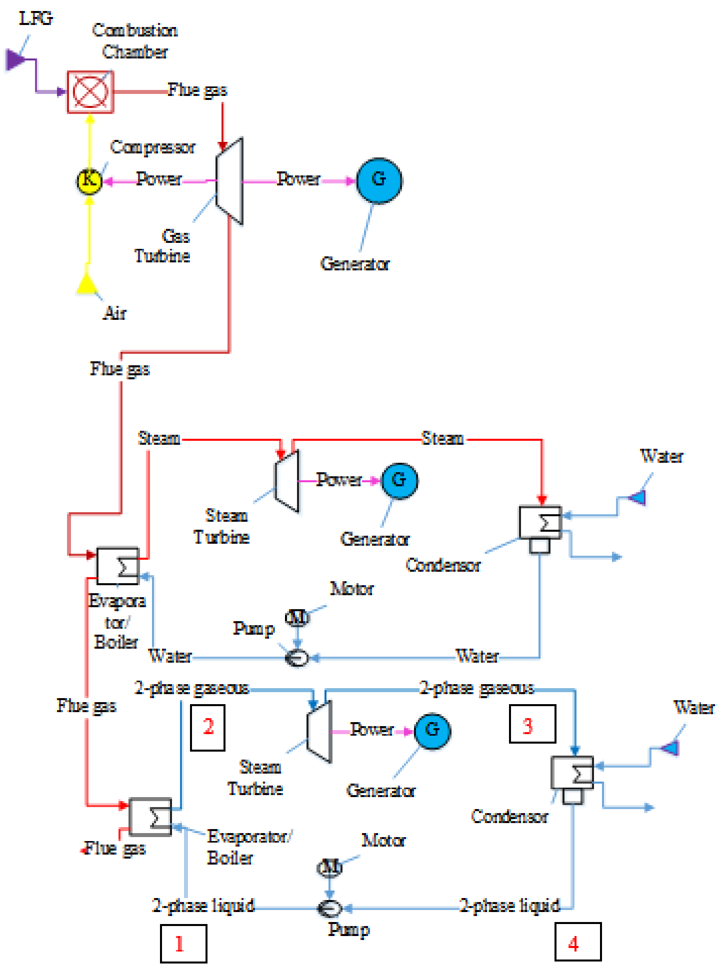

Fig. 23: LFG power generation modelling with triple combine cycle of simple rankine cycle, brayton cycle and organic rankine cycle

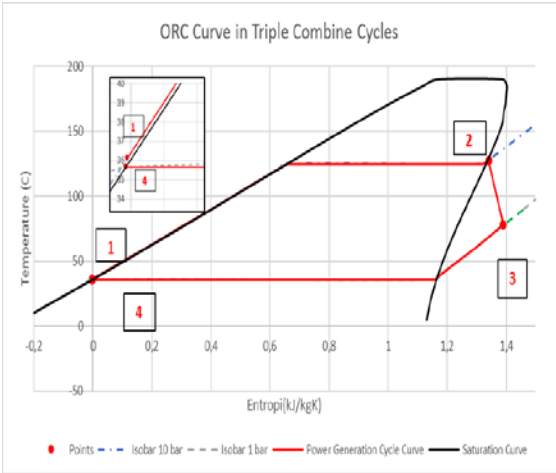

Fig. 24: ORC curve

Because the curve cycle and simulation data of brayton and rankine remain the same, we will use the ORC cyle curve, data and simulation result as follow

Table 8: Simulation data for rankine cycle and system result

Simulation data for ORC and Result	**Value**
Inlet pressure turbin(bar)	10
Working fluid mass flow rate (kg/s)	10
Condenser inlet pressure (bar)	1
Inlet evaporator temperature (°C)	254,658
Efficiency total system (%)	24,683
Total electrical power output(MW)	10,584 MW

From the picture and table above can be seen the efficiency of this generation is 24,683% with power yielded equal to 10,584 MW. The potential of this cycle is quite good by looking at the power generated as well as the highest efficiency of other systems.

The recapitulation data for all system is present in table below

Table 9: Recapitulation system

System	**Total electrical power output (MW)**	**Efficiency**
Simple rankine with ORC	6,86 MW	19,688%
Simple brayton cycle	6,393 MW	15,098%
Combine cycle (brayton and rankine cycle)	10,017 MW	23,397%
Triple Combine cycle (brayton, rankine and organic rankine cycle (ORC)	10,584 MW	24,683%

From this table above we know that the largest amount of electrical power output achiveini combine cycle using brayton, rankine and ORC witih total electrical power output are 10,584 MW and efficiency are 24,683%.

ESTIMATION OF ELECTRIC POWER GENERATION COST

For estimation of cost required in the waste power generation, data is needed in the form of investment costs, maintenance costs and fuel costs. Because in this final project study using emission gas from landfill, the fuel cost in the power generation cost will be 0 rupiah because the fuel used is emission gas which no longer has selling value. Then, the estimated cost value of this power generation is adjusted to the system with the greatest power value of a triple combine cycle system consisting of brayton cycle, rankine and organic rankine cycles (ORCs). The operational time of the plant is set to the new TPA condition by gas storage method so that the operational time of this PLTSa lasts for 25 years. Therefore, the costs that affect the calculation of generation estimates can be seen in the table below.

Table 10: Total components investment cost

Components	Price/unit		Unit value	Total cost
LFG Collector	995.381.357 (IDR)	/ Hectare[8]	40	39.815.254.315 (IDR)
Gas turbine	21.126.760 (IDR)	/ KW [8]	6.393	135.063.379.876 (IDR)
Steam turbine	17.154.929 (IDR)	/ KW [9]	3.624	62.169.464.602 (IDR)
Organic Rankine Cycle bundle	26.202.579 (IDR)	/ KW [10]	568	14.883.064.872 (IDR)
Total				251.931.163.666 (IDR)

Table 11: Total annual maintenance cost

Maintenance	Price/unit		Unit Value	Total Cost
Gas collector	167.057.011 (IDR)	/ Hektar [8]	40	6.682.280.444 (IDR)
Gas turbine	2.253.521 (IDR)	/ KW [8]	6.393	14.406.760.520(IDR)
Steam turbine	1.549.295 (IDR)	/ KW [9]	3.624	5.614.647.870 (IDR)
Organic Rankine Cycle bundle	778.887 (IDR)	/ KW [10]	571	442.408.187 (IDR)
Total				27.146.097.022 (IDR)

Then, in calculating depreciation, we use the straight line method with

$$Annual\ depreciation\ cost = \frac{Investment\ cost - Salvage\ Value}{Life\ time\ (year)} \quad (5.1)$$

Thus, with an investment cost of 251.931.163.666 (IDR) with residual value assumed to be 10% of the investment cost of 25.193.116.366 (IDR) with 25 years of service life, the depreciation of this power plant is 9.069.521.891 (IDR) per year.

Based on the data above, then the total annual expenses as follows

Table 12: Annual expenses tabulation

Cost	Annual expenses
Investation	27.762.814.236 (IDR)
Maintenance	27.146.097.022 (IDR)
Depreciation	9.069.521.891 (IDR)
Total	**45.839.389.366 (IDR)**

Based on the table above then for a minimum gain, the required income is 45.839.389.366 (IDR) / year. This revenue is the income needed for the generation of 10,584 MW so to get the value of IDR / KWh then the above value is distributed with the installed power (KW) x 8760 so that the value of IDR / KWhis 498,36 (IDR) / KWh.

CONCLUSION

Based on various calculations and data ranging from LFG gas modeling, calculation of plant operating time, WtE power plant planning for new landfill, it can be concluded that,

1. The development of LFG-based WtEpower generation in landfill with waste city condition will give 5,843 MW with operational time of 8 years (using gas storage) and 4 years (using flare) with operational time starting in 2019 when fuel mass flow rate is regulated at 1.5 kg / s
2. The operation time of waste power plant with new Final Disposal Place condition with initial start time of LFG collector and/or LFG storage is done one year after Final Disposal Place operation time is 25 years if the gas produced is stored and 14 years if using flare.
3. With a mass flow rate of 1.5 kg / s, the generation system can be increased with a maximum power value of 10,584 MW using a triple combine cycle system consist of steam-water Rankine cycle, Brayton cycle, and ORC.
4. By using LFG-based power generation, the emission of greenhouse gases produced by landfill can be significantly reduced because methane, which becomes one of the most dangerous sources of greenhouse gas emissions, can be used as fuel for this power plant.

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