power unit after their temperature decreasing to the 40^{o}C by using intercooler. In power unit there are one combustor, four heat exchanger and one power generator to produce electricity from the gas engine. This model is designed in Aspen Plus and analyzed in Engineering Equation Solver (EES) software programs. The exhaust gas which has temperature roughly 550-570^{o}C is discharged from the gas engine to the atmosphere after the turbocharger turbine.

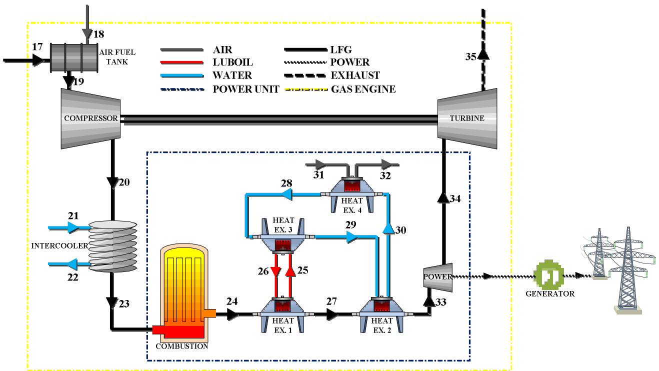

Fig. 2. Schematic layout of gas engine in Gaziantep Municipal Solid Waste Power Plant

The content of LFG (CH_4, O_2, CO_2, H_2S and other gases) is also another critical parameter to electricity production in landfill sites which is measured continuously and recorded. The average values of the components of LFG are given in Table I.

Table I. Volumetric composition of LFG produced in GMSWPP

Components	Chemical Formula	(%) Dry Volume
Methane	CH_4	50
Carbon dioxide	CO_2	29
Nitrogen	N_2	16.3
Oxygen	O_2	4
Other	-	0.7

III. THERMODYNAMIC ANALYSIS

Mass, energy and exergy balances for any control volume at steady state with negligible kinetic and potential energy changes can be expressed, respectively, by [12]

$$\sum \dot{m}_i = \sum \dot{m}_e \tag{1}$$

$$\dot{Q} - \dot{W} = \sum \dot{m}_e h_e - \sum \dot{m}_i h_i \tag{2}$$

$$\dot{E}x_{heat} - \dot{W} = \sum \dot{m}_e \psi_e - \sum \dot{m}_i \psi_i + \dot{E}x_d \tag{3}$$

where the subscripts e and i represent the exit and inlet states, $\dot{Q}$ and $\dot{W}$ are the net heat and work inputs, $\dot{m}$ is the mass flow rate, h is the enthalpy, $\dot{E}x_d$ is exergy destruction and $\dot{E}x_{heat}$ heat is the net exergy transfer by heat at temperature T, which are given by

$$\dot{E}x_d = T_0 \dot{S}_{gen} \tag{4}$$

$$\dot{E}x_{heat} = \sum \left(1 - \frac{T_0}{T}\right) \dot{Q} \tag{5}$$

The specific flow exergy is given by

$$\psi = (h - h_0) - T_0 (s - s_0) \tag{6}$$

$$\dot{E}x = \dot{m} \psi \tag{7}$$

where the subscript 0 stands for the restricted dead state. Isentropic efficiencies of turbine and compressor can be defined as [10]

$$\eta_t = \frac{w_a}{w_s} = \frac{h_i - h_e}{h_i - h_{es}} \tag{8}$$

$$\eta_{comp} = \frac{w_s}{w_a} = \frac{h_{es} - h_i}{h_e - h_i} \tag{9}$$

where w_a is the actual specific work, w_s is the isentropic specific work, the subscript es is reversibility for exit state. The thermal efficiency of a power plant can be evaluated by means of the following equation [13]

$$\eta_{th} = \dot{W}_b / \dot{m}_f \dot{Q}_{HV} \tag{10}$$

where $\dot{W}_b$ is break power, $\dot{m}_f$ is mass flow rate of fuel and $\dot{Q}_{LHV}$ is lower heating value of fuel in (10). The exergetic (second law) efficiencies of turbine and compressor are given as follows:

$$\varepsilon_t = \frac{w_a}{w_{rev}} = \frac{h_i - h_e}{h_i - h_e - T_0 (s_i - s_e)} \tag{11}$$

$$\varepsilon_{comp} = \frac{w_{rev}}{w_a} = \frac{h_e - h_i - T_0 (s_e - s_i)}{h_e - h_i} \tag{12}$$

where w_{rev}, reversible specific work is equal to the sum of specific exergy destruction and actual work. The exergetic efficiency of a heat exchanger in a power plant is measured by the increase in the exergy of the cold stream divided by the decrease in the exergy of the hot stream

$$\varepsilon_{he} = \frac{(\dot{E}x_e - \dot{E}x_i)_{cold}}{(\dot{E}x_i - \dot{E}x_e)_{hot}} = \frac{\dot{m}_{cold}\left[h_e - h_i - T_0(s_e - s_i\right]_{cold}}{\dot{m}_{hot}\left[h_i - h_e - T_0(s_i - s_e\right]_{hot}} \quad (13)$$

where $\dot{m}_{cold}$ and $\dot{m}_{hot}$ are the mass flow rates of the cold and hot streams, respectively.

In this study, Aspen Plus software program is used to evaluate thermodynamic analysis of GMSWPP using actual operating data that may be advantageous to optimize and improve electricity production. Energy and exergy analyses of the power plant are carried out by using actual operational data. Air and the exhaust gases are assumed as ideal gases. Heat transfer rates, work, exergy destructions and exergetic efficiencies are calculated using the governing equations given above.

Exergy efficiency of compressor is shown clearly less than turbine and power generator exergy efficiencies. The reason for the lower exergy efficiency of the compressor is related with exergy destruction value when compared to the turbine and power generator. The intercooler, heat exchangers 1 and 2 and chiller units have low exergy efficiencies. On the other hand blower, heat exchangers 3 and 4, and combustor have high exergy efficiencies. The energetic and exergetic analyses of all subcomponents are shown in Table II.

Table II. Energetic and exergetic analyses of subcomponents

Component	$\dot{Q}$ (kW)	$\dot{W}$ (kW)	$\dot{E}_F$ (kW)	$\dot{E}_P$ (kW)	$\dot{E}_D$ (kW)	ε (%)
Chiller	1.0	0.0	0.5	0.1	0.4	22.4
Blower	0.0	2.3	2.3	1.7	0.5	76.8
Compressor	0.0	248.3	248.3	197.4	50.9	79.5
Intercooler	196.8	0.0	36.9	12.8	24.1	34.7
Combustor	6730.9	0.0	6730.9	5976.1	754.8	88.8
Heat Ex. 1	132.0	0.0	105.5	26.5	79.0	25.1
Heat Ex. 2	1939.2	0.0	1646.2	390.3	1255.9	23.7
Heat Ex. 3	132.0	0.0	26.5	20.6	5.9	77.9
Heat Ex. 4	2170.6	0.0	410.9	306.2	104.7	74.5
Power Gen.	0.0	2664.0	3106.2	2664.0	442.2	85.8
Turbine	0.0	249.60	286.22	249.60	36.62	87.20
Energetic Efficiency						39.57 %

IV. COCLUSIONS

The amount of waste produced by inhabitants or industrial companies can be considered as one of the most serious environmental problems in the world. Waste to energy techniques are crucial to dispose waste and energy recovery from waste. For this reason, energy recovery from waste is an alternative source for energy production. In this study, energy and exergy analyses of the power plant are performed as well as the analyses of all subcomponents. The exergetic efficiencies of the compressor and the turbine of the turbocharger are 79.5% and 87.2%, respectively. This represents that a remarkable exergetic losses are shown from the turbocharger. The exergetic efficiencies of the heat exchangers, are calculated as 25.1%, 23.7%, 77.9%, and 74.5 respectively. It is clearly shown that heat exchanger 1 and 2 have low exergy efficiencies in contrast to heat exchangers 3 and 4. In addition to this chiller and intercooler have low exergy efficiencies likewise heat exchanger 1 and 2. On the other hand combustor has the maximum exergy efficiency when compare to other components of the power plant.

Thermodynamic analyses of all subcomponents are evaluated and the exergetic efficiency of the power plant is found to be 56.19%. Beside this, thermal efficiency of gas engine is evaluated as 39.6%. which is compatible with the technical specifications of the Jenbacher 416 type. Higher exergy destructions represent the most potential for possible improvements in the performance of the plant in the frame of the presented analysis. This study can be a guide for other researchers in order to perform thermodynamic analysis for any municipal solid waste power plant in recent years.

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