wjert, 2019, Vol. 5, Issue 5, 136-143. Original Article ISSN 2454-695X

World Journal of Engineering Research and Technology

WJERT

www.wjert.org SJIF Impact Factor: 5.218

MODELING OF GAS TURBINE OPERATED BY MUNICIPAL SOLID WASTE TO GIVE ELECTRICAL POWER AND SUPERHEATED STEAM IN KOLKATA CITY

Dr. Kamaljyoti Talukdar*

Assistant Professor, Department of Mechanical Engineering, Bineswar Brahma Engineering College, Kokrajhar, Assam.

Article Received on 25/06/2019 **Article Revised on 15/07/2019** **Article Accepted on 06/08/2019**

***Corresponding Author**
Dr. Kamaljyoti Talukdar
Assistant Professor, Department of Mechanical Engineering, Bineswar Brahma Engineering College, Kokrajhar, Assam.

ABSTRACT

As time is passing life style of society is improving and waste generation is increasing proportionally day by day especially municipal solid waste (MSW). This huge MSW created have disposal problem. If MSW can be used for constructive purpose, waste disposal problem can be solved. In this paper gas turbine system is operated by burning municipal solid waste (MSW) as fuel in combustion chamber. The net power output obtained from gas turbine system is 1 MW operated throughout the year and also producing superheated steam of 300^{o}C from the combustion gas coming out from the gas turbine in Kolkata city, West Bengal, India. The analysis is done for two months May (summer) and winter (January). Since May and January month have maximum and minimum temperature respectively, so if the system works well in these two months the gas turbine system will work well throughout the year.

KEYWORDS: Combustion chamber, Gas turbine, Municipal solid waste (MSW), Superheated steam.

I. INTRODUCTION

By gas turbine technology power, heat can be obtained. Many researchers have done work for obtaining power/heat from gas turbine.(Paisley and Anson 1997), used Battelle high-throughput gasification process to produce biogas from biomass to obtain power by using the gas in gas turbine. (Veyo et al, 2000) used exhaust gas coming from solid oxide fuel cell (SOFC) to power gas turbine. (Carno et al 1998) demonstrated plant in Northern Europe for small scale heat and power co-generation, a 40 kWe turbogenerator was installed by Vattenfall at Pappersgruppen in Gothenburg, Sweden. (Ohhashi and Arakawa , 1994)developed CCT303 a two-shaft regenerative ceramic gas turbine with rotary heat exchangers for the purpose of mobile power generator with power generation of 300 k W and 42% thermal efficiency at 1350^{o}C turbine inlet temperature. Ameri et al, 2010) authors used micro gas turbine producing 200 k W power and exhaust gases of this micro-gas turbine which are recovered in an HRSG (heat recovery steam generator) which are used in a steam ejector refrigeration system to produce cooling in summer and steam in HRSG to produce heating in winter.

In present paper gas turbine operated by municipal solid waste is used for obtaining power (1MW) and 300^{o}C superheated steam.

II. SYSTEM LAYOUT

Figure 1 shows a gas turbine system with 1MW power generation along with 300^{o}C superheated steam. Air at ambient temperature of Kolkata city is passed through compressor. At combustion chamber compressed air from compressor and fuel (MSW) are burnt. This burnt gas is sent through turbine and 1 MW power is obtained. The exhaust coming out from turbine is used to produce superheated steam of 300^{o}C.

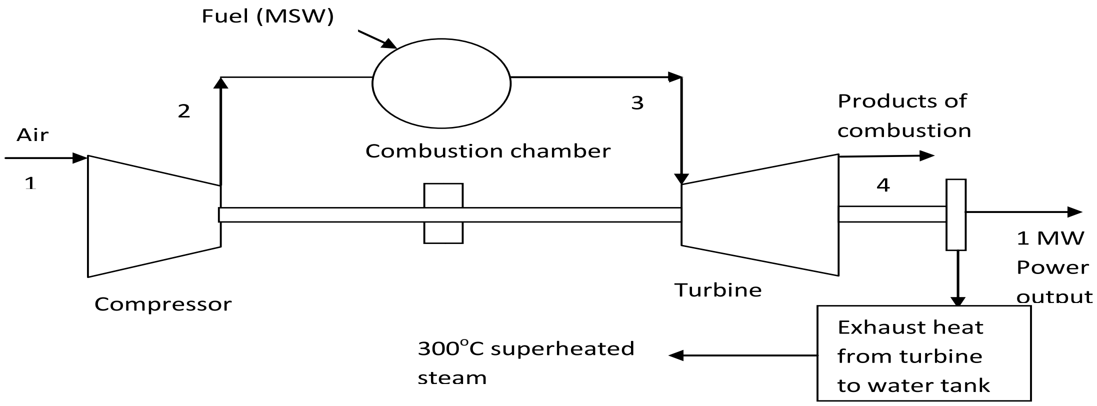

Figure 1: A typical GT plant operated by MSW to obtain power and superheated steam.

III. GAS TURBINE MODELING

Figure 2 shows temperature-entropy (T-S) diagram of GT plant. Process 1-2' shows isentropic compression of air in compressor. T_1 is the air inlet to compressor at ambient temperature of Kolkata city (Tiwari, 2004). $T_{2'}$ is the temperature given by equation no.1 (Ganesan, 2006):

$$T_{2'} = T_1 \times \left[\frac{P_2}{P_1}\right]^{\frac{\gamma_i - 1}{\gamma_i}} \tag{1}$$

$\frac{P_2}{P_1}$=pressure ratio (considered 6 in present study), γ_i=1.4 k J/ kg. K (Ganesan, 2006).

Process 1-2 shows actual compression of air given by equation no. 2 (Ganesan, 2006).

$$T_2 = T_1 + \frac{T_{2'} - T_1}{\eta_C} \tag{2}$$

η_C= 0.85.[5]

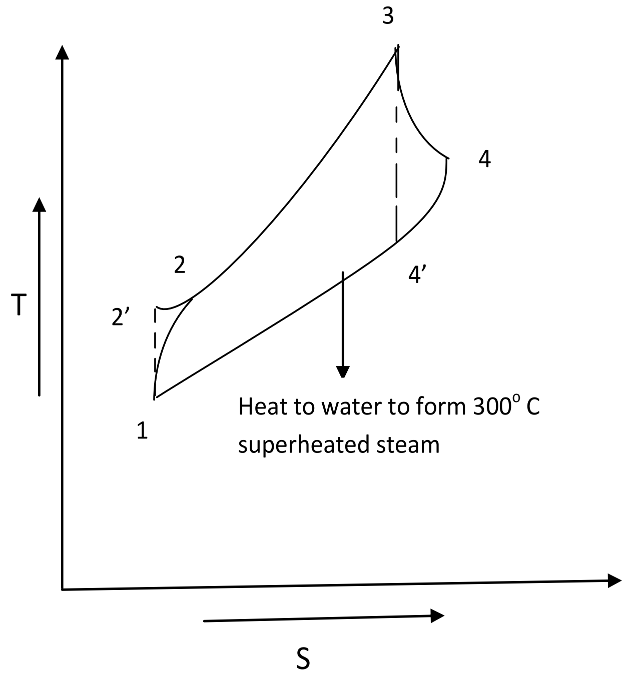

Figure 2: Temperature-entropy (T-S) diagram of figure 1.

Process 2-3 is the combustion process taking place in combustion chamber. Temperature of combustion gas (T_3) coming out from combustion chamber is considered constant (1000 K).

Process 3-4' is the isentropic expansion of combustion gas in GT and temperature ($T_{4'}$) is given by equation no. 3 (Ganesan, 2006):

$$T_{4'} = T_3 \times \left[\frac{P_4}{P_3}\right]^{\frac{\gamma_f - 1}{\gamma_f}} \tag{3}$$

$\frac{P_4}{P_3}$ = pressure ratio (considered $\frac{1}{6}$ in present study), γ_f=1.33 k J/kg. K (Ganesan, 2006):

Process 3-4 shows actual expansion of combustion gas in GT given by equation no. 4 (Ganesan, 2006):

$$T_4 = T_3 - \eta_T \left(T_3 - T_{4'}\right) \tag{4}$$

η_T=0.9.[6]

Now mass flow rate of air, fuel flow rate, turbine work, compressor work, net work and thermal efficiency are given by equations 5,6,7,8,9 and 10 respectively (Ganesan, 2006):

$$\dot{m}_a = \frac{1000}{\left[C_{pg} \times (T_3 - T_4) + \frac{C_{pg} \times (T_3 - T_2)}{LHV_{MSW} \times \eta_{comb}} \times C_{pg}(T_3 - T_4)\right] - \left[\frac{C_{pa}}{\eta_m} \times (T_2 - T_1)\right]} \tag{5}$$

C_{pg}=1.147 k J/ kg. K (Ganesan, 2006),η_{comb}=0.98 (Ganesan, 2006),η_m=0.95.[5]

The composition of MSW is as follows taken from (Becidan 2007): carbon-25%, hydrogen-3%, oxygen-20%, sulphur-0.3%, nitrogen-0.5%, ash-25%, moisture -25%. The LHV_{MSW} is calculated from (Kaushik and Singh, 2013).

$$\dot{m}_f = \frac{\dot{m}_a \times C_{pg} \times (T_3 - T_2)}{LHV_{MSW} \times \eta_{comb}} \tag{6}$$

$$W_T = \dot{m}_a \times C_{pg}(T_3 - T_4) + \dot{m}_f \times C_{pg}(T_3 - T_4) \tag{7}$$

$$W_C = \left[\frac{\dot{m}_a \times C_{pa} \times (T_2 - T_1)}{\eta_m}\right] \tag{8}$$

C_{pa}= 1.005 k J/kg.K (Ganesan, 2006)

$$W_{net} = W_T - W_C = 1000kW \tag{9}$$

After combustion gas comes out of turbine, it is sent to heat water to 300°C superheated steam.

Mass of superheated steam obtained in summer (May), considering water temperature to be 28° C is given by:

$$\dot{m}_{steam,s} = \frac{(\dot{m}_a + \dot{m}_f) \times C_{pg} \times (T_4 - T_1)}{[4.2 \times (100 - 28) + 2.1 \times (300 - 100)]} \qquad (10)$$

Where m_a, m_f, C_{pg},, T_4,T_1 are mass flow rate of air, mass flow rate of fuel(MSW), specific heat of combustion gas, exit temperature of combustion gas from turbine, inlet temperature of ambient air to compressor for Kolkata city respectively.

Also 4.2-specefic heat of water in k J/kg.K,[13] 100-boiling point temperature of water in °C, 28-ambient water temperature in °C, 2.1-specefic heat of superheated steam in k J/kg.K[14] 300-temperature of superheated steam in °C.

Mass of superheated steam obtained in winter (January), considering water temperature to be 22° C is given by:

$$\dot{m}_{steam,w} = \frac{(\dot{m}_a + \dot{m}_f) \times C_{pg} \times (T_4 - T_1)}{[4.2 \times (100 - 22) + 2.1 \times (300 - 100)]} \qquad (11)$$

IV. RESULTS AND DISCUSSIONS

The variation of air flow rate to compressor, fuel flow rate (MSW) to combustion chamber, turbine output power, compressor power consumption, and thermal efficiency and their reasons are explained in (Talukdar, 2019).

In the present paper variation of superheated steam of 300°C production in the months of May (summer) and January (winter) are presented.

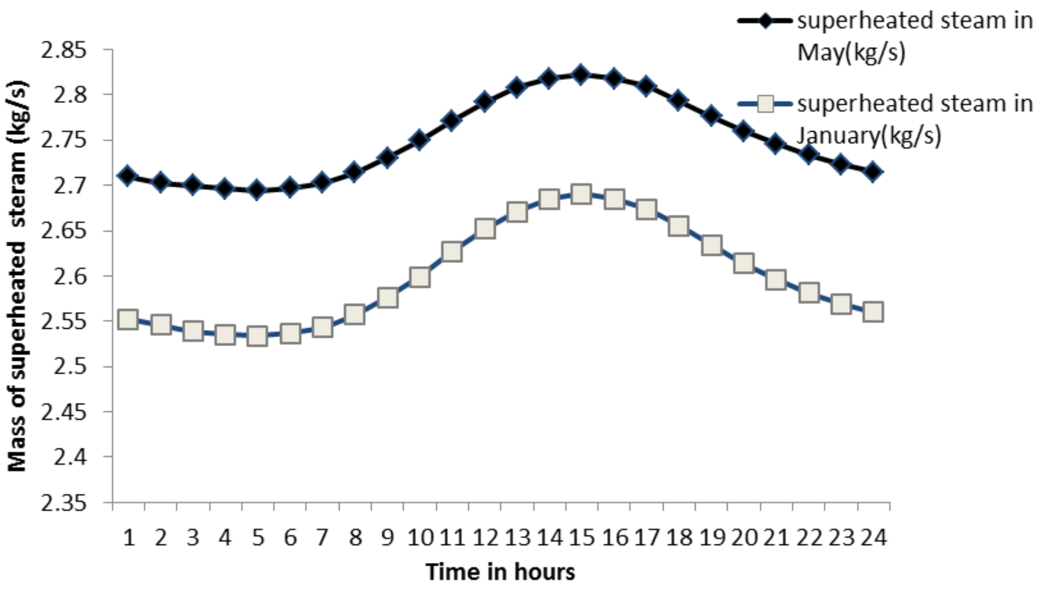

Figure 3: Variation of superheated steam (300^{o}C) in the months of May and January.

Nomenclature

C_{pa} C_{pg}	Specific heat of ambient air (k J/kg. K) Specific heat of combustion gas (k J/kg. K
GT LHV $\dot{m}_a$ $\dot{m}_f$	gas turbine lower heating value mass flow rate of air (kg/s) mass flow rate of fuel (kg/s)
MSW $\dot{m}_{steam,s}$ $\dot{m}_{steam,w}$	Municipal solid waste Mass flow rate of steam(kg/s) in summer(May) Mass flow rate of steam(kg/s) in winter(January)
P *T* W_C	Pressure (bar) Temperature (K) Compressor work (k W)
W_T	Turbine work (k W)
γ_i	Ratio of specific heat of air
γ_f	Ratio of specific heat of combustion gas
η_c	Isentropic efficiency of compressor
η_T	Isentropic efficiency of turbine
η_{comb}	Combustion efficiency of combustion chamber
η_m	Mechanical transmission efficiency of power from turbine to compressor

Mass flow rate of superheated steam in the months of May and January are given by equation number 10 and 11.In figure 3 it is seen that mass of superheated steam production in May is more than January. It is due to the fact that mass flow rate of air and fuel (MSW) in May in gas turbine is more (Talukdar, 2019) compared to January which is in numerator of equation 10 and 11. Also, temperature of water is considered more in May(28^{o}C) than in January(22^{o}C) which is in denominator of equation 10 and 11 respectively. Hence greater value in numerator and lesser value in denominator in equation 10 leads to greater production of superheated steam in May compared to superheated steam produced in January given by equation 11.

It is seen that superheated steam production decreases from 1:00 hours to 5:00 hours due to the fact that T_1 decreases and also air and fuel (MSW) flow rate decreases in numerator. But the effect of (T_4-T_1) increase is less dominant than decrease in air and fuel flow rate.

It is seen that superheated steam production increases from 6:00 hours to15:00 hours due to the fact that T_1 increases and also air and fuel (MSW) flow rate increases in numerator. But the effect of (T_4-T_1) decrease is less dominant than increase in air and fuel flow rate.
It is seen that superheated steam production again decreases from 16:00 hours to 24:00 hours due to the fact that T_1 decreases and also air and fuel (MSW) flow rate decreases in numerator. But the effect of (T_4-T_1) increase is less dominant than decrease in air and fuel flow rate.

V. CONCLUSIONS

The proposed gas turbine gives 1MW power and also superheated steam (300^{o}C) in the range from 2.71kg/s to 2.822 kg/s and 2.552 kg/s to 2.691kg/s in May and January respectively. The months May and January are chosen because since May and January have maximum and minimum temperature respectively and if it works well in these months the system will work throughout the year.

If gas turbine power increases the superheated steam production will increase.

REFERENCES

1. Ameri, M, Behbahaninia A, and Tanha A A “Thermodynamic analysis of a tri-generation system based on micro-gas turbine with a steam ejector refrigeration system,” Energy, 2010; 35(5): 2203-2209.

2. Becidan M "Experimental Studies on Municipal Solid Waste and Biomass Pyrolysis", Doctoral thesis. Norwegian University of Science and Technology, Trondheim, 2007.
3. Carno J, Cavani A and Liinanki L "Micro Gas Turbine for Combined Heat and Power in Distributed Generation public access," ASME International Gas Turbine and Aeroengine Congress and Exhibition, 1998.
4. Ganesan V Gas turbines 2nd edition, Tata Mcgraw Hill Publishing Company Limted, New Delhi, 2006.
5. How to Estimate Compressor Efficiency? | Campbell Tip of the Month, http://www.jmcampbell.com/tip-of-the-month/2015/07/how-to-estimate-compressor-efficiency/, accessed 20th December, 2018.
6. Isentropic Efficiency - Turbine/Compressor/Nozzle - nuclear-power.net, accessed on 20th December, 2018. https://www.nuclear-power.net/nuclear engineering/thermodynamics/ thermodynamic-processes/isentropic-process/isentropic-efficiency-turbinecompressornozzle/, accessed on 20th December, 2018.
7. Kaushik S C and Singh O K "Estimation of chemical exergy of solid, liquid and gaseous fuels used in thermal power plants", J. Therm. Anal. Calorim., 2013; 115: 903-908.
8. Ohhashi I and Arakawa S. "Development of 300kW Class Ceramic Gas Turbine (CGT303) public access," ASME International Gas Turbine and Aeroengine Congress and Exposition, 1994.
9. Paisley M A and Anson D "Biomass Gasification for Gas Turbine Based Power Generation public access," ASME International Gas Turbine and Aeroengine Congress and Exhibition, 1997.
10. Talukdar K "Modeling of gas turbine operated by municipal solid waste", IOSR Journal of Mechanical and Civil Engineering, 2019; 16(2): 14-19.
11. Tiwari G N Solar energy-Fundamentals, Design, Modeling and Applications. Narosa Publishing House, New Delhi, 2004.
12. Veyo S E, Shockling L A, Derer J T, Gillette J E, and Lundberg W L "Tubular Solid Oxide Fuel Cell/Gas Turbine Hybrid Cycle Power Systems — Status," ASME Turbo Expo 2000: Power for Land, Sea, and Air, 2000.
13. Water -Thermophysical Properties - Engineering ToolBox,, https://www. engineeringtoolbox.com/water-thermal-properties-d_162.html, accessedon8th July, 2019.
14. What is the value for specific heat capacity of superheated steam.., https://www.quora.com/What-is-the-value-for-specific-heat-capacity-of-superheated-steam, accessed on 8th July, 2019.