THE ENERGETIC AND EXERGIC PERFORMANCE OF GAS TURBINE COGENERATION SYSTEM

HAZI ANETA[*], HAZI GHEORGHE[*], VERNICA SORIN [*], GOGA FLORIN [**]

[*] *University of Bacau,* [**] *S.C.CET S.A. Bacau*

Abstract: This paper presents a performant evaluation of gas turbine cogeneration system. For a gas turbine cogeneration system, which generates electricity and hot water, an energetic and exergetic analysis was made. Finally, energy and exergy efficiency was evaluated.

Keywords: gas turbine cogeneration, energy and exergy analyze

1. INTRODUCTION

The term cogeneration is generally used for description of electrical and heat energy joint production. Such cogeneration systems facilitate a considerable decrease of primary energy consumption for heat and power production in comparison with the conventional separate production of these energy flows.

Gas turbines can be used in a variety of configurations. One of them is combined heat and power (CHP) operation which is a simple cycle gas turbine with a heat recovery heat exchanger which recovers the heat in the turbine exhaust and converts it to useful thermal energy in the form of hot water. This configuration is studied in this paper.

Thermodynamic analysis can be a perfect tool for identifying the ways of improving the efficiency of fuel use. The first law of thermodynamics makes only an energy balance of a system or a control volume. It does not make any distinction of different forms of energy. It is the second law, which asserts from engineering viewpoint. Exergy is a measure of energy quality and exergetic (or second law) efficiency is a measure of the perfects of a thermal system.

The exergy analysis of plants requires in general the determination of all energy flows that are transferred between the distinguished apparatuses or unit operations of such a plant. The resulting exergy losses can provide useful information with regard to the overall performance of the considered plant.

In this paper, an energetic and exergetic analysis was performed for a 14 MW gas turbine cogeneration plant. Mass and energy conservation laws were applied to all system. Quantitative exergy balance for whole system was considered. The performance of gas turbine cogeneration system was evaluated using this analysis.

2. DESCRIPTION OF GAS TURBINE COGENERATION SYSTEM

The flowsheet of the gas turbine cogeneration system is shown in fig.1 and T-s diagram – in fig.2.

Air at atmospheric pressure is compressed by the air compressor from state 1 to state 2, [1] Fuel, natural gas, is added in the combustion chamber to increase the temperature at constant pressure to state 3. The hot gas is then expanded to state 4 in the gas turbine, which connected to the shaft of generator for producing electricity. Hot exhaust from the power turbine is the waste heat source for process heat production into the heat recovery boiler which generates hot water supplied to users through heat interchanger, [2]

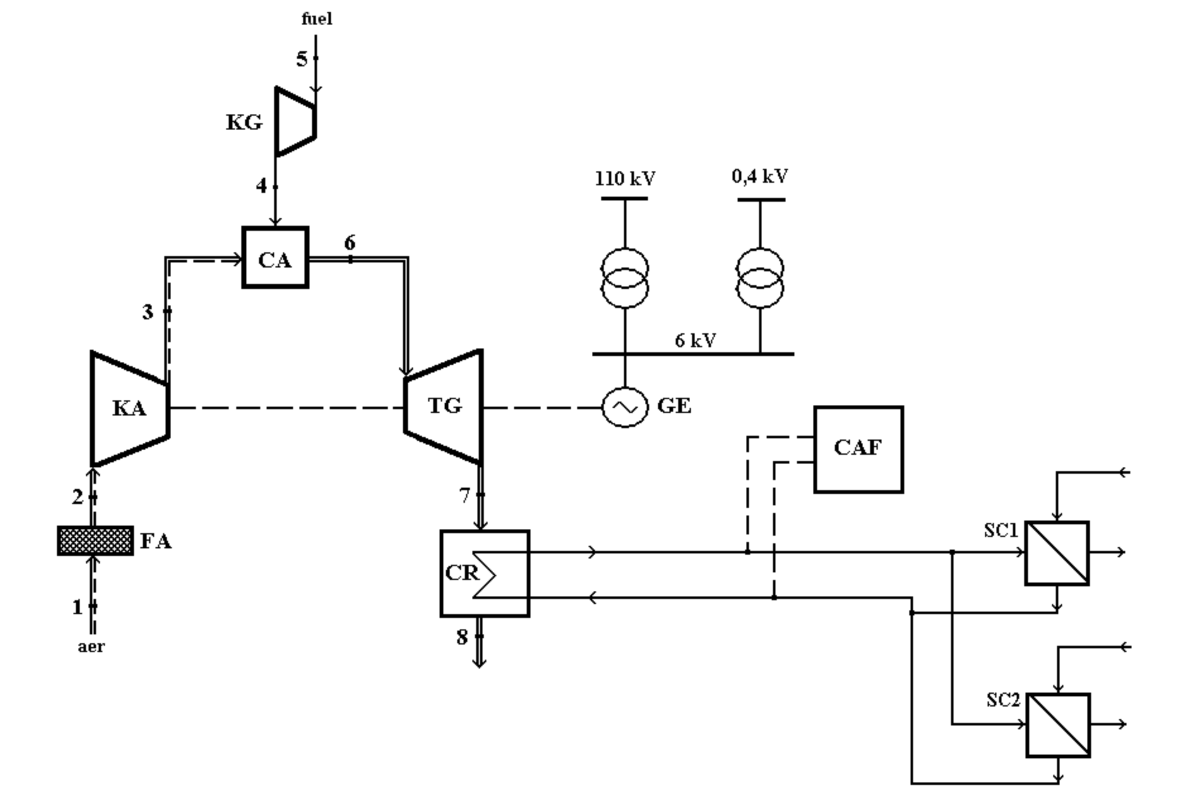
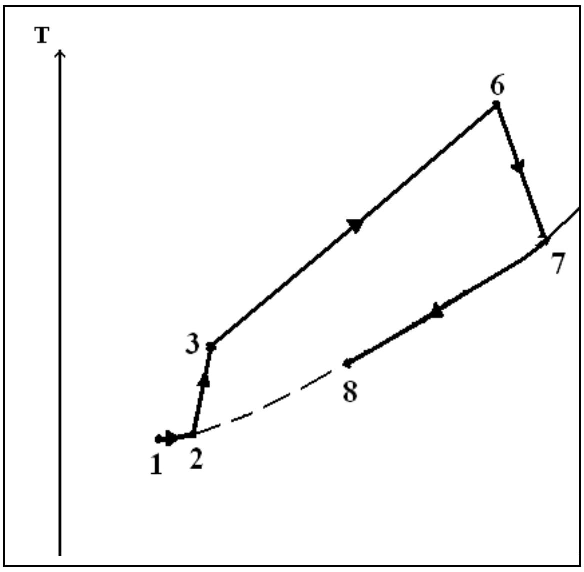


Figure 1. The flowsheet of the gas turbine cogeneration system: FA – air filter; KA – air compressor; CA – combustion chamber; KG – fuel compressor; TG – gas turbine; GE – generator; CR – recovery boiler; CAF – hot water boiler; SC1, SC2 – heat exchanger.



3. ENERGY AND EXERGY PERFORMANCE PARAMETERS

The relevant parameters required for the thermodynamic performance evaluation of combustion gas turbine cogeneration system may be considered energy efficiency and exergy efficiency.

For evaluation of these parameters, energy and exergy analysis based on the first and second law of thermodynamics was made.

The energy balance equation for overall gas turbine plant is follow:

$$P_{cc} + P_{sc} = P_n + P_t + \Delta P_{\cos} + \Delta P_m + \Delta P_G + \Delta P_{CR} + \Delta P_{PT} + \Delta P_{TSP} + \Delta P_{ma} \text{ [kW]} \qquad (1)$$

where: $(P_T - P_R) = P_t$ - heat flux delivered to the district heating; $(P_{g\cos} - P_a) = \Delta P_{\cos}$ - heat losses at the chimney; P_{cc} - the heat flux supplied by the fuel, in the combustion chamber; P_{sc} - heat flux due to inlet enthalpy of fuel; P_a - heat flux due to inlet temperature of air in the compressor; P_R - heat flux of water which return from district heating; P_n - net power delivered in the network; P_T - heat flux of water input to district heating; $P_{g\cos}$ - heat flux due to enthalpy of gas exhaust to the atmosphere; ΔP_m - mechanical losses of the entire installation; ΔP_G - electrical losses of the generator; ΔP_{CR} - heat losses of the recovery boiler to the environment; ΔP_{PT} - heat losses of the heat exchangers, of pumps, of conducts; ΔP_{TSP} - electrical losses of the transformer 6/0.4 kV; ΔP_{ma} - heat losses to the environment for the other installations: electrical engines, gas compressor, electrical cables.

For calculation heat fluxes there are known relations. For example, the heat flux supplied by the fuel, in the combustion chamber is calculated as, [3]:

$$P_{cc} = V_{comb} \cdot P_{ci} \quad \text{[kW]} \qquad (2)$$

where: V_{comb} – flow rate of fuel, Nm^3/s; P_{ci} – heat calorific value, kJ/ Nm^3

The heat flux due to inlet enthalpy of fuel is:

$$P_{sc} = V_{comb} \cdot i_1 \quad \text{[kW]} \qquad (3)$$

where i_1 is enthalpy of fuel.

The exergy balance equation for overall installation is the same with (1). The exergy content of heat is determined by its temperature as defined by the formula:

$$E_q = Q \cdot \left(1 - \frac{T_0}{T}\right) \quad \text{[kW]} \qquad (4)$$

where Q denotes the quantity of heat and T its temperature in Kelvin. T_0 is the ambient temperature.

The physical exergy for a stream is given by the following expression:

$$E_s = D \cdot \left[i - i_0 - T_0 \cdot (s - s_0)\right] \quad \text{[kW]} \qquad (5)$$

Here I, kJ/kg, and s, kJ/kg^{0}K, are the enthalpy and entropy of the stream at the actual temperature T and pressure p, while i_0 and s_0 are the same properties at the environmental conditions T_0 and p_0; D is mass flow, kg/s.

The thermal and mechanical components of the exergy stream for an ideal gas with constant specific heat may be written as, [4]:

$$E_T = D \cdot c_p \cdot \left[T - T_0 - T_0 \ln \frac{T}{T_0} \right] \ \text{[kW]} \tag{6}$$

$$E_P = D \cdot R \cdot T_0 \ln \frac{p}{p_0} \qquad \text{[kW]} \tag{7}$$

where c_p is specific heat, kJ/kg^{0}K; R - universal constant, kJ/kg ^{0}K.

Performance parameters of gas turbine plant are:

- energy efficiency: $\eta = \dfrac{P_T + P_n}{P_{cc}}$ (8)

- exergy efficiency: $\eta_{ex} = \dfrac{E_T + P_n}{E_{cc}}$ (9)

because power P_n is exergy.

4. RESULTS AND DISCUSSION

The main conditions and parameters used in the calculation are shown in the table 1.

Conditions and parameters used in the calculation. Table 1

Nr.crt.	Description	Value
1	Ambient condition	15 ^{0}C / 101.3 kPa
2	Compressor inlet temperature	7 ^{0}C
3	Compressor pressure ratio	17.656
4	Flow rate of air	1.1565 Nm^3/s
5	Flow rate of fuel	1,1565 Nm^3/s
6	Heating value fuel	35515.9 kJ/ Nm^3
7	Gas turbine inlet temperature	1109 ^{0}C
8	Gas turbine outlet temperature	499 ^{0}C
9	Fluegas temperature	95 ^{0}C
10	Gas turbine output (electricity)	15060 kW

Energy balance for a gas turbine cogeneration plant.Table 2

Input power	Symbol	Value		Output power	Symbol	Value	
		kW	%			kW	%
heat flux supplied by the fuel	P_{cc}	41074.14	99.969	net electric power delivered to the network	P_n	13936.53	33.920
heat flux due to inlet enthalpy of fuel	P_{sc}	12.84	0.031	heat flux delivered to the district heating	P_t	20659.90	50.283
				Useful power: $P_n + P_t$	P_u	**34596.43**	**84.203**

Input power	Symbol	Value		Output power	Symbol	Value	
		kW	%			kW	%
				heat flux due to enthalpy of gas exhaust to the atmosphere	$\Delta P_{\cos}$	4481.82	10.908
				mechanical losses of the overall installation	ΔP_m	142.50	0.347
				electrical losses of the generator	ΔP_G	451.80	1.100
				heat losses of the recovery boiler to the environment	ΔP_{CR}	196.20	0.478
				heat losses of the heat exchangers, of pumps, of conducts	ΔP_{PT}	357.70	0.871
				electrical losses of the transformer 6/0.4 kV	ΔP_{TSP}	2.07	0.003
				heat losses to the environment	ΔP_{ma}	858.46	2.090
				Total losses	ΔP	**6490.55**	**15.797**
Total input power	P_{ti}	41086.98	100.00	Total output power	P_{te}	41086.98	100.00

Exergy balance for a gas turbine cogeneration plant.Table 3

Input exergy	Symbol	Value		Output exergy	Symbol	Value	
		kW	%			kW	%
Fuel chemical exergy	E_{cc}	41074.1	100.00	Net exergy delivered to the network	E_n	13936.53	33.930
Fuel physical exergy	E_{cf}	-0.4	-0.001	heat flux delivered to the district heating	E_t	4178.9	10.174
				Useful exergy: $E_n + E_t$	E_u	**18115.4**	**44.105**
				Exergy losses with gas exhaust to the atmosphere	$\Delta E_{g\cos}$	1046.33	2.547
				Exergy losses due to mecanical losses	ΔE_m	142.5	0.347
				Exergy losses of the generator	ΔE_G	451.8	1.100
				Exergy losses of the recovery boiler to the environment	ΔE_{CR}	18.5	0.045
				exergy losses of the heat echangers, of pumps, of conducts	ΔE_{PT}	23.2	0.057
				exergy losses of the transformer 6/0.4 kV	ΔE_{TSP}	2.07	0.005
				other losses	ΔE_{ma}	21273.92	51.794

				Total exergy losses	ΔE	**22958.3**	55.895
Total input exergy	E_{ti}	41073.8	100.00	Total output exergy	E_{te}	41073.8	100.00

Table 2 shows energy flow rates for entire gas turbine cogeneration plant. These flow rates were calculated based on the values of measured properties such as pressure, temperature, and mass flow rate at various points and using relation presented up. Note, from the total input energy, 33.92% represents net electric power delivered to the network from own 6kV substation, 50.28% - heat flux delivered to the district heating and 15.8 % - total losses. The biggest losses, 68.9% from the total losses, are heat flux due to enthalpy of gas exhaust to the atmosphere. Power required for the own service of plant and electrical losses are 8% from the gas turbine output (gross electric power).

The energetic efficiency of the total plant is also shown: it amounts to 84.2%. Results of the exergy analysis are shown in the table 3. The largest exergy-loss contributor was the combustor of the gas turbine. The exergetic efficiency is only 44%.

4. CONCLUSIONS

Energetic and exergetic analysis is a good tool for identifying the ways of improving the efficiency of fuel use. An exergy balance applied to a whole plant tells us how much of the usable work potential, or exergy, supplied as the input to the system under consideration has been consumed (irretrievably lost) by the process. The loss of exergy, or irreversibility, provides a generally applicable quantitative measure of process inefficiency.

The energetic and exergetic analysis applied to a 14 MW gas turbine cogeneration plant shows that the exergetic efficiency is much lower than energy efficiency. Considerable exergy destruction occurs in the combustion chamber.

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