Application of exergy balances for the optimization of regenerative gas turbine cycle

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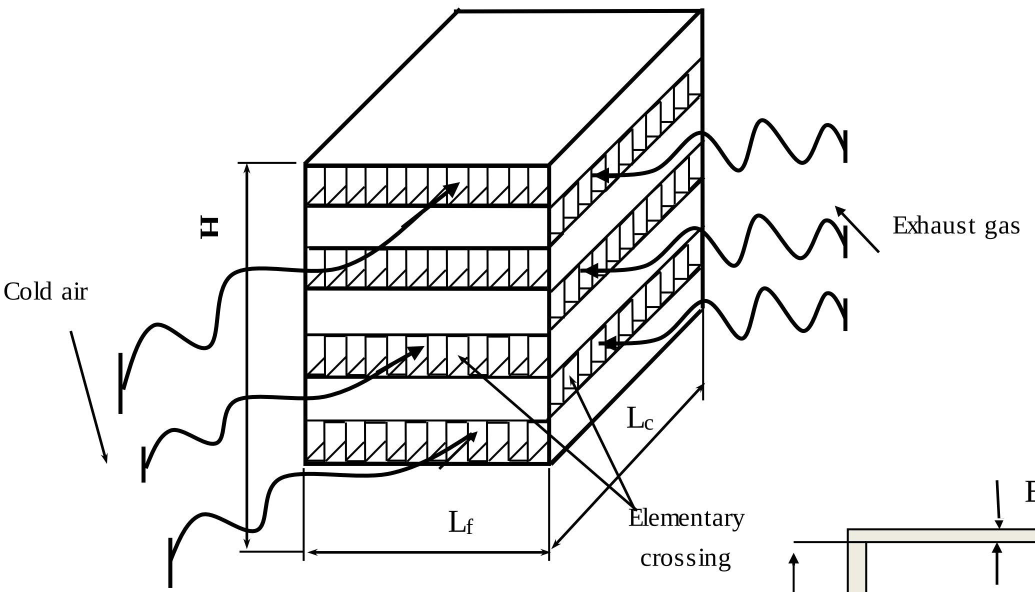
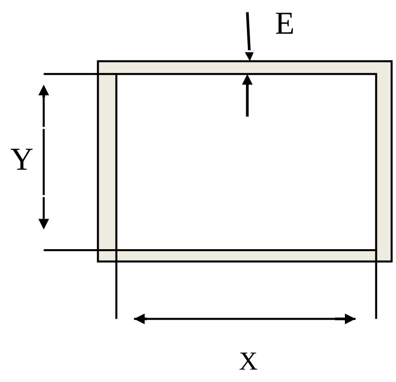
Abstract: An exergetic and second law efficiency analysis was performed for a 100 MW regenerative gas turbine. The effect of compressor pressure ratio and turbine inlet temperature on exergy destroyed and second law efficiency was investigated using quantitative exergy balance for each component and for the whole system. The results are given graphically with the appropriate discussion and conclusion.

Key words: exergy analysis, optimization, regenerator, gas turbine.



parameter	H	L_f	L_c	X	Y	E
Value (m)	1.2376	1.004	1.506	0.05	1.76*X	0.0002



Regenerator model

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1. Introduction

In gas turbine units, the temperature of the exhaust gases leaving the turbine is often considerably higher than the temperature of compressed air leaves compressor [1,2,3].Therefore, the high pressure air leaving the compressor can be heated up by transferring heat to it from the hot gases leaving the turbine by a heat exchanger called regenerator before expelling to atmosphere. The thermal efficiency of gas turbine cycle increases as a result of regeneration since the portion of energy of exhaust gases that is normally rejected to the surrounding is now used to preheat the compressed air entering the combustion chamber this, in turn, decrease the mass of fuel required for the same turbine inlet temperature T_3[1,3].

In thermodynamics, the concern is not only for the quantity of energy but also for quality of energy [4]. The first law efficiency does not take into account the quality of energy.

The current work is aimed to analyze the gas turbine efficiency with alternative regenerator from second law. Exergy analysis has been widely applied to gas turbine and gas turbine based power plants. Ebadi and Gorji-Bandpy [5] have performed an exergetic analysis of a gas turbine power plant and showed that the plant's efficiency and exergy destruction are greatly affected by the variation in turbine inlet gas temperature.

2. Simple gas turbine

In the simple cycle, from the compressor inlet point 1, the ambient air is compressed to reach the high pressure at point 2. No heat is added, however, the compression increases the air temperature, so that at the compressor outlet the air is at high temperature and pressure. Leaving the compressor, the air enters into the combustion chamber where the fuel is injected and the combustion occurs practically at constant pressure,in fact, the temperature of exhaust gas exiting the turbine is usually much higher than the temperature of the air leaving the compressor Therefore, the high pressure air leaving the compressor can be heated by heat transfer from the exhaust gas in a heat exchanger acting as a recuperator regenerator. [6].

The GT with regenerator is shown in Figure1.

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The thermal efficiency is

$$\eta_{rég} = \frac{\dot{m}_g \eta_t c_{pg} T_3 \left(1 - \frac{1}{PR^{\frac{k-1}{k}}}\right) - \dot{m}_a \frac{c_{pa} T_1}{\eta_c} \left(\frac{T_{2s}}{T_1} - 1\right)}{\dot{m}_f PCI_g \eta_{cc} - \varepsilon c_{min} (T_2 - T_4)} \qquad (1)$$

3. Exerg study of the regenerative cycle

3.1 exergy in the compressor

For all equipment the exergy efficiency is :

$$\eta_{ex,i} = \frac{\dot{E}_{p,i}}{\dot{E}_{f,i}} \qquad (2)$$

We denotes by p: product and f : fuel.

Then for the compressor:

$$\dot{E}_{p,c} = \dot{m}_a * ((c_{p,a} * (T_2 - T_1) - T_0 * ((c_{p,a} * \ln\left(\frac{T_2}{T_1}\right) - R_a * \ln\left(\frac{P_2}{P_1}\right))) \qquad (3)$$

$$\dot{E}_{f,c} = \dot{W}_c = \dot{m}_a * c_{p,a} * (T_2 - T_1) \qquad (4)$$

3.2 exergy in the combustion chamber

$$\dot{E}_{f,cc} = \dot{E}_{fuel} \qquad (5)$$

$$\dot{E}_{f,cc} = \dot{m}_f * PCI \qquad (6)$$

$$\dot{E}_{p,cc} = \dot{E}_3 - \dot{E}_5 \qquad (7)$$

$$\dot{E}_5 = \dot{m}_a * (c_{p,a} * (T_5 - T_0) - T_0 * \left(c_{p,a} * \ln\left(\frac{T_5}{T_0}\right) - R \ln\left(\frac{P_5}{p_0}\right)\right)) \qquad (8)$$

$$ex_3 = ex_3^{ph} + ex_3^{chim} \qquad (9)$$

$$ex_3^{ph} = \dot{m}_g * (c_{p,g} * (T_3 - T_0) - T_0 * \left(c_{p,g} * \ln\left(\frac{T_3}{T_0}\right) - R \ln\left(\frac{P_3}{p_0}\right)\right)) \qquad (10)$$

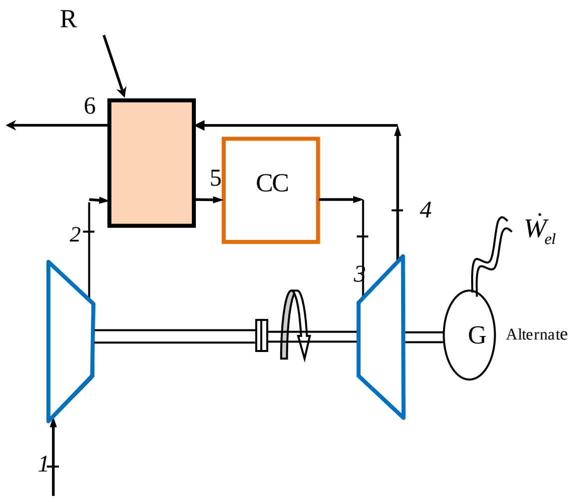

Fig 1. GT with regenerator operating mode

$$ex_3^{chim} = \sum_{i=1}^{n} X_i * ex_i^{ch} + R * T_0 \sum_{i=1}^{n} X_i * \ln(X_i) \quad (11)$$

$$ex_i^{ch} = \mu_{i,0} - \mu_i^{e} \quad (12)$$

The reaction of combustion is :

$$aCH_4 + bC_2H_6 + dC_3H_8 + eN_2 + kCO_2 + jO_2 \longrightarrow lCO_2 + mN_2 + nO_2 + oH2O + pNO \quad (13)$$

4 .3 exergy in the regenerator

$$\dot{E}_{p,reg} = \dot{E}_5 - \dot{E}_2 \quad (14)$$

$$\dot{E}_{f,reg} = \dot{E}_4 - \dot{E}_6 \quad (15)$$

3.4 exergy in the turbine

$$\dot{E}_{p,t} = \dot{W}_t \quad (16)$$

$$\dot{E}_{f,t} = \dot{E}_3 - \dot{E}_4 \quad (17)$$

3.5 exergy of the cycle

$$\eta_{ex,cyle} = \frac{\dot{W}_{net}}{\dot{E}_{fuel}} \quad (18)$$

4. Numerical simulation

To analyze the influence operating variables on the cycle performances, a simulation code is established using the software EES for a net power of 100 MW. The operating conditions and the air properties are defined according to those usually considered for the STEG (Tunisian Society of Electricity and Gas) power plant.

The operating variable ranges are given in Table 1.

The figures bellow shows some variation of exergy efficiencies with some operating parameters:

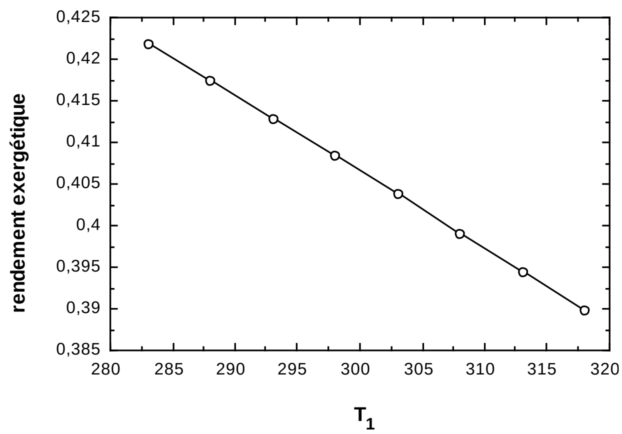

Fig2. variation of exergy efficiency with ambient temperature

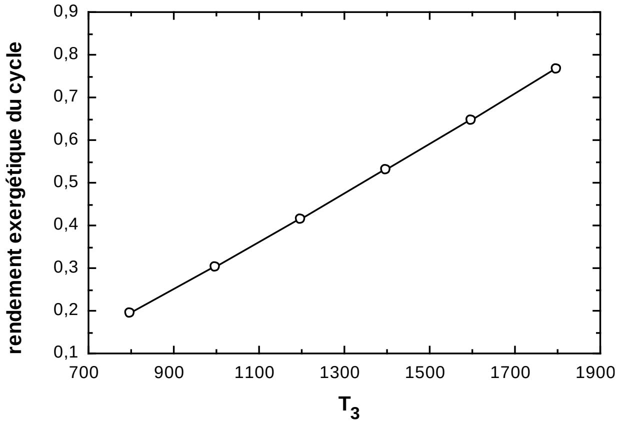

Fig3. variation of exergy efficiency with combustion temperature

Table 1. range of variable of operating parameters

Variables	Range
Input temperature	10-45 °C
Air humidity ratio	0,45-0.5
Pressure rate	10 – 16
Hot gas temperature	800-1600

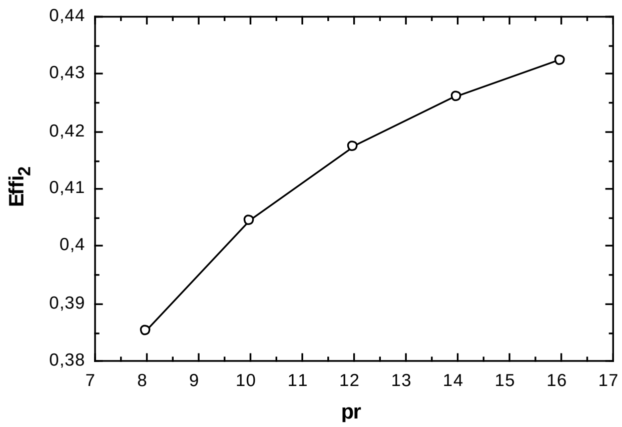

Fig4. variation of exergy efficiency with pressure ratio.

5. Conclusions

A numerical simulation is performed for a gas turbine of 100 MW of net power with steam injection device. According to obtained results, following remarks can be pointed out:

- The exergy efficiency of the cycle gas turbine decreases with the increase of ambient temperature
- The exery efficiency of the cycle increases as the pressure ratio increases and the combustion temperature.
- The combustion chamber has the lower exergy effeciency.

References

[1] A.Yunus,Cengel,A.Micheal. Boles, Thermodynamics an engineering Approch,Mc Graw-Hill com,

[2] Ashock Kumar,S S Kachhwaha and R S Mishra, Thermodynamics Analysis of a Regenerative Gas Turbine. Cogeneration Plant,Journal of scientific and Industrial Research, vol 69 ,pp 225-231,March 2010.

[3] Alaandro Franco, Claudio Casarosa,On some Perspective for Increasing The Efficiency of Combined Cycle Power Plants. Applied Thermal Engineering, Vol.22, pp 1501-1518, 2002.

[4] A. Cihan, O. Hacihaafizogluo, K. Kahvesi, Energy-exergy Analysis and modimization suggestions for a combined-cycle power plant. Int.J Energy Res 2006; 30:115-26.

[5] MJ. Ebadi, M. Corj-Bandpy, Exergetic analysis of gas turbine plants. Int J Exergy 2005; 2(1):31-9.

[6] P.Frank, Incropera, P. David, De Witt, Fundamentals of Heat and man transfer Handbook, Third Edition, Chapter 11.