EXERGY ANALYSIS OF OXY-FUEL POWER CYCLE

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***Abstract*: By keeping the carbon balances in the atmosphere sustainable developments can be achieved. Zero emission cycles are economic, safe, flexible, durable, reliable and clean. In this study, some thermodynamic properties such as temperature, pressure, enthalpy, entropy, mass flow rate in each stream of the oxy-fuel cycle are calculated. The oxy-fuel power cycle is analyzed by using first law of thermodynamics and exergy analyses method. Exergetic efficiency, exergy losses of each component, and other parameters are calculated. Thermodynamic and performance analyses of this cycle are studied with a computer program that prepared by the author.**

***Index Terms*: Exergy, power cycle, oxy-fuel.**

I. INTRODUCTION

The sustainable developments can be achieved by keeping the carbon balances in the atmosphere. According to world energy report, 80% of the world energy production is made by fossil fuels, 14% are from the renewable energies, and 6% from nuclear energy. The CO_2 emission due to fuel-oil is 75 kgCO_2/GJ, coal based energy production is 95 kgCO_2/GJ, and from natural gas is 56 kgCO_2/GJ [1, 2]. Zero emission cycles are flexible, clean, safe, durable, reliable and economic. Removing and storing technology of CO_2 is a possible and economical process. Capturing or separating CO_2 process can be realized by pre-combustion, post-combustion or oxy-fuel (de-nitrogenated) processes [2, 3]. In a pre-combustion process, capturing CO_2 by de-carbonizing of the fuel, combustion happens between oxygen and hydrogen. A steam cycle is generated with a pre-reformer unit which is used to convert the fuel to hydrogen. Separating CO_2 by pre-combustion process is cheaper, efficient, and needs less energy.

In oxy-fuel process a cryogenic air separation unit is used to separate oxygen from the air. The combustion happens between fuel and oxygen. The major part of exhaust gases contains CO_2 and H_2O. H_2O is separated from exhaust gases by condensation. [3, 4].

For CO_2 storage geological places such as oil reservoir or natural gas, and ocean basin deeper than 2700 meters are suitable. The ocean basin is deeper than 2700 meters and constitutes 75% of the total oceans suitable. In power plants disposing CO_2 methods is mainly, storage of liquid CO_2 with chemical reactions adsorption on to coal, or mineralization into carbonate [2, 5].

Among all zero emissions cycles the SOFC+GT (solid oxide fuel cell integrated with a gas turbine cycle) has the maximum efficiency. Instead of combustion chamber in SOFC+GT a unit that has a cathode and an anode to separate and then to capture CO_2 is used. The SOFC+GT cycle includes an after burner, because the fuel is not completely inverted in the fuel cell. The electrical efficiency of the SOFC+GT is over 55% of hydrogen energy and the exhaust gases temperature are 900-1100 ^{0}C. By using the exhaust heat energy, the electrical efficiency can be reach about 70% of the LHV of H_2. For large scales, the SOFC+GT cycle is not realized (maximum 20 MW), however with an after burner the use of fuel energy has reached 95% [2, 5, 6].

The zero CO_2 emission cycles are not yet competitive with classical power cycles. And their efficiencies are low, however they have improving potential with using as cogeneration. Zero CO_2 emission cogeneration cycles are emerging recently and not studied sufficiently in the literature yet. Therefore this present study is addressed from these points.

II. THERMODYNAMIC MODEL OF THE OXY-FUEL CYCLE

The oxy-fuel cycle in this study is presented in Fig. 1. The cycle is applicable for large scales industrial applications. Working fluid of the oxy-fuel cycle are oxygen, carbon dioxide, and steam (96% CO_2, 2% O_2 and 2% H_2O). The working fluid is compressed in a compressor and after that the heat energy is given in a recuperator. This hot working fluid is reacted with oxygen and methane. The oxygen is obtained by using the air separation unit.

The hot exhaust gases expand in the gas turbine to produce work. After that in the recuperator and in the heat exchanger some of heat energy of the exhaust gases goes to the working fluid and water. The exhaust gases outlet temperature of the heat exchanger is 303,15 K and at the outlet temperature (303,15 K). Some of the steam is condensed so that some of its energy is transferred into back to the cycle. Some of the exhaust gases (96% CO_2, 2% H_2O and 2% O_2) is sent to the compressor to be compressed to 75012,9 kPa pressure. Some of the heat energy of the compressed exhaust gases in the heat exchanger, is given to water to produce steam. And then the CO_2 is sent for storage [1, 2, 8]. The pressure losses in the system is neglected, and the isentropic efficiencies of the gas turbine and the compressor are taken as η_{st}= 0.90, and η_{sc}= 0.88, respectively. Specific enthalpies and specific entropies are calculated for each stream from the equations of the reference [7].

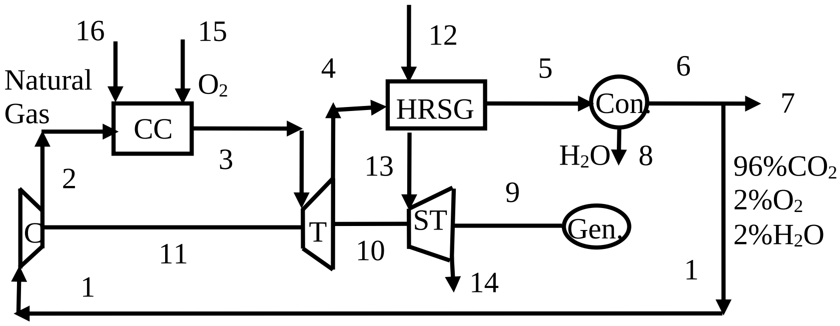

Figure 1. Oxy-fuel power cycle

$$\overline{h}_i = f(T_i) \quad (1)$$

$$\bar{s}_i = f(T_i, P_i) \quad (2)$$

The energy and exergy balances for the cycle, can be written as;

$$\sum \dot{m}_i h_i - \sum \dot{m}_o h_o + \dot{Q} - \dot{W} = 0 \quad (3)$$

The physical and chemical exergy is calculated as,

$$\dot{E} = \dot{E}_{ph} + \dot{E}_{ch} \quad (4)$$

$$\dot{E}_{ph} = \dot{m}(h - h_0 - T_0(s - s_0)) \quad (5)$$

$$\dot{E}_{ch} = \frac{\dot{m}}{M}\left\{\sum x_k \bar{e}_k^{ch} + \bar{R}T_0 \sum x_k \, ln x_k\right\} \quad (6)$$

Methane is taken as fuel to simplify the calculations. The stoichiometric combustion is given as follows.

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O \quad (7)$$

Exergetic efficiency of the oxy-fuel cycle is,

$$\eta_{ex} = \frac{\dot{W}_{net,T} + \dot{W}_{net,ST}}{\dot{E}_{12} - \dot{E}_{16}} \quad (8)$$

III. RESULTS AND DISCUSSION

With the thermodynamic model given above the electrical power outputs, the exergy efficiency, the compression work, the combustion chamber and the gas turbine outlet temperatures are obtained and analyzed. Thermodynamic analyses of this cycle are made with a computer program which is written in FORTRAN codes by the author. Some of these analyses results are presented in Fig. 2-5.

In Fig.2 the variations of the gas and the steam turbines net works with the compression rates for the oxy-fuel cycle are given. Increasing the compression rates increases the gas turbine net work, but decreases the steam turbine net work. However, the total work is increasing with increasing the compression rates. The cycle has better performance in high compression rates.

In Fig.3 variations of the exergy efficiency with compression rates for the oxy-fuel cycle are given. As can be seen in Fig.3 increasing compression rates from 4 to 16, increases the exergy efficiency of the cycle about 8%. The Fig.2 and the Fig.3 shows that the compression rates of the cycle should be about 16 to have better performances. The optimum exergy efficiency of the recuperated gas turbine cogeneration cycle without separating or capturing CO_2 is given that is 52 % and for the base design is about 51% in the literature. However the exergy efficiency of the zero CO_2 emissions oxy-fuel cycle for the base design is 51.3%.

In Fig.4 the variations of the gas and the steam turbines net work with working fluid mass are given. Increasing the working fluid mass increases the net work of the gas turbine, but decreases the net work of the steam turbine. However, the total work increases with increasing the working fluid mass so that the capacity of the components should calculated carefully.

In Fig.5 the variations of the exergy efficiency with the working fluid mass for the oxy-fuel cycle are given. Increasing the working fluid mass increases the exergy efficiency of the cycle. Increasing the working fluid mass from 80 kg/s to 100 kg/s increases the exergy efficiency about 1% of the cycle. That means increasing the working fluid mass effects the exergy efficiency very small that can be ignores.

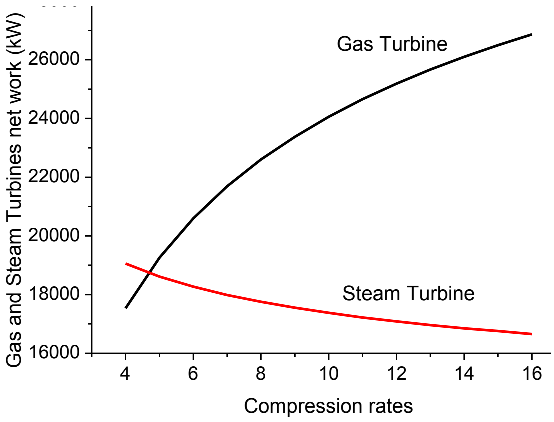

Figure 2

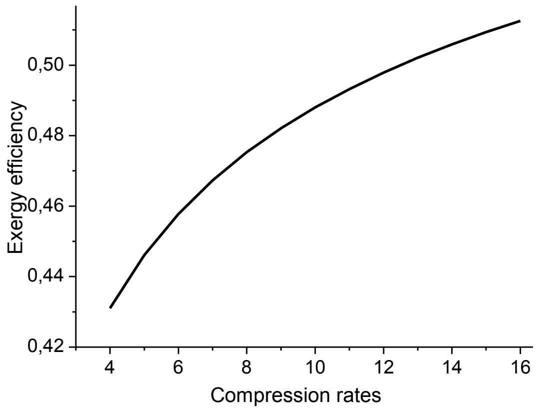

Figure 3

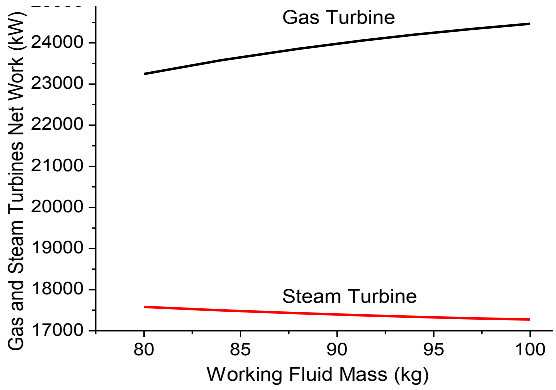

Figure 4

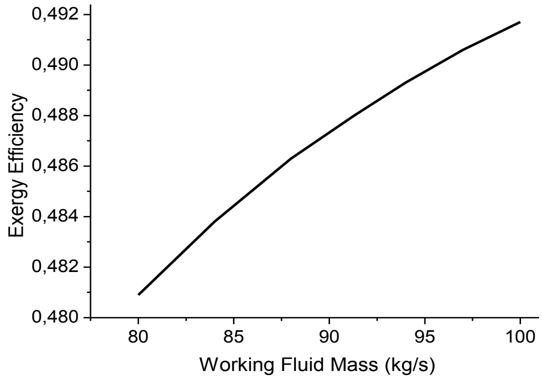

Figure 5

IV. CONCLUSION

By separating CO_2 from flue gases and storage of it, using fossil fuels safely without any harm on the environment can be achieved. In this study, thermodynamic properties such as temperature, pressure, enthalpy, entropy, mass flow rate in each stream are calculated. The oxy-fuel power cycle thermodynamically modeled and analyzed by using the first law of thermodynamics and the exergy analyses method. Exergetic efficiency and other parameters are calculated. The optimum exergy efficiency of the recuperated gas turbine cogeneration cycle without separating or capturing CO_2 is given that is 52 % and for the base design is about 51% in the literature. However the exergy efficiency of the zero CO_2 emissions oxy-fuel cycle for the base design is 51.3%. Increasing the compression rates from 4 to 16 increases the exergy efficiency of the cycle about 8%, and increasing the working fluid mass from 80 kg/s to 100 kg/s increases the exergy efficiency about 1%.That shows that compression rates are more effective on the exergy efficiency of the cycle than the fluid mass.

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