2nd Oxyfuel Combustion Conference

Efficiency of gas turbine assemblies operating under oxygen enhanced combustion (OEC)

Amir Roberto De Toni Júnior, Leonardo Zimmer, Paulo Smith Schneider, Wagner da Silva Boeira, Cristiano Frandalozo Maidana

Federal University of Rio Grande do Sul, Rua Sarmento Leite 425, Porto Alegre, 90050-170, Brazil

Keywords: gas turbine cycle efficiency; oxygen enhanced combustion

1. Introduction

The objective of this paper is the theoretical analysis of the performance of a gas turbine running under Oxygen-Enhanced Combustion (OEC) conditions, with the oxidant ranging from atmospheric composition up to 30% in oxygen content. The adopted methodology is a numerical thermodynamic modeling of a gas turbine, considering the integration of heat exchangers to improve its efficiency. Five different assemblies have been studied, including intercoolers and regenerators, in order to check the behavior of the cycle coupled with these equipments and with variable oxygen content in the oxidant stream. Cycle overall efficiency and oxygen consumption were evaluated according to variable oxygen feed concentration under stoichiometric combustion. All chemical species were taken as ideal gases. The main results obtained were the increase in the cycle efficiency and oxygen consumption with the increase in the oxygen proportion in the oxidant, for all cases.

2. Literature Review

According to Bisio et al., 2002, the barrier to couple the oxygen in the power cycles continues to be the high cost of oxygen production in cryogenic plants, but the use of membranes technology to obtain air enriched with 30-45% oxygen may offset the costs of oxygen implementation with the fuel saving obtained.

Poola et al., 1996, carried out studies of OEC in internal combustion engines for locomotives, and reported a 13% increase in thermal efficiency for naturally-aspirated engines and a 4% increase for turbocharged engines. Wu et al., 2010, studied the influence of oxygen concentration from 21 to 30% in the combustion of natural gas in the heating and furnace-temperature fixing tests. The most attractive gain is that the fuel consumption at 30% O2 was reduced by 26.1% if compared to atmospheric concentrations (21% O2) when the furnace temperature was at 1220°C.

3. Modeling and simulation

A base cycle has been used, which had been proposed by Maidana et al., 2010, with the purpose of getting reference data to the analysis of this work. This base cycle is an open Brayton cycle formed by a compression stage, an expansion turbine, and a combustion system, which is composed by a combustion chamber and auxiliary devices, as an air splitter, a gas mixer, and an oxygen injector.

The base cycle and the full assembly cycle proposed in this work are shown in the Figure 1.

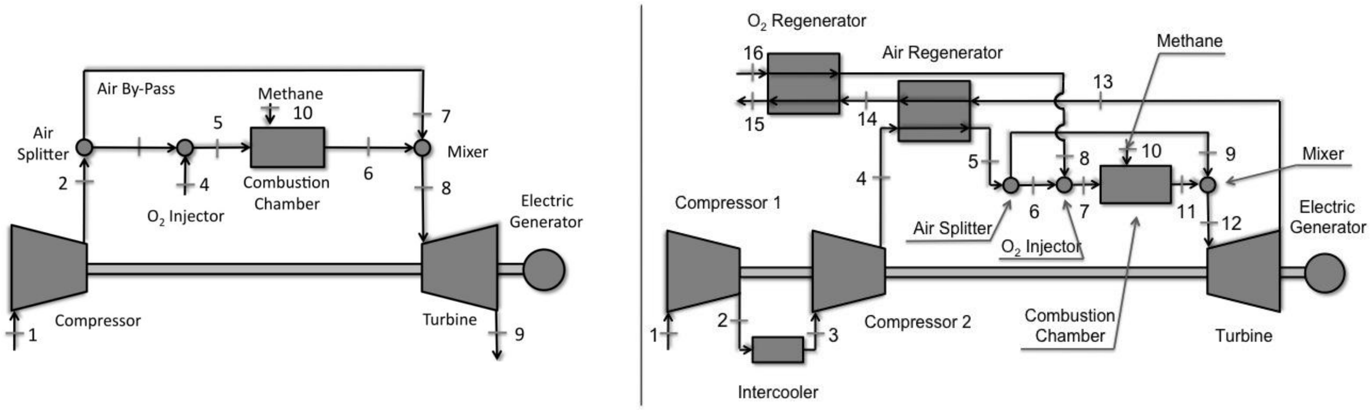

Figure 1 – Base cycle (at left) and complete assembly (at right)

In this turbine, air was the working fluid and its operation followed a conventional Brayton cycle, besides the addition of an oxygen injection system to promote the oxygen enrichment. The complete assembly incorporated heat exchangers to improve cycle efficiency. Several sequential improvements from the base cycle until the complete assembly were proposed and are listed in the Table 1.

Table 1: Proposed assemblies

ASSEMBLY	DESCRIPTION
1	Base cycle
2	Base cycle + Intercooler
3	Base cycle + Air regenerator
4	Base cycle + Intercooler + Air regenerator
5	Base cycle + Intercooler + Air regenerator + O_2 regenerator

All cases were modeled through mass, specie and energy balances for each equipment, and simulated with the aid of the Engineering Equation Solver (EES) software, a Newton-Raphson based equation solver which provides an extensive thermodynamic properties database.

Compared to the original cycle of Maidana et al., 2010, the isentropic efficiencies of the compressor and turbine has been changed from 60% to 80%, and from 80% to 86%, respectively. This modification has been made to reach values usually found in regular equipments as well as in the CGAM case, Bejan et al., 1996.

For all five cases the oxygen content was ranged from 21 %, atmospheric condition, to 30 %, maintaining the ratio oxygen/fuel within the stoichiometric limit. As a standard to all cases the net power was set to 30 MW.

4. Results and conclusions

Simulations were done to evaluate the assembly efficiencies as a function of oxygen content in stoichiometric combustion, compared to the base cycle result. The results can be seen in the Figure 2.

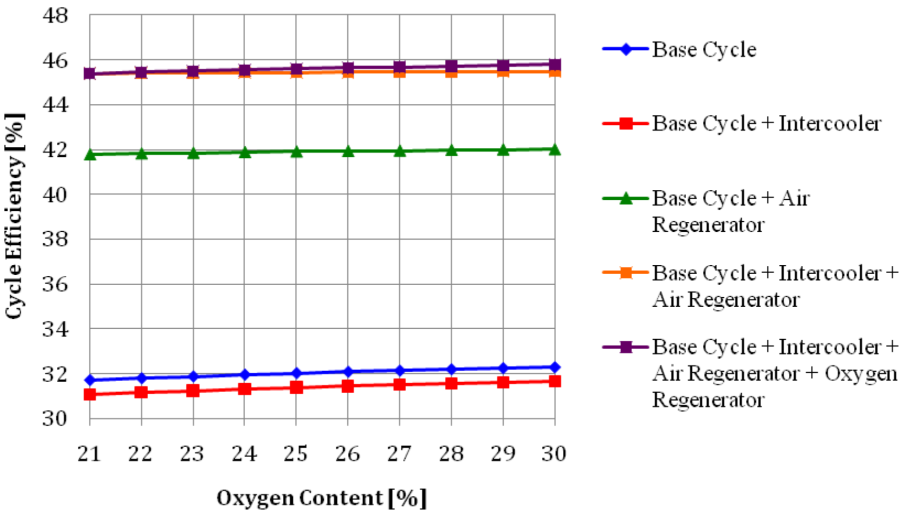

Figure 2 – Cycle efficiencies for the five different assemblies proposed due to oxygen content in the oxidant.

As it can be verified, the oxygen enrichment increased the cycle efficiency for all configurations, nevertheless is important to stress that the second assembly, with the intercooler, presented a decrease in the cycle efficiency compared to the base cycle. This is due to the decrease of the air temperature in the combustion chamber inlet, that led to a higher fuel consumption.

Also, it's possible to notice the decrease of the oxygen enrichment effect in cases which only the air regenerator is included, without oxygen regenerator. This effect can be justified due to the fact that oxygen is added at ambient temperature, resulting in a decrease on the combustion temperature. Thereby, the higher the enrichment level the lower the combustion chamber inlet temperature, reducing the effect on the efficiency increase.

According to the simulation results, the complete assembly displayed the highest cycle efficiency, around 45%, against 32% of the base cycle. In addition, it's remarkable that the main improvement in the cycle efficiency is due to the air regenerator. The assembly with air regenerator and intercooler increases the efficiency even further, while the case with intercooler only decreases the efficiency compared to the base cycle.

The main disadvantage of the OEC is the high cost of a pure oxygen injection in the combustion chamber. According to Bolland and Mathieu, 1998, the energy cost to separate oxygen from air is 0.25 kWh/ kg O_2. In the case with oxygen content of 30 % in the oxidant stream, the pure oxygen consumption for stoichiometric combustion is 1.984 kg O_2/s, corresponding to an energy cost of 1.78 MW. However, there are several oxygen separation processes, like PSA (pressure swing adsorption) and membrane technology, that can yield oxygen-enriched stream to the cycle and offset the costs.

5. References

Bejan, A., Tsatsaronis, G., Moran, M., 1996. "Thermal Design and Optimization". Ed. John Wiley & Sons, Inc., USA, 542 p.

Bisio, G., Bosio, A., Rubatto, G., 2002. "Thermodynamics applied to oxygen enrichment of combustion air". Energy Conversion and Management 43, 2589-2600.

Bolland, O., Mathieu, P., 1998. "Comparison of two CO_2 removal options in combined cycle power plants". Energy Conversion Management 39, 1653-1663.

Maidana, C.F., Carotenuto, A.R.S., Schneider, P.S., 2010. "Analysis of Oxygen-Enhanced Combustion of gas Power Cycle". 13th Brazilian Congress of Thermal Sciences and Engineering.

Poola, B.R., Sekar, R., Assanis, D.N., Cataldi, G.R., 1996. "Study of using oxygen-enriched combustion air for locomotive diesel engines". Available at *www.scienceaccelerator.gov*. Accessed in Nov. 22nd, 2010.

Wu, K., Chang, Y., Chen, C., Chen, Y., 2010. "High-efficiency combustion of natural gas with 21-30% oxygen-enriched air". Fuel (article in press).