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Evaluation of a pre-combustion capture cycle based on hydrogen fired gas turbine with exhaust gas recirculation (EGR)

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Abstract

Pre-combustion capture technology is a promising route to power generation with CO_2 free emissions, by transforming the fossil hydrocarbon fuel into a hydrogen rich fuel with near zero Carbon containing species. This gaseous fuel also allows to use a high efficiency gas turbine into a coal based power plant. The gas turbine combustor however has to meet the challenge of high temperature flame responsible for unacceptable NOx emissions, and a highly reacting fuel impeding the use of conventional dry low NOx combustion technologies. The actual solution to this problem is to dilute the hydrogen fuel with up to 50% Nitrogen. This paper presents a concept where the exhaust gas of the gas turbine is recirculated (EGR) such as to deplete the air of oxygen to produce a low temperature combustion with undiluted hydrogen fuel while flame stability is still ensured by the highly reactive properties of hydrogen. The study compares the concept with a cycle using Selective Catalytic Reduction for NOx control.

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Keywords: Hydrogen combustion; exhaust gas recirculation (EGR); pre-combustion CO_2 capture

1. Introduction

Hydrogen fired gas turbines are foreseen used in two possible applications: as a key component of the pre-combustion CO_2 capture alternative and for power plants in a fully developed renewable energy based society, where hydrogen (H_2) is used as energy storage in case of excess wind and solar power. Although CO_2 free, the emissions to the environment of an H_2 fired gas turbine contain pollutants known as Nitrogen Oxides (NOx) that are responsible

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for acid rains and are strongly regulated. To date, the solutions to lower these emissions to acceptable levels such as the end of pipe technologies are expensive in terms of efficiency penalties or OPEX/CAPEX, for example Selective Catalytic Reduction (SCR). The preferred solution for NOx control in H_2 fired gas turbine is fuel dilution with Nitrogen, which is available as a by-product of the Air Separation Unit process. In addition to limiting flame temperature and hereby NOx formation, it also render the highly reactive H_2 rich fuel easier to handle for the combustor. Even though Nitrogen has no cost for the plant, the compression required for blending with the fuel represents up to 20-30% of the auxiliary power consumption of the whole pre-combustion power plant. Comparatively, it is higher than the CO_2 compression power.

The present work suggests a gas turbine cycle alternative that has the potential of inherently limiting the formation of NO_x by recirculating part of the exhaust gas to the gas turbine compressor inlet. This technology is known as Exhaust Gas Recirculation (EGR) and has been mostly considered for conventional NGCC [1]. Figure 1 shows a simplified sketch of the power process principle. Instead of diluting the H_2 rich fuel, a high EGR rate will generate an oxygen-depleted working fluid, in which the H_2 rich fuel loses its high reactivity. In conventional NGCC with EGR, it is known that a maximum of approximately 35 % EGR is the higher limit before combustion stability issues arise [2,3] due to the lack of oxygen. When using H_2 rich fuels, the practical maximum limit is bound to be higher as the combustion properties are much stronger in terms of stability. The objectives of the study are to determine the EGR rate limits allowable in such a process and to map the benefits and constraints through a performance analysis.

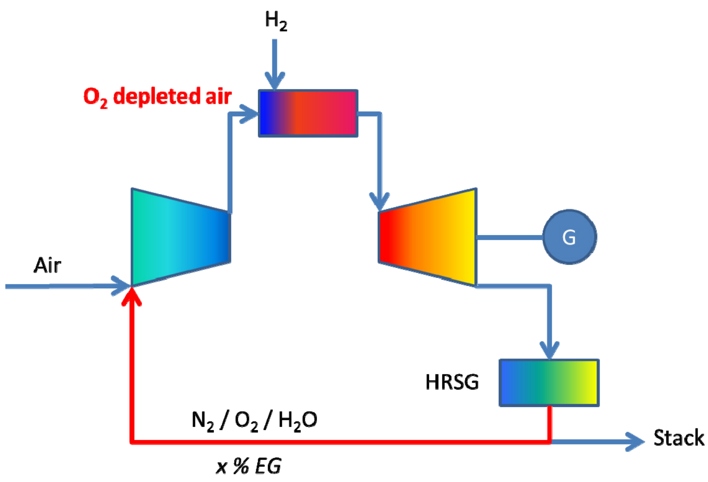

Fig. 1: Simplified sketch of core H_2 fired gas turbine with exhaust gas recirculation

2. Methods

Cycle performance simulations have been conducted in Aspen Plus. The working fluid composition and temperature at the combustor inlet are calculated from the gas turbine case of the European Benchmarking Task Force (EBTF) Guidelines IGCC cycle. The exhaust gas of the gas turbine is recycled for various rates and the composition is calculated in each case. The turbine inlet temperature is set at 1300 °C and the pressure ratio is 18.1.

Table 1. Fuel gas composition.

H_2	CO	CO_2	N_2	Ar	H_2O
85,64%	2,66%	3,24%	7,27%	1,14%	0,05%

3. Results and Discussion

Figure 2 shows the NO_x content before and after SCR. It is clear that the concentration of NO_x drops with the increase of EGR ratio. Consequently, as shown in Figure 3, the volume of exhausted gas and the NH_3 consumed by SCR also decreases clearly with EGR.

Figure 4 shows the oxygen content before and after combustion. Due to the high O_2% in the exhaust gas, even though at a high EGR ratio, the O_2% is high before combustion. Plus the high combustion temperature of the H_2 combustor, high EGR is practicable. Figure 5 shows the efficiency for the simple cycle that it rises slightly with the increase of EGR. However, as more exhaust gas is recirculated, more cooling is required.

According to the preliminary simulation results, it is clear that applying EGR in the H_2 fuelled gas turbine cycle is an effective way to reduce the formation of NO_x and without obvious effects on the combustion stability. As a result, with the increase of EGR ratio, less NH_3 is demanded and the cycle efficiency rises slightly.

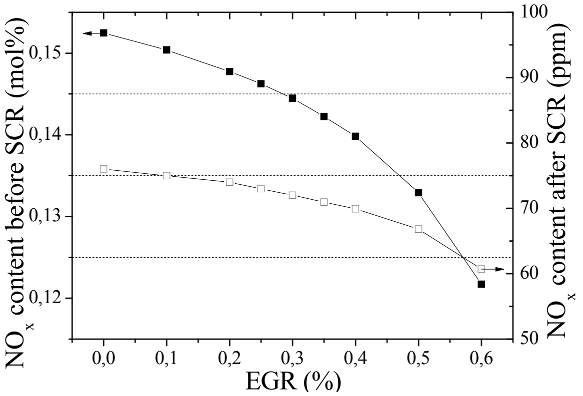

Fig. 2 NOx content before and after SCR

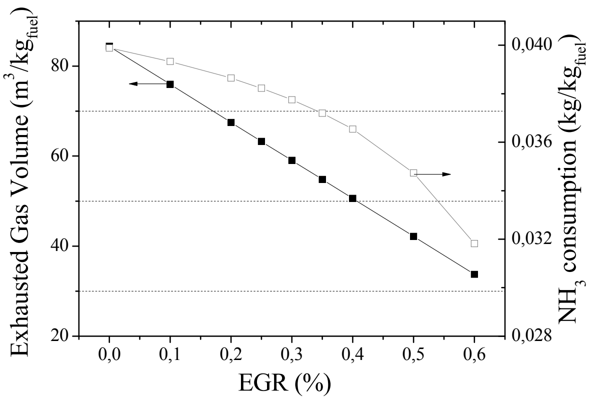

Fig. 3 EG Volume and NH3 consumption

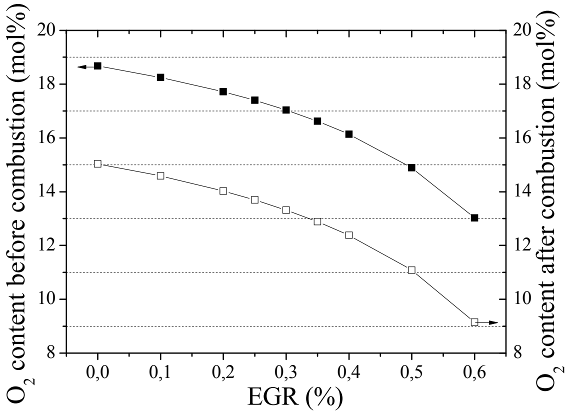

Fig. 4 oxygen content before and after combustion

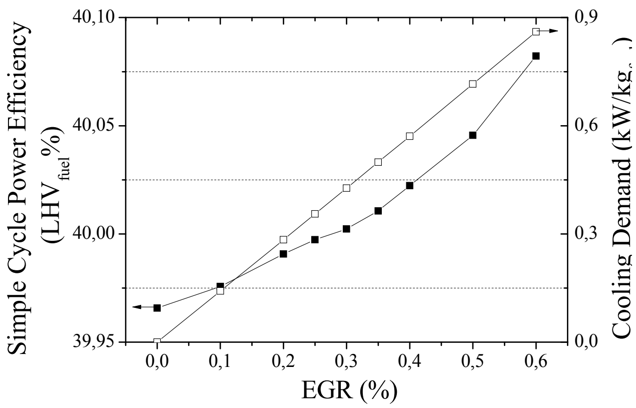

Fig. 5 Cycle efficiency and cooling demand

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