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Feasibility of Selective Exhaust Gas Recycle process for membrane-based CO_2 capture from Natural Gas Combined Cycles – showstoppers and alternative process configurations

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Abstract

This work presents the limitations of the Selective Exhaust Gas Recycle process for post-combustion capture from natural gas combined cycles using membranes and proposes a novel oxygen enriched air combustion with exhaust gas recirculation process that overcomes the limitations.

Keywords: NGCC; Selective Exhaust Gas Recycle; Exhaust Gas Recycle; Membranes; Post-combustion

1. Background

Natural Gas Combined Cycle power plants with CO_2 capture are expected to play an important role in a future carbon constrained energy scenario. While post-combustion capture from NGCC using solvents are considered as mature technology, the technology has disadvantages such as solvent degradation, high cost of capture and large footprint, the last of which is relevant for off-shore CO_2 capture. Gas separation membranes are considered among one of the promising capture technologies [1] and has a few advantages over amine based solvent systems in that the process has no steam requirement and thus easy to retrofit to existing power plants and no environmental impacts caused by solvent losses and degradation. Further the process can be quite compact making it suitable for offshore applications.

2. Selective Exhaust Gas Recycle

2.1. Introduction

Membrane-based post-combustion capture from NGCC is however challenging due to the low CO_2 concentration in

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the NGCC exhaust gas (3-4 vol%). Exhaust Gas Recirculation (EGR) has the potential to increase the CO_2 concentration in flue gas to around 8 vol% [2], however membrane-based post-combustion capture is still not competitive at these conditions [3]. Merkel et al. [4] presented a novel Selective Exhaust Gas Recycle (S-EGR) scheme to increase the exhaust gas CO_2 concentration to 15-20 vol%. The S-EGR process includes a membrane system that utilizes the air to the gas turbine as sweep to separate the CO_2 selectively for recycle back to the gas turbine process downstream of the membrane based post-combustion capture process, as shown in Figure 1. This process scheme has been subsequently used by other research groups to present a case for membrane based post-combustion capture from NGCC [5].

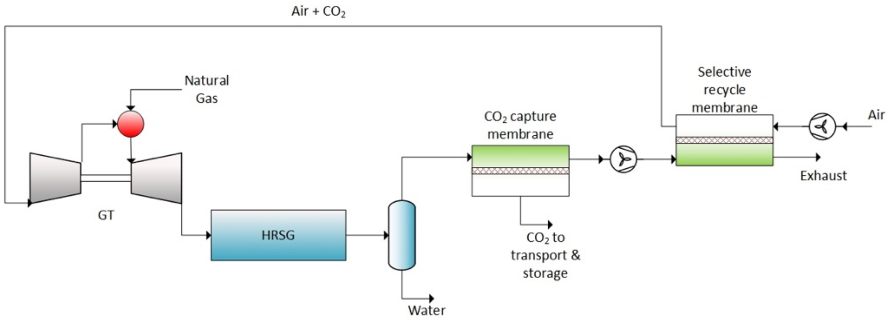

Figure 1: Selective Exhaust Gas Recirculation process scheme

2.2. Potential showstoppers

One of the limitations of the S-EGR process noted in literature [5] is that the gas turbine components will have to be redesigned as the gas turbine operates in highly CO_2 enriched conditions. The major technical impact of EGR is on the combustion systems as it affects the composition of the air entering the combustor. As part of the air is replaced by exhaust gases, the concentration of O_2 decreases and that of CO_2 increases. Both have negative effects on combustion stability. CO_2 has indeed a stronger thermal and chemical effects on the combustion kinetics than nitrogen, and O_2 is the primary oxidizer of combustion. The earlier works on S-EGR however ignore this even though it is a critical factor as it impacts the feasibility of the process itself.

The oxidizer parameters that reduce combustion reactivity and efficiency as characterized by flame stability (propensity for the flame to blow out or to generate thermoacoustic instabilities) and higher emissions of CO and unburned hydrocarbons (UHC) are:

- Decrease in oxygen concentration
- Increase in concentration of gases with higher heat capacity than N_2 (e.g. CO_2, H_2O)
- Increase in concentration of gases with kinetic activity (e.g. CO_2) limiting full oxidation of intermediate species
- Decrease in temperature
- Increase in pressure

Experiments performed in laboratory conditions for conventional EGR (3-5 vol% CO_2 in combustor inlet gas) indicate that 16% O_2 concentration is a limit to ensure complete combustion and limit CO emissions [6-9]. However, no experimental data is available for S-EGR conditions where CO_2 concentration in the combustion inlet gas is around 9-18 vol% depending on the process design and membrane performance. Based on the above discussion it is expected that O_2 concentration in excess of 16 vol% would be required to ensure complete combustion and flame stability.

To gain a better understanding on the feasibility of S-EGR process, this work presents operational windows for O_2

concentration in the GT combustor inlet gas based on targeted experimental studies with a CO_2 concentration in the range 10 – 20 vol% and temperature in the range 430-500 °C. A relation between the CO_2 concentration in the combustion inlet gas and the required O_2 concentration will be provided from the experimental campaign to assess the feasibility of existing process designs.

3. Oxygen Enriched Air Combustion with Exhaust Gas Recirculation

The operational limits from the experimental results provide a basis for process design of a feasible S-EGR process that is a variant of the process shown in Figure 1. A novel process, shown in Figure 2, includes a membrane-based air enrichment process in addition to standard EGR process. The main advantage of the air enrichment process is that it allows for higher CO_2 recycle thus increasing the CO_2 concentration in the flue gas while keeping the O_2 concentration in the combustor inlet gas above required levels. A techno-economic analysis of the two processes will be presented and compared to a reference MEA process for post-combustion capture.

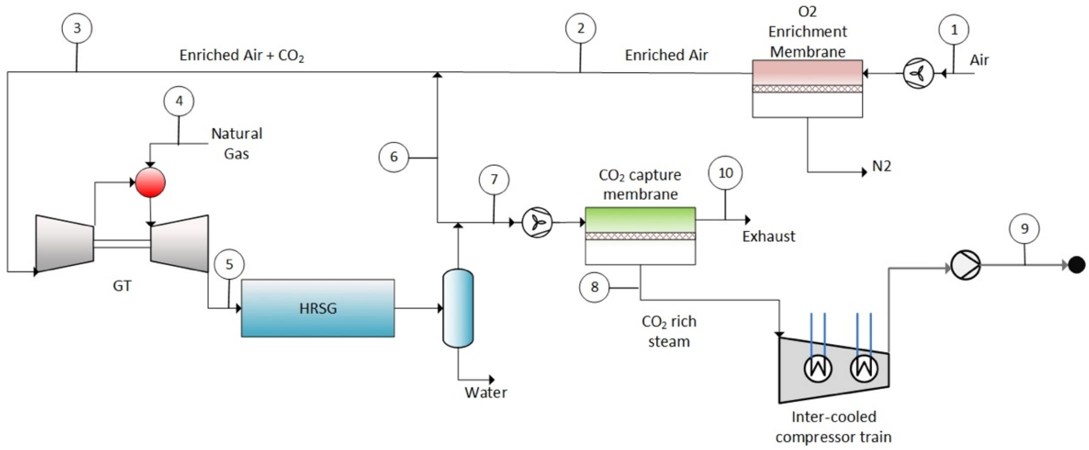

Figure 2: Process schematic of the Oxygen Enriched Air combustion with Exhaust Gas Recirculation

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