Introduction

The growing share of renewable energies in the electricity production is adding a severe constraint on the reliability and stability of the electricity grid. Indeed, given the lacking capacity storage of batteries, electricity production has to become more flexible to keep demand and production balanced. Micro Gas Turbines (mGTs) are good candidates to provide this necessary flexibility. Still, their carbon footprint has to be reduced (and even become zero) to move towards a carbon-clean power production in 2050. The application of post-combustion Carbon Capture (CC) offers a solution to remove CO$_2$ from mGT flue gases. Applying a conventional CC process with monoethanolamine (MEA) to mGT has already been numerically investigated in previous work [1]. Results highlighted however the strong negative impact of applying CC on mGT performances: 7.9 absolute% decrease in electric efficiency, mainly due to the high energy requirement for the CC process. Indeed, compared to coal or large-scale gas turbines power plants, applying CC to mGTs is more disadvantageous because of the low CO$_2$ content of their flue gases: 1.5 vol.% or still below 5%, even when Exhaust Gas Recirculation (EGR) is applied. Therefore, the energy consumption of the CC plant must be reduced to make carbon clean mGT more efficient and profitable. Next to a better integration of the different mGT and CC heat streams [2], the selection of the appropriate solvent and process configuration will help reducing the energy penalty: for instance, the use of a promising blend of methyl diethanolamine with piperazine (MDEA/PZ) as solvent is investigated in this work. The benefit of using the MDEA/PZ blend instead of the conventional MEA solvent for removing CO$_2$ has already been shown in coal-fired power plant or cement plant flue gases [3,4], yet, no study has been carried out on application with a specific low CO$_2$ content, as those found in mGT flue gases. Next to the careful selection of the solvent, further reduction in CC energy consumption can be achieved by improving the process configuration. The absorber intercooling configuration has proven to be more efficient for coal-fired or cement plants applications but has not been investigated for low CO$_2$ content flue gases.

Methodology

Due to the lack of studies dealing with the CC process improvement for mGT application, an in-depth investigation to select the most appropriate solvent and process configuration is needed. Hence, this work presents a preliminary study on the effect of using various MDEA/PZ blends with the conventional CC configuration, the impact of altering specific CC plant operating parameters, as well as absorber intercooling on the CC energy demand, as a first step.
towards this in-depth analysis. The comparison between solvents and configurations has been performed using Aspen Plus v9. A typical mGT, namely the Turbec T100, has been modelled including Exhaust Gas Recirculation (EGR) for increased CO$_2$ content of the flue gases (Fig. 1). Using this model, the mass flow rate of mGT flue gases was assessed at 0.291 kg/s with a CO$_2$ concentration of 4.31 vol.%. The CC plant has been modelled based upon the model of the Pilot-scale Advanced Capture Technology (PACT) facilities at the UK Carbon Capture and Storage Research Center (UKCCSRC) (Fig. 1). The CC plant has been designed by Giorgetti et al. for the mGT application [1]. The rate-based approach has been used to model the absorber and stripper columns and a CC efficiency of 90% has been considered.

**Results**

The solvent flow rate has been optimized for each process to reduce the Specific Reboiler Duty (SRD). Moreover, several MDEA/PZ blend compositions have been investigated to select the most appropriate one, corresponding to 10 wt.% MDEA/20 wt.% PZ. As shown in Fig.3, this MDEA/PZ blend allows to reduce the SRD by 10.6% compared to the conventional MEA process. In addition, Fig. 3 shows that operating at higher stripper pressure allows to further reduce the reboiler duty and thus increase the global electrical efficiency. The MDEA/PZ solvent can be regenerated at higher pressure than MEA (5 bar vs 2.1 bar) for thermal stability constraints and thus results in a more significant energy consumption reduction (SRD=3.21 MJ/kgCO$_2$). In summary, compared to the conventional MEA process, the electrical efficiency increases from 22.1% to 23.3% by replacing the solvent and optimizing operating conditions.

Fig. 1. Layout of a typical mGT, the Turbec T100, coupled with a conventional amines-based CC process. The CO$_2$ concentration in flue gases is increased by applying Exhaust Gas Recirculation (EGR), which consists of recirculating a fraction of the exhaust gases into the mGT cycle (in orange). From the CC side, the intercooling absorber configuration aims to reduce the solvent temperature inside the absorber (in red).

Fig. 3. Comparison of specific reboiler duty (a) and global electrical efficiency (b) between the 30 wt.% MEA and the 10 wt.% MDEA/20 wt.% PZ for the conventional process, at the highest stripper pressure (2.1 bar for MEA and 5 bar for MDEA/PZ) and with the absorber intercooling configuration, highlights that the MDEA/PZ solvent leads to the lowest SRD and energy penalty and the intercooling has no real impact on performances.
Finally, performing absorber intercooling, by cooling down the solvent to 40°C in the middle of the absorber, does not show any significant improvement in CC performances. Indeed, the low CO₂ concentration in mGT flue gases induces a low heat of reaction, resulting in a temperature increase of about 10-15°C into the absorber, while the temperature can increase by 20-30°C for coal-fired power or cement plant applications. Therefore, the cooling effect is less significant for mGTs than for other processes.

Conclusions

This work highlights the benefit of using the MDEA/PZ solvent instead of the conventional MEA solvent for CC applied to mGTs. Moreover, the investigation of absorber intercooling does not show significant improvements in CC performances. The implementation of other advanced CC configurations, such as the Rich Vapor Compression (RVC) and the Cold Solvent Split (CSS), will be envisaged in future works. Once the most appropriate configuration will be determined, the better integration of mGT and CC heat streams will be performed to further increase the global plant efficiency.

Keywords: Micro gas turbine; Absorption based carbon capture; Penalty reduction; Thermodynamic cycle simulations; Solvent selection

Bibliography