Selective Exhaust Gas Recirculation for Gas Turbine Combined Cycles with Carbon Capture: The SELECT project

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Abstract

Combined cycle gas turbine (CCGT) power plants with carbon capture and storage (CCS) are expected to play an important part in low-carbon electricity systems, providing dispatchable low carbon energy while maintaining system flexibility. For example, one out of two gas-fired power plants are equipped with CCS post 2030 in the International Energy Agency Technology roadmap for CCS [IEA 2013]. There is also a growing consensus about the cost effectiveness of CCS to decarbonise electricity generation in the UK [DECC 2012a] and the role of gas-fired CCS power plants in the 2020s and the 2030s. [ETI 2013, DECC 2012b]

This paper investigates at the level of power plant systems the integration of options with selective recycling of carbon dioxide (also called Selective Exhaust Gas Recirculation or S-EGR) and with post-combustion capture technologies. With most of the work in this area focused on the benefits of a high exhaust gas CO_2-concentration for carbon capture and associated development of novel gas separation technology [e.g. Merkel et al, 2012], the performance of the power plant system had received little attention so far and is still poorly understood. It is nonetheless important to determine whether off-the-shelf gas turbines are capable of operating at high CO2 recirculation ratios to facilitate uptake of the technology.

The paper presents important findings a large R&D consortia funded by the UK Research Councils: the SELECT project[1], started in 2015.

We present the results of a turbomachinery model developed in gPROMs with a model of a post-combustion capture processes to evaluate net power output with carbon capture, and examine the impact on the performance and operation of key components, namely the compressor, the gas turbine, the heat recovery steam generator and the steam cycle. It specifically shows how:

- the challenges of low CO_2 concentration and large gas throughputs for post-combustion capture can be addressed by selectively recycling CO_2 into the compressor air intake, without recirculating other components of the flue gas, such as nitrogen.

[1] http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/M001482/1

- oxygen levels in the combustor can be maintained above the limiting value to ensure good ignition, complete combustion and flame stability
- increased concentration of CO_2 in the exhaust gas and reduced gas throughput can result in energetics savings and capital cost reduction in the carbon capture plant.

A parametric assessment of key performance indicator for CO_2 transfer from the exhaust gas to the combustion air - CO_2 selectivity, O_2 transfer, heat transfer and pressure drop - provides guidelines for capture and CO_2 transfer technology developers, gas turbine manufacturers and users with a particular focus on the operation of the gas turbine.

We then examine the effects of high CO2 recirculation levels on flashback and blowoff limit envelopes of a premixed swirl-stabilised generic natural gas burner to determine limits to stable combustion operation and the maximum achievable S-EGR recycling ratio. The results of experimental flame stability and burner operation studies from a series of experiments simulating S-EGR conditions conducted at Cardiff University's Gas Turbine Research Centre (GTRC) are presented. Key physical phenomena governing combustion stability, namely chemical and hydrodynamic timescales within the flame zone, are examined with the shape and intensity change of the recirculation zone as the momentum flux is altered with S-EGR.

Finally, we present the results from a test campaign at the UK PACT Facilities (national specialist R&D facilities for combustion and carbon capture research[2]), where a highly-instrumented pilot-scale gas turbine engine is operated at high CO2 recirculation conditions to understand the impact over the operating envelope of the gas turbine. The gas turbine engine is connected to the onsite solvent-based carbon capture plant and thus the full system impacts of S-EGR on both the performance (predominantly the efficiencies) of the turbine and the capture plant are presented.

Overall, the paper proposes an independent assessment of challenges and opportunities of selective exhaust gas recirculation ratio and its potential for cost reduction for Gas CCS power generation.

References:

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[2] http://www.pact.ac.uk/