TECHNO-ECONOMICAL STUDY OF THE ZERO EMISSION GAS POWER CONCEPT (ZEG)

Julien Meyer[a], Johann Mastin[a], Tor-K. Bjørnebøle[b], Tomas Ryberg[b], Nils Eldrup[c]
[a]Institute for Energy Technology, P.O. Box 40, Kjeller N-2027, Norway
[b]CMR Prototech, P.O. Box 6034 Postterminalen, Bergen N-5892, Norway
[c]Tel-Tek, Kjølnes ring 30, Porsgrunn N-3918, Norway
Julien.Meyer@ife.no

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Text

Because of growing concerns over increased man-made greenhouse gas emissions, technologies for carbon capture and storage (CCS) are being seriously considered to enable reduced emissions. Natural gas and coal fired power plants have been identified as important point sources of CO_2 emissions, and several technologies for CO_2 capture have been proposed. Common for these technologies, however, is the large efficiency penalty associated with the separation and compression of the CO_2. Typically, a natural gas fired power plant looses 10%-points of its efficiency. This means that a state-of-the-art combined cycle plant would lower its efficiency from 60% to 50% which corresponds to 20% higher fuel consumption per kWh produced. A major challenge for the application of CCS is the development of new energy technologies which successfully combine high energy efficiency and CO_2 capture. In order to address the challenge of combining CO_2 capture and high energy efficiency in energy plants, the ZEG concept has been proposed by Institute for Energy Technology (IFE) and Christian Michelsen Research (CMR). In this novel hybrid high efficiency pre-combustion concept, Sorption-Enhanced Steam Methane Reforming of natural gas (SE-SMR) is closely integrated with a high temperature Solid Oxide Fuel Cell (SOFC). When these two technologies are integrated, the heat from the fuel cell is used for upgrading natural gas to hydrogen and essentially no energy is wasted.

The objective of this study has been to evaluate the technical and economical feasibility of the ZEG concept, featuring production of electrical power from natural gas with integrated CO_2 capture. In this concept, natural gas is reformed to a hydrogen-rich gas mixture using the novel SE-SMR reforming technology. The reaction of methane with steam is carried out in the presence of a mixture of a reforming catalyst and a selective high temperature solid sorbent for CO_2. When a solid CO_2-sorbent (in this study calcined dolomite- CaO-MgO) is mixed with a reforming catalyst, the CO_2 in the synthesis gas mixture is removed as it is formed, causing the reforming and water gas shift reactions to proceed simultaneously beyond the thermodynamic limits. The water gas shift (WGS) section is then eliminated. Moreover, when CO_2 is captured *in situ*, near to pure CO_2 is obtained by regenerating the sorbent using temperature swing with steam generation, eliminating costly separation steps downstream. Reforming, CO_2 capture and CO_2 removal are integrated within only two vessels: a reformer producing hydrogen and capturing CO_2, and a regenerator releasing CO_2. The hydrogen concentration is typically around 95mole% (dry basis) after the SE-SMR unit and the reformate gas is fed to the SOFC for electricity production. The heat required to regenerate the solid sorbent in the SE-SMR unit is provided by the SOFC waste heat (at around 1000^{o}C) through an internal heat transfer loop including the integration of a high temperature heat exchanger in the regenerator. The continuous nature of the SE-SMR process makes the use of a fluidized bed reactor technology with circulation of solids a clear alternative to run the process in an efficient manner. The study is based on a reactor concept using a Dual Bubbling Fluidized Bed reactor system with circulating solids, at near atmospheric pressure, where the solids are circulated between a reformer and a regenerator. The CO_2 captured by the solid sorbent is released in the regenerator using steam as fluidization gas, and the condensate water is separated out prior to compression. The gas is first compressed to 80 bar in a sequence of compressors with inter-coolers and flash drums for water separation, then condensed (cooled to 20°C) and finally pumped up to 110 bar. The small amounts of CO_2 which are not captured in the reformer are recycled in the system so that basically no CO_2 is emitted.

Technical design, process simulations using the Aspen HYSYS software coupled with a MATLAB reactor model, and the preparation of detailed equipment lists have been carried out to calculate capital expenditure (CAPEX) and operation expenditure (OPEX) of the process. The OPEX value is calculated as the balance between the annual income and expenditures related to the input streams and cost elements. The total annual income is calculated as the value sum of the produced electric power and the captured CO_2, when it has a sales value. The annual energy costs are the value sum of the natural gas feed and the electric power consumption of the plant. Based on the specified values of the parameters above, the OPEX is calculated and together with the CAPEX data it forms the basis for the net present value (NPV) calculation. The NPV-values are based on 8000 operating hours/year, 25 years operation and 7.5% interest rate. A cost analysis has been carried out for different price scenarios involving natural gas and electrical power prices, as well as CO_2-quota cost and CO_2 sales value. The ZEG concept has been compared with a more conventional pre-combustion technology alternative as a reference case (REF), involving the coupling of auto-thermal reforming, water gas shift, amine CO_2 capture technology and a combined cycle. The results of this study show that the ZEG-case technology is likely to be profitable with relatively high net present values (NPV) in most of the price scenarios chosen, while the REF-case technology, using more conventional pre-combustion available technologies, shows negative NPV-values for all scenarios. Even with no income for the CO_2 captured and a quite moderate natural gas price of 19 EUR/MWh, the ZEG-case shows profitability for an electric power price of 50 EUR/MWh or higher. The promising and encouraging results of this study show the potential of the two technologies and of their close integration towards future zero emission power plants on a medium to long term perspective.