

ENERGY INTEGRATION OF HIGH PRESSURE PROCESSES USING GAS TURBINES AND INTERNAL COMBUSTION ENGINES

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High pressure processes (e.g. sustainable hydrothermal manufacturing of nanomaterials [1], supercritical water oxidation (SCWO) [2] and biomass hydrolysis [3]) require high operational conditions. Water at high pressure and temperature conditions improves kinetic, selectivity and efficiency of these processes but entail high-energy operational expenditure. Use of fluids at high operational conditions makes necessary to supply heat of high quality, as well as power. Because of this, it is necessary to study reasonable solutions for energy recovery and integration in order to achieve the energy self-sufficiency of the process and, if possible, the net power production and with a viable efficiency [4].

In this work, the energy integration of supercritical water oxidation process is being studied. One solution that has been recently proposed is the integration of supercritical processes with energy production in cogeneration or Combined Heat and Power (CHP) cycles. Cogeneration is defined as the simultaneous production of various forms of energy – being the most frequent heat and shaft work, i.e., power – from one power source. The implementation of CHP processes is often joined to the use of gas turbines (GT) [3, 5]. SCWO process produces a high pressure reactor outlet stream, being these mainly composed of water, nitrogen and carbon dioxide and can be thermally integrated if there is a necessity of heat in other parts of the process. At the same time, it is possible to use this effluent to implement a steam injection in the gas turbine, which will improve the efficiency of the global process. This mechanism links the process of SCWO with the cogeneration process (Fig. 1). Steam injection is a technique which can increase the ability of a plant to generate extra power without burning extra fuel and requiring moderate capital investment. In its most basic form, steam injection works by increasing the global mass flow rate through the gas turbine without increasing the mass of air compressed.

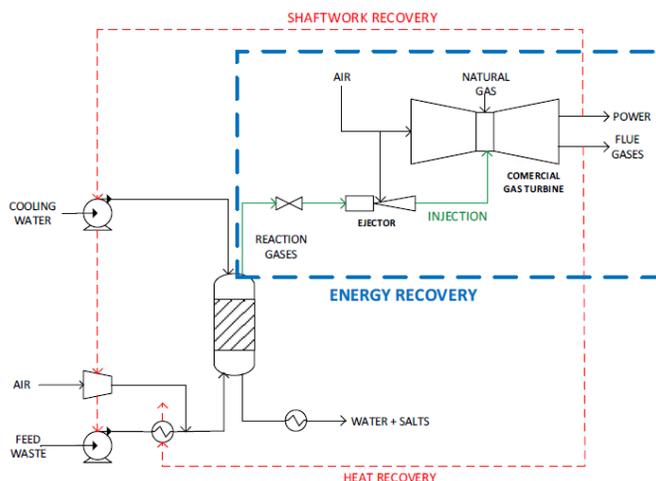


Fig 1. Flow Diagram of Energy recovery using a Gas Turbine (SCWO process)

In previous work, several configurations were simulated using the implementation of GT in a real process (pilot plant). Initial values obtained previously [2] in the SCWO pilot plant at the University of Valladolid were used for the simulation (Fig. 2).



Fig 2. Pilot Plant Reactor (SCWO) at the University of Valladolid

The reactor outlet stream injection into the GT combustor was simulated, the high pressure and temperature of this stream allowing the energy integration. Energetic efficiencies were studied and compared using a simulation software. Also, the mass and energy balances were calculated for several proposed schemes. The difference between cases was the injection pressure. Efficiencies obtained in every configuration using GT system were over 25% and going to up 34.6% in the best case (Fig. 3) [5].

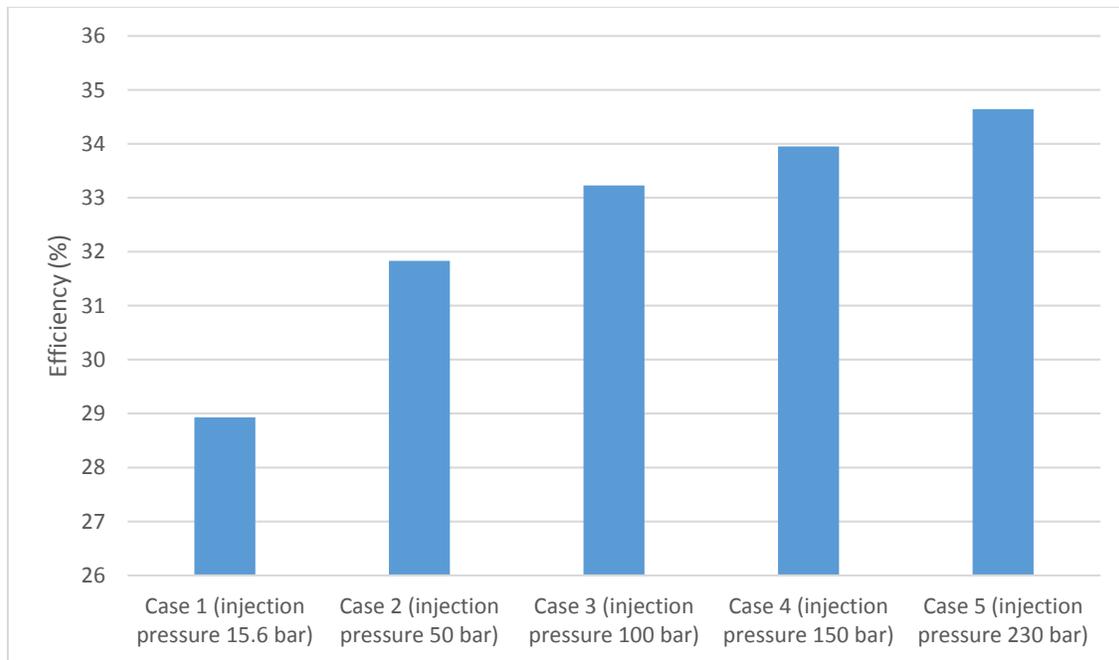


Fig 3. Efficiency of different configurations of GT energy integration

In this chart can be seen that it is possible to get positive net power that could be used in other parts of the process to supply energy needs. The best case (case 5) full outlet reactor pressure is used in the expansion gas turbine and the net power obtained is about 3.2 kW (taking into account the small size of gas turbine).

Other solution which is being explored currently is the energy recovery by the injection/expansion into internal combustion engines (ICE) [6] (Fig 4). These devices yield higher efficiency than GT (up to 50% ICE and 30-35% GT) and furthermore, due to increased pressure and temperature in modern commercial ICEs, it is possible, in principle, the injection at high pressure and temperature conditions, taking then advantage of the high enthalpy content of the reactor outlet stream.

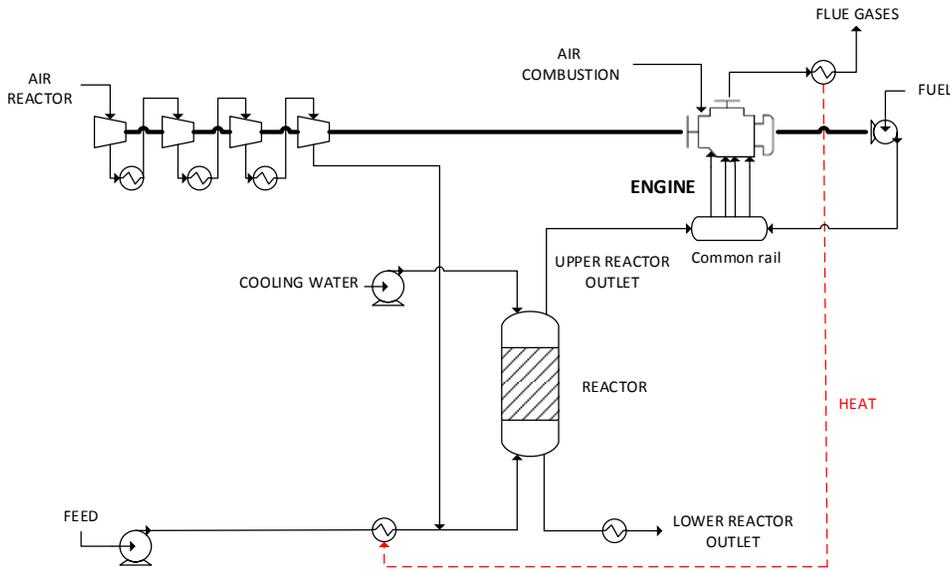


Fig 4. Flow Diagram Energy recovery using a Gas Turbine (SCWO process)

Flexibility and wider efficiency range concerning operating regimes, heat recovery at multiple temperature levels, ICE emissions reduction, autonomous start-up possibilities and ICE nominal power extremely wide ranges foster the applicability of this exploration.

Other authors observed NO_x emissions can be reduced injecting water into the engine cylinder since maximum flame temperature decreases [6]. In the SCWO process, the reactor outlet stream consists of water (59%) mainly, so injection of this effluent in an ICE is possible, taking in advantage its high pressure and temperature conditions to produce energy by the expansion combustion gases causing the piston motion. Therefore, the injection of the reactor outlet stream (SCWO process) led to the NO_x reduction in an internal combustion engine and furthermore could be possible the energy integration of this process.

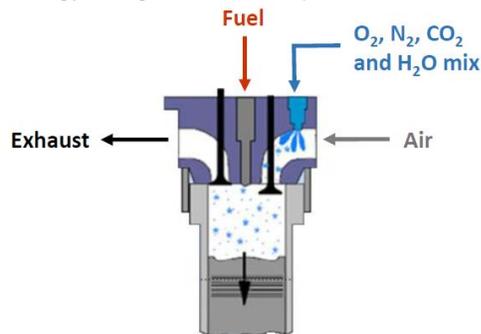


Fig 5. Internal Combustion Engine chart

To carry out this study is necessary, firstly, to explore and study the expansion inside the cylinder, which is an inherently non-steady state process and then cannot be modeled using commercial process simulators. Besides, the wide range of conditions from the high-pressure, high-temperature at the reactor outlet and ICE injection throughout non-steady expansion to near-ambient conditions at cylinder outlet, moreover taking into account strong non-idealities caused by water and carbon dioxide molecular interactions between them as well as the rest of combustion compounds into the expanding mixture suggest a custom thermodynamic properties

representation path. For these reasons custom code has been developed: thermodynamic properties in this process has been modeled using the Peng-Robinson equation of state [7], with the Boston-Mathias alpha function as well as other modifications suitable for high pressure environments, and the Aly-Lee method [8] has been used to calculate ideal energy properties. This modeling process has been implemented using MatLab software. Promising results from the energy recovery point of view had been obtained, the simulation suggesting the worth of exploring the details of an engineering implementation in real ICEs.

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