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Analysis of the control structures for an integrated ethanol processor for proton exchange membrane fuel cell systems

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ABSTRACT

The aim of this work is to investigate which would be a good preliminary plantwide control structure for the process of Hydrogen production from bioethanol to be used in a proton exchange membrane (PEM) accounting only steady-state information. The objective is to keep the process under optimal operation point, that is doing energy integration to achieve the maximum efficiency. Ethanol, produced from renewable feedstocks, feeds a fuel processor investigated for steam reforming, followed by high- and low-temperature shift reactors and preferential oxidation, which are coupled to a polymeric fuel cell. Applying steady-state simulation techniques and using thermodynamic models the performance of the complete system with two different control structures have been evaluated for the most typical perturbations. A sensitivity analysis for the key process variables together with the rigorous operability requirements for the fuel cell are taking into account for defining acceptable plantwide control structure. This is the first work showing an alternative control structure applied to this kind of process.

1. Introduction

The current industrial hydrogen production technology could only partially meet the requirement of the small-scale fuel processors, which must be compact, turnkey and of high efficiency by combining component functionalities and eliminating unnecessary components. Although the on-board fuel processor program has been put on hold by the U.S. Department of Energy (DOE), a number of new approaches for the establishment of hydrogen refueling station based on some form of a fuel processor are being pursued [1]. Particularly among all the alcohols, methanol is the most popular fuel for reforming, not only because it requires mild reforming conditions and has potential for attainment of highest possible efficiency, but also because of its possibility to be produced from renewable resources [2,3]. Another alcohol is ethanol, which is already used as one of the main additives for gasoline for both its high octane number (RON and MON) and low toxicity, has gained popularity for its environmentally friendliness as well as sustainability [4]. Biomass, including bioethanol and other high molecular weight materials such as sugar alcohol is considered to be promising raw material in terms of their carbon cycling neutrality. Conventionally, hydrogen can be obtained by high temperature gasification/pyrolysis of biomass followed by catalytic reforming of the gas/liquid product [5]. A good recent review about different technologies for integrated fuel processors for fuel cell application is given in Qi et al. [6]. They emphasized that process intensification technologies such as engineered catalysts, on-site heat production/removal and product purification can not only allow precise control of reaction and heat/mass transfer rates, but also help optimize the operation conditions, and, consequently, improve overall efficiency and mitigate the requirement for materials and capital investment.

On the other side, feedback control of fuel cell power systems has recently started to attract attention. Several control problems for fuel cell-powered electric vehicles are outlined in Powers and Nicastri [7]. Boettner et al. [8] have identified control opportunities for the compressor within the fuel cell system. Control of the electrical power output and oxidant supply in electrical power generation for a fuel cell powered vehicle is discussed in Mufford and Strasky [9]. Pukrushpan et al. [10] have derived a lumped dynamic model of the cell stack, and regulated the net power output by controlling the air supply to the cathode. More recently, a comparison of PI and LQG controls for air supply is presented in Rodatz et al. [11]. In Pukrushpan et al. [12] have demonstrated a model-based multivariable control design for the fuel processing system (FPS) to regulate the temperature of CPO and the mole fraction of hydrogen in the anode. Gorgun [13] presented a control-oriented physics-based modeling of FPS reactors in fuel cell power systems. In both last references methane is used as the feed and dynamic models were employed for defining the proposed control structure.

As the authors understand, up to now, there is no works considering the overall FPS with PEM, using bioethanol, where the

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