243b Multi-Objective Optimization of Membrane Reactor for Hydrogen Production

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In recent years, the demand of hydrogen keeps steadily increasing due to its wide industrial applications. Methane steam reforming is currently the primary hydrogen production route on industrial scale, owing to the current abundance of natural gas and its economic advantages over other processes. This process is highly endothermic and equilibrium limited. In order to achieve a high conversion of methane, it has to be carried out at high temperature in conventional reactors, leading to high energy consumption. An alternative strategy to shift the equilibrium toward the products is to continuously remove at least one of the products from the reaction zone. Membrane reactors provide such possibility by integrating chemical reaction and membrane separation into one single unit. However, there is a price to pay in terms of increased complexity in process design and operation. In such an integrated unit, there are a large number of design and operating parameters such as membrane area, reactor dimensions, catalyst weight, reaction temperature, methane to steam feed ratio, feed flow rate, sweep gas flow rate, reaction side pressure, permeation side pressure, etc. These variables impose a complex interplay on the reactor behaviors and influence the reactor performances usually in conflicting ways, which lead to any desirable change in one objective function resulting in an unfavorable change in another objective function. This implies that there is a trade-off between the usually concerned process objectives, including maximization of hydrogen production rate, methane conversion, hydrogen recovery yield and minimization of catalyst weight and membrane area, etc. Therefore, in order to thoroughly explore the potential of methane steam reforming in membrane reactors and successfully apply it on industrial scale, the novel process design strategy, simultaneous optimization of multiple objectives, should be adopted in the evaluation of membrane reactors for hydrogen production. In principle, multi-objective optimization is very different from single objective optimization. In single objective optimization, one attempts to obtain the best solution, which is usually the global minimum or the global maximum. In the case of multiple objectives, there may not exist one solution that is best with respect to all objectives. The goal of multi-objective optimization is to obtain a set of equally good solutions, which are known as Pareto optimal solutions. In a set of Pareto solutions, no solution can be considered better than any other solutions with respect o all objective functions, since one solution is better than the other in one objective, but is worse in the others. So the selection of any optimal solution from a Pareto set will depend on auxiliary information. However, by narrowing down the choices, the Pareto set does provide decision makers with useful guidance in selecting the desired design and operating conditions (called the preferred solution) from among the (restricted) set of Pareto optimal solutions, rather than from a much larger number of possibilities. In this work, multi-objective optimizations of methane steam reforming in membrane reactors were performed with respect to maximization of hydrogen production rate, methane conversion or hydrogen recovery yield and minimization of membrane area or catalyst weight to evaluate their potentials and get a deeper understanding of their behaviors. A robust, non-traditional global optimization technique known as the non-dominated sorting genetic algorithm (NSGA) was applied in obtaining the Pareto optimal solutions.