Design of a Methanol Reactor-Separator-Recycle System to Use Steelworks Off-gases

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Highlights

- The methanol reactor/recycle/column was modeled and simulated using Aspen Hysys®
- The performance of the process was evaluated by analyzing the effect of the composition at the unit inlet
- Total annual cost, energy efficiency and carbon footprint are evaluated.

1. Introduction

The steel industry is the main generator of CO_2 among the different industrial sectors. Indeed, this industry is responsible for 30 % [1] of industrial emissions (6.5 Gt in 2011 [2]). In the steel production process, using the technology of the blast furnace, three main gases have to be considered, namely Blast Furnace Gas (BFG), Coke-Oven Gas (COG) and Basic Oxygen Furnace Gas (BOFG). Each stream exhibits specific characteristics (flow and compositions). In this context, the VALORCO (VALOrization and Reduction of CO_2 emissions in the industry) project was launched. The general objective of the project is to determine the best solutions to valorize these CO_2–rich gases. In a previuos stage, the methanol has been identified as an interesting product in the context of the VALORCO project. This work focus on the design of the methanol reactor, including the recycle loop and the purification proccess by distillation. Methanol is synthetized from the components of syngas (H_2, CO and CO_2). The conventional methanol production process uses the syngas made from the reforming of several raw material, such as coal, biomass or typically CH_4 contained in natural gas.

In our case, the syngas will be generated from the steelwork off-gases using CO_2 separation and CO and H_2 recovery processes. In any case, the syngas may have variable proportions of H_2, CO and CO_2. One way to characterize the syngas is using the parameter M [3], defined from the molar fractions (see Figure 1). The parameter M has a value of 2 for a stoichiometric $CO/CO_2/H_2$ mixture. A larger value indicates a H_2 rich mixture, and reciprocally. However, a syngas with a composition such that the value of the parameter M is slightly above 2 is the optimum for methanol synthesis. The syngas also may contain methane and nitrogen since these two compounds are present in the steelworks off-gases from which the syngas is produced. These two compounds are not involved in the methanol synthesis reactions, so they are considered as inert. Because per-pass conversion of methanol is limited by chemical equilibrium, a recycle loop is necessary. To avoid an accumulation of inert gases, a purge stream is required, which involve a loss of reactants and then a decrease in the production rate. Higher inert compositions require larger reactors and more recycle, which increase the capital expenditure (CAPEX) and the operating expense (OPEX). The purpose of this article is to study the impact of the integration of the reactor in the recycle loop. The performance of the process will be evaluated by analyzing the effect of the composition (Variation of M parameter and % inert fraction) at the unit fresh inlet on the overall reagent conversion, recycle ratio, reactor inlet composition, total annual cost, energy efficiency and carbon footprint.

2. Methods

The methanol synthesis process flowsheet from syngas is presented in Figure 1. The process is simulated using the software Aspen Hysys®. The heat exchanger network is determined by a pinch analysis. The sizing of the main equipment is completed in order to estimate the capital expenditure (CAPEX). Utilities and maintenance cost are considered to determine the operational expenditure (OPEX). The flowsheet is finally evaluated by calculating different criteria: the energy efficiency, the carbon footprint and the total annual cost of the produced methanol. Results are compared against the conventional pathway of methanol production from different raw materials according to the information available in the literature.

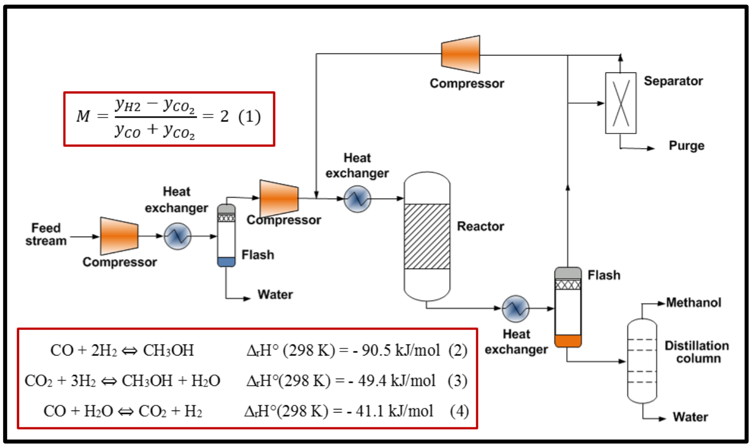

Figure 1. Process flowsheet to produce methanol from syngas.

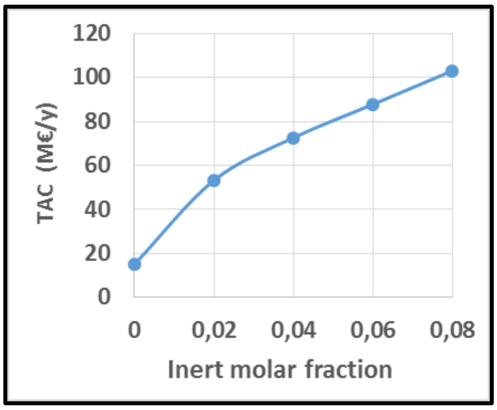

Figure 2. Effect of the concentration of inert at the unit fresh inlet on the TAC

3. Results and discussion

Figure 2 shows the variation of the Total Annual Cost (TAC) as a function of the inert molar fraction at the unit fresh inlet (Feed stream on Figure 1). The TAC is the sum of annual CAPEX (according to the lifespan of each equipment) and the OPEX (electricity power cost of driving the compressor, cooling water, fixed cost, etc.). It is clearly shown that the feed impurity has a large impact on the process economy. Only a 0.02 molar fraction of inert components triples the TAC and almost double the reactor size. The increase in % inert fraction also has a negative impact on the energy efficiency and the carbon footprint of the process.

4. Conclusions

In this paper, the steady-state methanol synthesis process was studied using a 3E performance (economic, environment and energy efficiency) analysis. This process feature some significant design trade-offs among the reactor size, recycle flowrate (purge ratio and reactant losses) and process inlet conditions (temperature, pressure and composition). There is a strong influence of composition (Variation of M and % inert fraction) at the unit fresh inlet on the global performance of the process.

References

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Keywords
Methanol synthesis; steelwork off-gases; process design; performance evaluation.