Operational limits in e–methanol production with variable hydrogen feed

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Highlights

- The model is able to simulate process flow changes caused by electrolytic H_2 feed fluctuations.
- Crude methanol synthesis can continuously operate in a standby mode.
- According to the model, the maximum ramping rate is ~ 50 %/min.

1. Introduction

Flexible operation of methanol synthesis in the power-to-methanol (P2M) process plays an important role in contributing to higher sharing of renewable power and lower levelized cost of methanol. Many studies have been carried out in terms of the dynamic behavior of methanol synthesis process: 1D and 2D mathematical models of reactor [1,2], and plant-level models [3,4]. However, there has been no clear explanation and description about the minimum load and the maximum ramping rate of the processes. The models also have a heavy dependence on H_2/battery storage in case of no H_2 feed. This paper figured out these limitations and introduced a feasible approach to continuously operate a P2M process.

2. Methods

Crude methanol (~ 1:1 mixture of methanol and water) production corresponding to ~25,000 tonnes/year via CO_2 hydrogenation at steady state was modeled in Aspen Plus V14 and then converted to a dynamic model in Aspen Plus Dynamics V14. The flowsheet of the crude methanol synthesis process is shown in Figure 1. Electrolytic H_2 and CO_2 with the ratio of H_2/CO_2 = 3 were compressed and heated up to operating conditions. The reactor effluent was cooled down for unconverted gas separation. Bypassing around heaters E–101 and E–103 was used to manipulate the reactor inlet temperature. Most unconverted gases were separated, recompressed, and recycled to the reactor's feed, meanwhile, ~ 0.5 % of gases were purged out. Dissolved gases at the bottom of FS–101 were further separated and the crude methanol was collected.

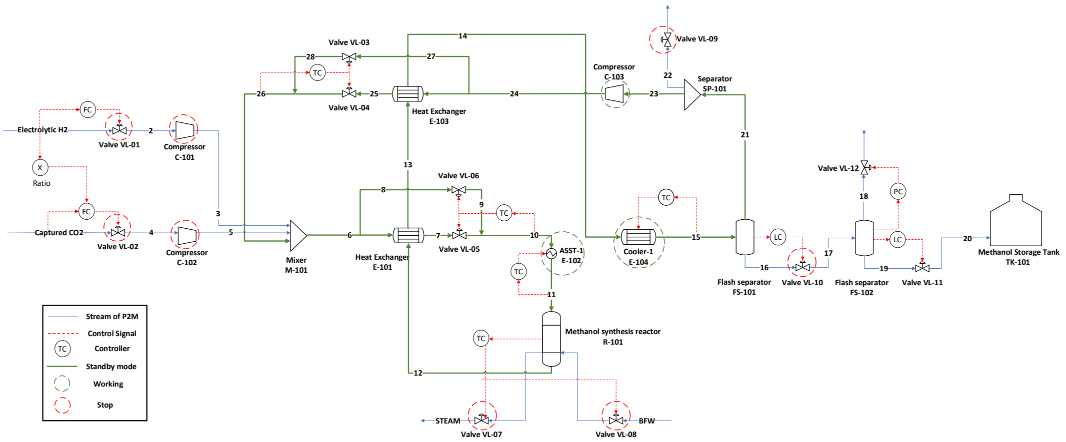

Figure 1. Flowsheet of crude methanol synthesis via CO_2 hydrogenation with standby mode configuration.

All proportional-integral controllers were tuned based on Tyreus–Luyben and Ziegler–Nichols rules [5] . For conservative controlling, a 1–minute first–order lag time or 1–minute dead time (only apply to R–101) block was added to each temperature controller loop. The standby mode is activated when the model load is in the range of 0–10 %. In this mode, valves, compressors (in red dashed circles, see

Figure 1) are closed; while compressor, heater, and cooler (in green dashed circles, see Figure 1) still operate to remain the circulation and the temperature of the reactor.

3. Results and discussion

The transient behaviour of the model is shown in Figure 2. The model can tolerate high variation of real-time solar-based electrolytic H_2-feed rate. Per-pass methanol yield decreases when decreasing the capacity; however, the ratio of methanol/water of crude methanol remains ~1/1 due to increasing recycle ratio (recycle/feeds). Bypass loops implementation results in stable reactor inlet temperature during load change. In standby mode, the system can continuously operate without gas feeds. Hydrogen concentration in gas is very high (>99 mol%), which helps to maintain catalyst activity. Interestingly, the process can tolerate maximum ramping rates of ±50 %/minute according to the model developed.

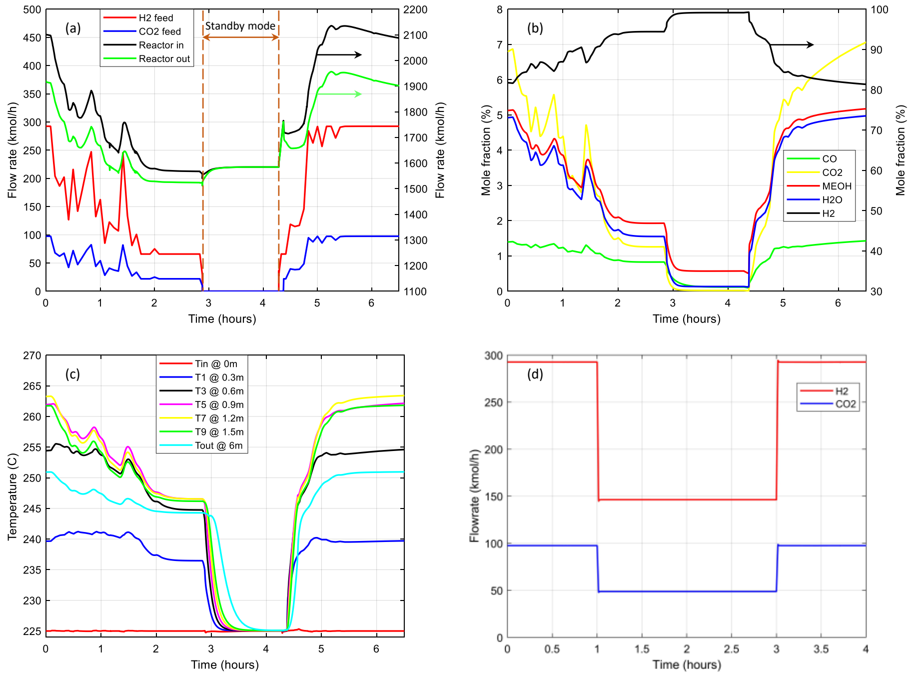

Figure 2. (a) Flowrate of feeds and the reactor streams; (b) reactor outlet composition; (c) reactor temperature along the length under variation of H_2; (d) Maximum achievable ramping rates of the model between 100 % ↔ 50 % load.

4. Conclusions

The model shows that the process exhibits a well-handled performance under high fluctuation of electrolytic H_2 feed opening a potential to full coupling between electrolyzer and methanol synthesis process. Specially, the introduction of a standby mode ensures a continuous operation of the synthesis part consequently resulting in potentially significant size reduction of H_2/battery storage and reduced need for grid connection.

References

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Keywords

Power-to-methanol, electrolytic hydrogen variation, continuous operation, Aspen Plus Dynamics modeling.