Use of Commercial Process Simulator to Mode Transition Control of the Tennessee Eastman Challenge Problem

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Abstract

The Tennessee Eastman (TE) benchmark process provided by Downs and Vogel in 1993 is a realistic simulation of an actual commercial process. Due to the confidential considerations, real components, some physical properties, and kinetic data in this TE program are modified for academic research and industrial training. It is known that TE plant has seven possible operating modes for three different production mass ratios. Since then, several researches have utilized this TE plant to evaluate optimal operating conditions and performance of the proposed process flowsheets and control schemes.

By studying the characteristics of different TE control structures presented in the literature, this work first apply commercial process design simulators to setting reasonable TE process flowsheets. Different operating modes and control performance are then tested by steady-state and dynamic simulations of this designed TE flowsheet. Finally, mode transition control strategies proposed by Tu (2006) are then used to transfer the TE plant from one operating mode to other modes.

Introduction

In 1993, Downs and Vogel proposed the TE plantwide industrial process control problem as a study of alternative control and optimization strategies. In next year, McAvoy and Ye presented a multiple single-input single-output control loop structure to handle this plantwide control problem. They used NI and RGA rules to analyze the pairings between manipulated variables and controlled variables. This systematic base control structure for TE process was tested by use of four design stages. McAvoy et al. (1995) then modified the base control structure to improve the disturbance rejection ability. The main change was to choose the more suitable pairing for reactor pressure. Therefore, it could manage the disturbances in TE process more effectively. It has been reported that the TE process is highly nonlinear and is open-loop unstable (Downs and Vogel, 1993). Ricker and Lee (1995) developed a model predictive control algorithm by use of a simplified nonlinear model to improve the TE process control performance.

It is known TE plant has seven possible operating modes for three different production mass ratios. The nominal operating condition is set as base case mode. In this direction, Tian and Hoo (2005) proposed two model predictive control approaches which differ in the type of models used to deal with regulation and transition control problems. They claimed better closed-loop regulation and mode transition performance especially when the worse disturbance is presented could be obtained by use of their control strategies. On the other hand, Tu (2006) treated the mentioned TE mode transition control under the case of multiple single-input single-output control loops.

By studying the characteristics of different TE control structures presented in the literature, this work first apply commercial process design simulators to setting reasonable TE process flowsheets. Different operating modes and control performance are then tested by steady-state and dynamic simulations of this designed TE flowsheet. Finally, mode transition control strategies proposed by Tu (2006) are then used to transfer the TE plant from one operating mode to other modes.

Control Schemes for Tennessee Eastman Process

The Tennessee Eastman process, as shown in Figure 1, involves five major unit operations: a two-phase chemical reactor, a partial condenser, a vapor-liquid separator, a product stripper, and a recycle compressor (Downs and Vogel, 1993). Four gaseous reactants A, C, D, and E and an inert B are fed to the exothermic reactor where two liquid products G and H are formed. A liquid byproduct F is also produced by two side reactions.

Table 1 gives seven modes of process operation corresponding to different products G/H mass ratios (50/50, 10/90, and 90/10) and production rates for TE plant. The base operating mode is a 50/50 G/H mass ratio and a production rate of 14,072 lb/hr. The plant simulation gives 12 manipulated variables, 41 measurements, and 50 state variables. Four setpoint changes, 20 different types of disturbances, and some process constraints are also specified by Downs and Vogel (1993).

Since 1993, several researches have utilized the TE for evaluating process control technology. Early work on this problem was reported by McAvoy and Ye (1994), who developed a decentralized plantwide control system design based on multiple single-input single-output control loops. They used steady-state tools such as the RGA, NI, and disturbance analysis and dynamic simulation to determine the most promising pairings of the TE control loops. Figure 2 shows the alternative decentralized control structures. Ricker and Lee (1995) tested this base control strategy and found that the reactor pressure loop cannot handle a large disturbance in the A feed (IDV(6)) and the compressor power loop may cause saturation problem for large setpoint changes. Therefore, McAvoy et al. (1995) proposed an improved base control scheme shown in Figure 3 which uses the A feed to control the A/C ratio in the reactor feed. Moreover, it is clear that the three-level cascade control for the TE reactor with cooling jacket was designed to enhance the regulatory control performance of the reactor pressure loop.

The Proposed Flowsheet for Tennessee Eastman Process

The chemical reactions occurred in TE reactor are expressed as below

A(g) + C(g) + D(g) → G(liq)
A(g) + C(g) + E(g) → H(liq)
A(g) + E(g) → F(liq)
3D(g) → 2F(liq)

and assumed that all the reactions are irreversible and exothermic. It can be found that basic physical properties of these components are shown by Downs and Vogel (1993) but the true chemical formulas of these components are not given. In this study, by trying any possible reacting cases, the following reactions are determined to represent the original TE reactions.

$$H_2 + CO + CH_3OH \rightarrow C_2H_6O_2$$
$$H_2 + CO + C_2H_5OH \rightarrow C_3H_8O_2$$
$$H_2 + CO + CH_3OH \rightarrow C_2H_6O_2$$
$$H_2 + CO + C_2H_5OH \rightarrow C_3H_8O_2$$

As shown in Figure 4, reasonable TE process flowsheet can be constructed by using commercial process simulator such as Aspen Plus. Lin (2008) has presented the fact that the obtained steady-state operation conditions under base case are consistent with those shown in the literature. Figure 5 shows the different disturbance responses for step change in D feed temperature in stream 2. It is apparent that the corresponding response of reactor pressure in the designed dynamic flowsheet is consistent with those shown in the literature.

Mode Transition Control Performance

It is well known that Tennessee Eastman process has seven possible operating modes for three different production mass ratios (50/50, 10/90, and 90/10) and production rates. How to smoothly transfer the TE plant from one operating mode to other modes is an important issue for practical industry. In the work, according to the mode transition control strategies proposed by Tu (2006), one can complete the corresponding flowsheet of plandwide control structure for TE plant as shown in Figure 6.

It is known that the performance testing and evaluation of various TE process control strategies can be done with four setpoint changes and/or 20 different types of disturbances specified by Downs and Vogel (1993). Here, mode transition control performance from base case to mode 2 for TE plant is shown in Figure 7. The responses of reactor temperature and reactor pressures are quite fast. Figure 7 also shows the smooth but slow response of the G/H mass ratio. In fact, this hysteresis characteristics can be improved by fine tune the controller parameters (Tu, 2006).

Conclusions

By studying the characteristics of different TE control structures presented in the literature, this work first apply commercial process design simulators to setting reasonable TE process flowsheets. Different operating modes and control performance are then tested by steady-state and dynamic simulations of this designed TE flowsheet. The obtained steady-state operation conditions and closed-loop control performance under base case are consistent with those shown in the literature. Finally, mode transition control strategies proposed by Tu (2006) are then used to transfer the TE plant from one operating mode to other modes. The smooth but slow response of the G/H mass ratio should be further improved.

Acknowledgements

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Table 1. Several operating modes for TE process (Downs and Vogel, 1993).

Mode	G/H mass ratio	Production rate (Stream 11)
1	50/50	7,038kgh^{-1} G and 7,038kgh^{-1} H (Base case)
2	10/90	1,408 kgh^{-1} G and 12,669 kgh^{-1} H
3	90/10	10,000 kgh^{-1} G and 1,111 kgh^{-1} H
4	50/50	maximum production rate
5	10/90	maximum production rate
6	90/10	maximum production rate

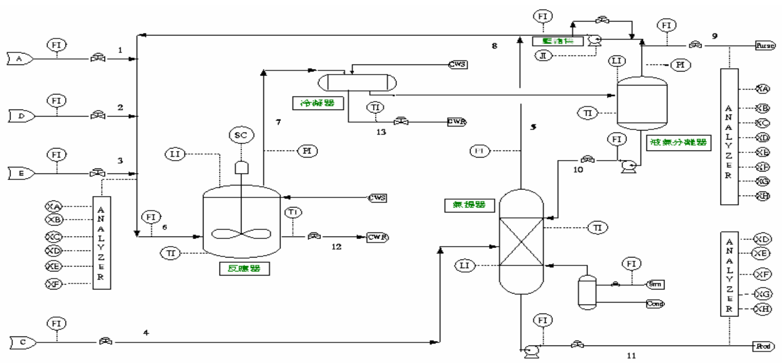

Figure 1. TE process flowsheet (Downs and Vogel, 1993).

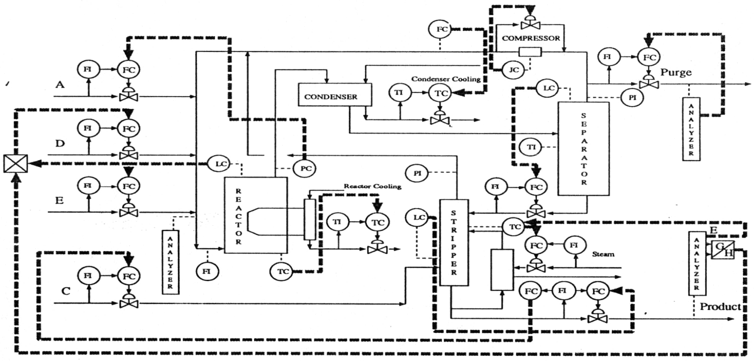

Figure 2. Base control structure by McAvoy and Ye (1994).

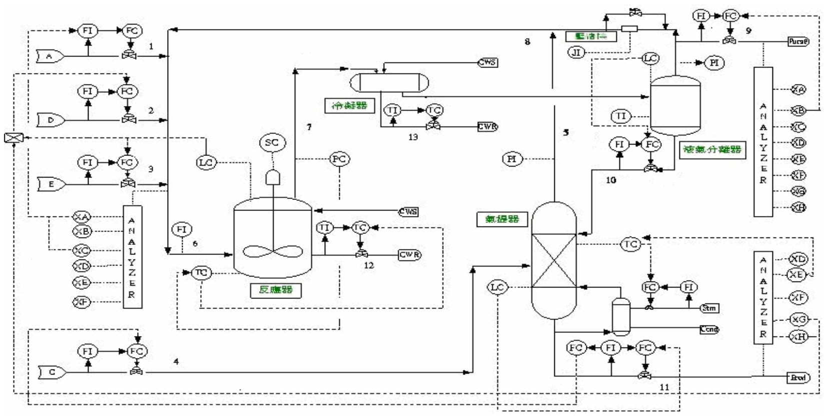

Figure 3. Improved control structure by McAvoy et al. (1995).

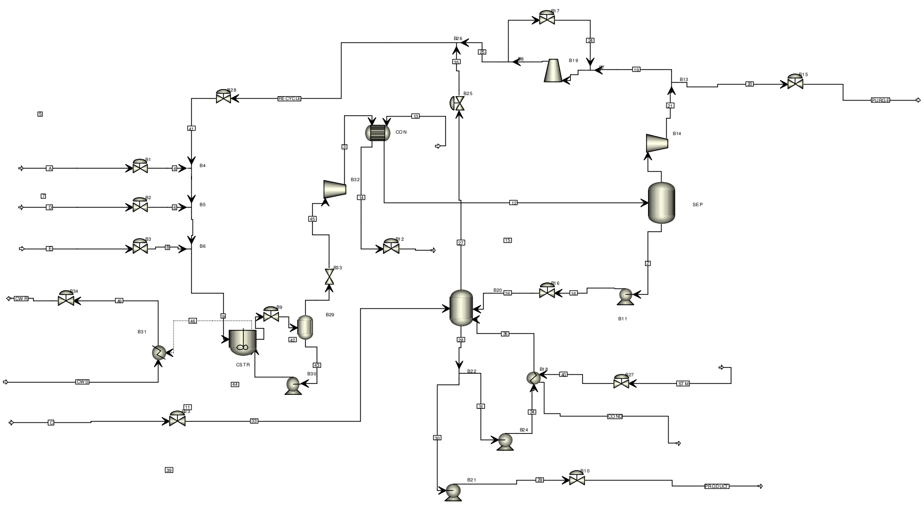

Figure 4. Steady-state process flowsheet for TE plant.

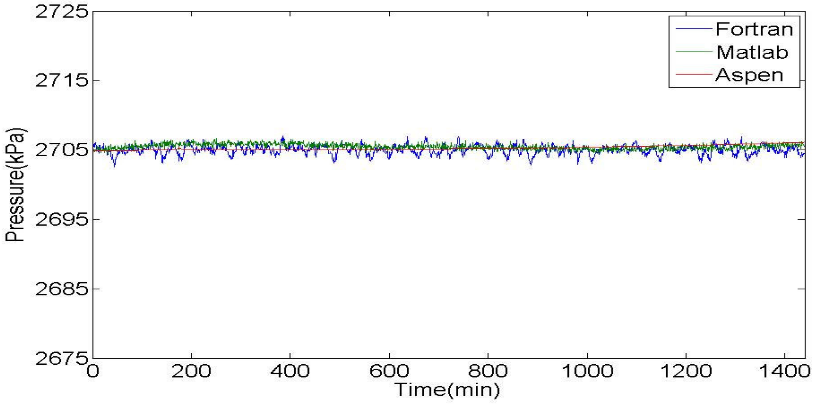

Figure 5. Comparison of load responses for TE process subject to IDV(3).

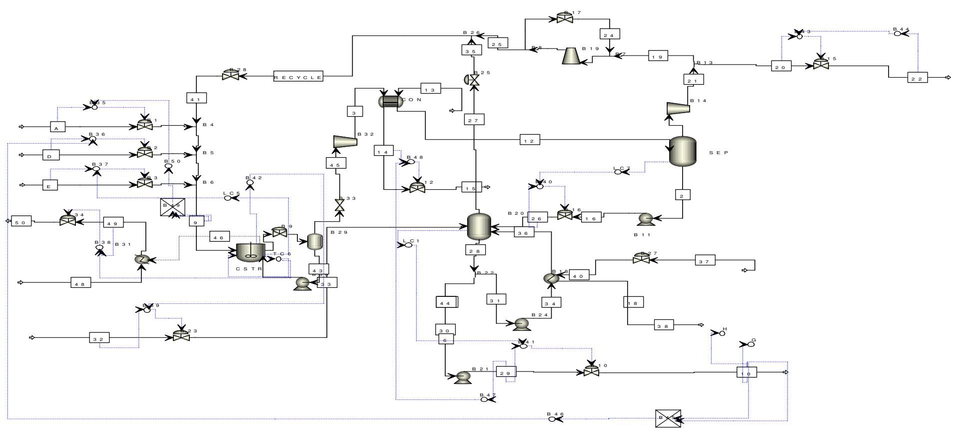

Figure 6. Proposed flowsheet of plandwide control structure for TE plant (Lin, 2008).

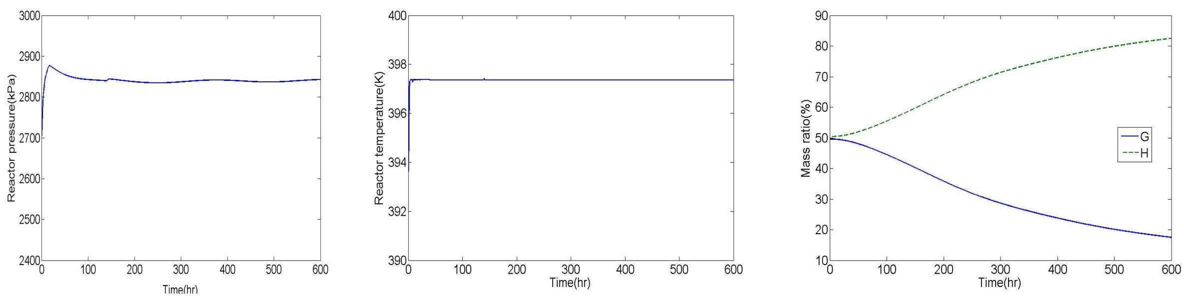

Figure 7. Mode transition control performance from base case to mode 2 for TE plant.