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Economic Analysis of Model Predictive Control on Dimethyl Ether Purification Process

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Abstract. The dimethyl ether product (DME) can be used as an alternative energy that is more environmentally friendly and sustainable. At the DME purification plant, the mixture of DME, methanol and air in the feed will be separated to obtain a pure DME of 99% concentration. Model predictive control is used to control the processes in the DME purification plant using first order plus dead-time models (FOPDT). This study examines the use of MPC technically by comparing it with the control performance of the proportional-integral (PI) controller and analyzed economically. The result, the eight single MPCs (SMPCs) performances are better than the PI controllers in overcoming the disturbance with the decrease of the integral of absolute error (IAE) by 40 % to 96%. Thus, there is a saving of utility (water) used is 0,015%. Since the utility is water, the economic value is low. This led to a considerable payback period (PBP) of 14.5 years, and net present value (NPV) of USD -846 in the feed flowrate disturbance scenario of 5%, so that the use of SMPC in the DME purification plant is economically unfeasible. However, the use of two multivariable MPCs (MMPCs) instead of the eight SMPCs will decrease the PBP and will increase the NPV, therefore, the use of MMPC can be considered for further research.

INTRODUCTION

The use of dimethyl ether (DME) is increasing because DME has many advantages over other energy sources, especially fossil energy. The advantages of DME can be seen from the technical side (as fuel for motor vehicles, power plants or LPG replacement households), the environment (pollution free, non-toxic, easily degraded naturally, no Sulphur content), and in terms of availability because it is one of renewable energy. In addition, raw materials are also easily obtained domestically, namely from biomass, waste, agricultural products and fossil fuels such as natural gas and coal, as well as other advantages, namely having a high cetane number [1].

There are two types of dimethyl ether (DME) synthesis processes, namely direct synthesis and indirect synthesis [1-2]. In the direct synthesis, a synthesis gas (syngas) which is a mixture of carbon monoxide (CO) and hydrogen (H_2) is synthesized directly into DME. While, in the indirect synthesis, the syngas is synthesized into methanol first, then the methanol is dehydrated to DME. This last process is applied in this study.

Wahid and Gunawan [3] have examined the use of proportional-integral (PI) controllers to control the DME purification process. However, the use of conventional controllers has limitations in controlling complex, multi-variable processes and has a high nonlinearity. Therefore, in this research, one of the advanced process controls (APC) is used, namely model predictive control (MPC), because the use of MPC can improve control performance of PI controllers [4-5]. Nevertheless, the use of MPC in the industry is still very limited [6] so that it needs to be introduced to the industrial world. The MPC itself began to be used in industry in the 1980s [7]. Among the important things that need to be studied besides those related to technical matters (modelling, control, and control performance) are those that are economically related (is it economically feasible). This is different from the studies conducted by Asawachatroj & Banjerdpongchai [8] and Ribiero et al. [9] which only focus their studies on economic aspects or Narraway et al. [10] which only discusses aspects of economic benefits for performance control.

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METHOD

Because the product consists of DME, methanol and water, it is necessary to carry out two purification or separation processes, namely DME-methanol and methanol-water separation (see Figure 1). The both purification processes rely on distillation units that have operating temperatures of 190^{o}C and pressures of 1950 kPa and were controlled using MPC instead of the PI controllers that have been studied previously [3]. However, only eight of the 14 PI controllers were changed to MPC consisting of four temperature controls (TCs) in the T-101 condenser, T-103 condenser, E-100 cooler, and E-101 cooler; and four level controls (LCs) in the T-101 condenser, T-103 condenser, T-101 column, and T-103 column. The eight PI controllers that were changed to MPC are those that have an important role to play in increasing the product flow rate and quality.

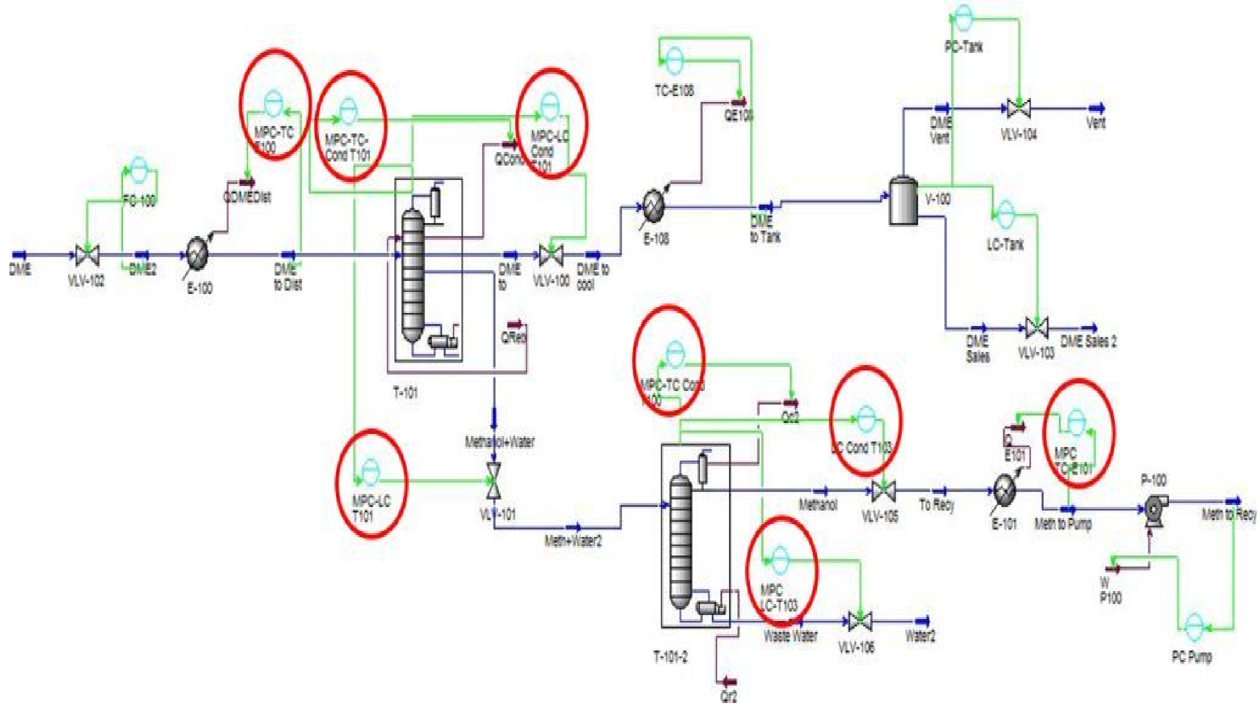

FIGURE 1. Unisim model of purification DME process

TABLE 1. The best FOPDT models

Controller	Kp	τ	θ
TC Cooler E-100	-3.300	0.320	0.001
TC Condenser T-101	-0.643	7.235	0.013
LC Condenser T-101	-9.330	0.265	0.048
LC Column T-101	-43.670	0.210	0.024
TC Condenser T-103	-0.532	0.236	0.021
LC Condenser T-103	-0.768	3.949	0.116
LC Column T-103	-0.320	0.762	0.017
TC Cooler E-101	-1.320	0.423	0.001

The model used in this study is a first-order plus dead-time (FOPDT) model that is derived in a closed loop using a re-identification system (RIS) as used by Wahid and Nararya [11] and Wahid and Taqwallah [12]. The best results of the FOPDT model are shown in Table 1. Economic feasibility calculations are carried out using the NPV method and payback period. For this reason, it is necessary to assume several things, namely the MARR (minimum of acceptable rate of return) of 8% and the useful life of the control equipment is 20 years.

RESULTS AND DISCUSSION

Control Performance due to Changes in Feed Flow Rate Disturbance by 5%

In the Unisim simulator, there is no time delay when controlling, which means that every time a change occurs in the feed, it immediately affects the entire process unit. This is different from what actually happens in the actual process, where changes that occur in the feed will affect the process that is at the back with a certain time lag according

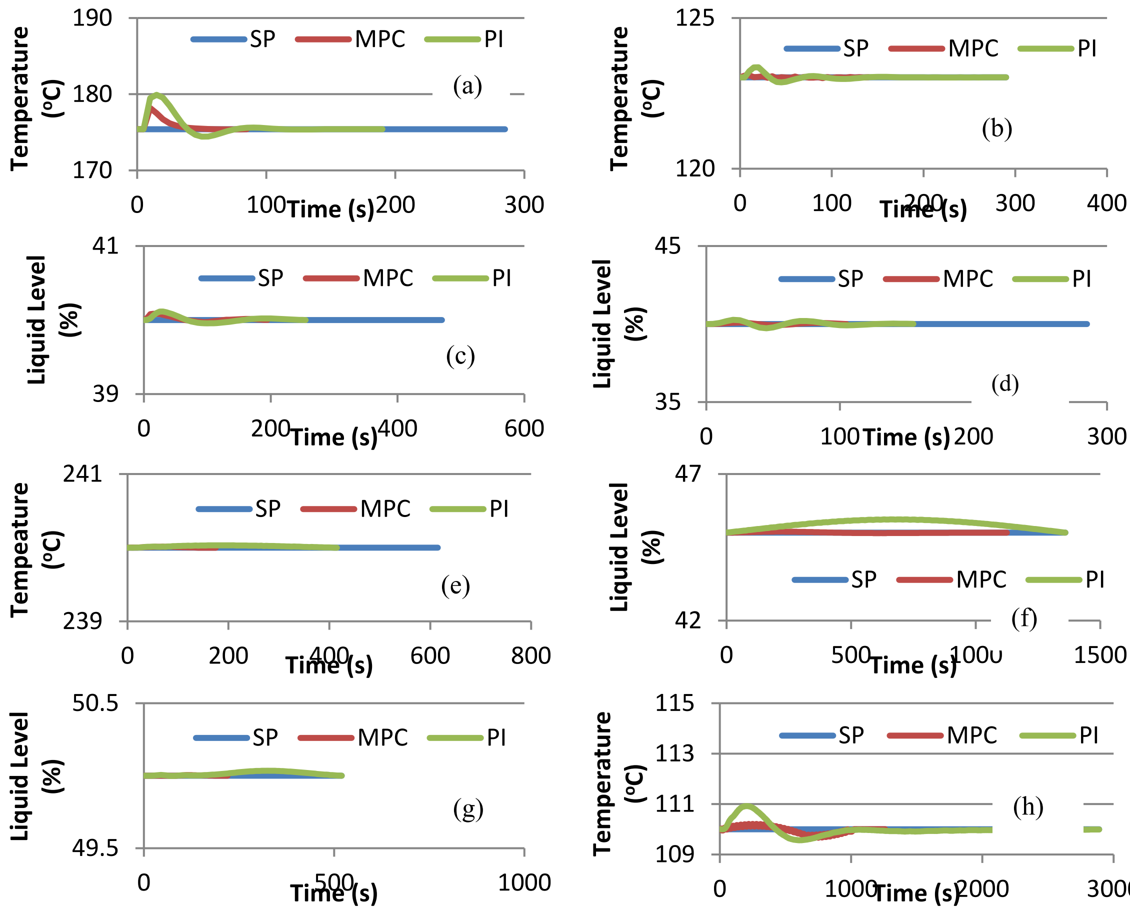

FIGURE 2. Control performance cause of disturbance change of 5% on feed flow rate

TABLE 2. Control performance cause of feed flow rate change of 5%

Controlled Variable	Unit	IAE MPC	IAE PI	Improvement (%)
Temperature	TC Cooler E-100	41.07	119.17	65.54
Temperature	TC Condenser T-101	1.46	11.65	87.45
Liquid Level	LC Condenser T-101	4.73	7.90	40.08
Liquid Level	LC Column T-101	4.66	14.68	68.24
Temperature	TC Condenser T-103	0.98	7.80	87.44
Liquid Level	LC Condenser T-103	13.44	312.99	95.70
Liquid Level	LC Column T-103	0.28	7.55	96.26
Temperature	TC Cooler E-101	139.75	437.84	68.08

to the flow that occurs. The absence of time delay in this simulator is caused by a process that only uses the streamline and not the pipe. If the simulation uses pipes, the fluid mechanics aspect will be more considered and closer to reality. But for this study, the use of a streamline is sufficient to analyze the controller's performance and economic feasibility.

The increase in feed flow rate will affect the temperature at E100 cooler, because the heat flow previously set is not sufficient to reduce the stream temperature to the initial set point (SP). According to the Black's principle that $Q_{\text{release}} = Q_{\text{accept}}$, because $Q = mc\Delta T$, the heat that must be released will be proportional to the increase in mass flow rate so that if the flow rate rises then Q which must be released to reach the same final temperature will rise. Whereas if the amount of Q used to release heat in the previous conditions and increase the flow rate is the same, of course the final temperature will rise. Therefore, the control valve opening will increase which will return the temperature to the initial SP. From Figure 2a, the results of the MPC controller have fewer temperature deviations, with IAE values of MPC is 41.07 and IAE of PI controller is 199.17. The high deviation and the oscillation on the PI controller show that this controller has a large open response but is not accompanied by the ability to go to a good SP.

As shown in Figure 2b, MPC have better performance than PI controller in the TC of Condenser T-101 with IAE of MPC = 1.46 and IAE of PI = 11.65. For LC of Condenser T-101 (Figure 2c), IAE of MPC = 4.73 and IAE of PI = 7.9. Figure 2d (LC of Column T-101) also shows that MPC is better than PI, with IAE of MPC = 4.66 and IAE of PI = 14.67. For TC Condenser T-103 (Figure 2e), IAE of MPC = 0.979 and IAE of PI = 7.79, so is LC Condenser T-103 (Figure 2f), IAE of MPC = 13.44 and IAE of PI = 312.9. In LC Column T-103 (Figure 2g), MPC shows good performance with the least deviation occurring, which is only 0.04%; IAE of MPC = 0.28 and IAE of PI = 7.55.

The E-101 is the rear unit that controls temperature. The results of the control in this unit will be very dependent on the results of controlling the LC Condenser T-103 (Figure 2h) because this unit accepts all changes in flow rate caused by the level control. So naturally, if the control in this unit takes a long time, up to 15 minutes even though it is only to control the temperature. In this unit, MPC is also better than PI, namely with IAE of MPC = 139.75 and IAE of PI = 437.8. MPCs provide better performance than PIs in controlling disturbances. The increase in MPC performance compared to PI can be seen in Table 2.

From the results of the overall process control over the disruption of the feed flow rate, it appears that the controller at the front of the process has a very important role to properly control the overall process. The front process unit also has the greatest effect of change because there are no controllers in front of it which extinguish the effects of disturbance. In addition, in a continuous process, changes to the previous unit can be a disturbance to the next unit, especially if the manipulated variable (MV) of the controller is directly related. For example, in this system, changes to the liquid level of condenser directly change (give upset) to the cooler unit, afterwards. This shows that in designing a control system, the control unit that is in the front process must be better adjusted. In a system that has a controller with an MV that directly affects the controller afterwards, which might occur if the controller is not set properly are total control is very slow, the system on the back becomes unstable, and controller deviations become very large.

Change in Product Flow Rate and Utility due to Changes in Disturbance (Flow Rate and Feed Temperature) by 5%

Figure 3 shows that for disturbance with increasing feed flow rates, there is a difference of 22.1 lb DME which is obtained more using MPC for 1 hour. But this difference is too small to be called an increase due to control. This difference can occur due to a factor of integration errors. Therefore, an increase in income cannot be calculated from the difference in the number of products, in other words the control with MPC provides the flow rate of the same DME product as the PI controller.

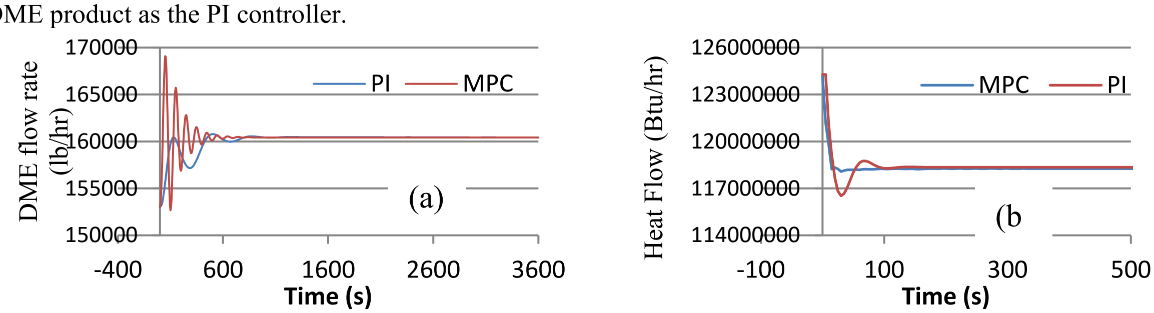

FIGURE 3. Product flow rate and utility due to changes in disturbance by 5%

TABLE 3. Difference in use of utilities as a result of disturbance

Unit	Feed flow rate of 3.5 MMSCFD (5%)		Feed temperature of 27.8°F		Difference (Btu)	
	MPC	PI	MPC	PI		
Q E100	118,339,921	118,361,581	118,359,156	11,830,2791	-21,660	-56,365
Q Cond T101	77,189,242	77,199,829	76,960,566	76,965,532	-10,587	-4,966
Q Reb T101	85,000,000	85,000,000	85,000,000	85,000,000	0	0
Q Cond T103	69,065,932	69,074,130	69,075,932	69,084,130	-8,198	-8,198
Q Reb T103	64,000,000	64,000,000	64,000,000	64,000,000	0	0
Q E101	6,527,631	6,550,826	5,684,499	5,686,334	-23,195	-1,835
Q E108	4,581,270	4,572,423	4,378,643	4,378,616	8,847	27
Total Difference					-54,793	-71,337

Utilities in the DME purification process related to process control are condenser load, reboiler load, and cooler load. In the same way as looking for the difference in the rate of DME products, this time the difference between the heat flow (utility) needed by the PI controller and MPC to deal with disturbance is sought. The heat flow data of the Q utility is shown in Figure 3 and Table 3. If the result of the minus is a saving, on the contrary if a plus means a waste of energy is used. In total, the use of MPC provides an opportunity to save energy in the process.

Economic Feasibility Analysis

The negative NPV indicates that the economic value of MPC installation compared to current PI is not profitable (Table 4). With this result it can be concluded that the MPC controlling installation in the DME purification plant is economically unfeasible.

TABLE 4. Economic analysis

Economic Parameters	Values
Savings of cooling water utilities (Tone/month)	32.64
Money saving (USD/month)	15.35
NPV (USD)	-846
Payback Period (years)	14.5

If the process is analyzed as a whole, it is known why the installation of the MPC in the DME purification process is not profitable even though it has better control performance than the PI controller: (1) The purification process of DME is only half of the whole DME synthesis process. The front part of the purification process is a synthesis process that has a reactor, so the results of the analysis of economic feasibility studies can change into account all units in the DME synthesis plant. (2) Although this process has a separation process that can determine the number of products, the quality of both types of controllers is able to maintain the concentration of DME products to remain good. This is because the DME separation process is not a complex process that requires high controller accuracy. Then the results of economic analysis can change if the example of the process analyzed is a crude distillation that has a complex system. (3) The utility in this process that is controlled (made MV) is a cheap utility that is cooling water, so the savings obtained are only a little. Then the value of savings can be greater in the process of having high-priced utilities such as steam and refrigerant. (4) The DME purification plant in this study design has a production capacity that is not too large, which is only 70 MMSCFD. With this insignificant capacity, the savings made are not too large so that it cannot cover the increase in capital costs because of the more expensive MPC prices. However, the use of two multivariable MPCs (MMPCs) instead of the eight SMPCs will decrease the PBP and increase the NPV significantly. Therefore, the use of MMPC can be considered for further research [13,14].

CONCLUSION

In this article, we shown that the eight single MPCs (SMPCs) performances are better than the PI controllers in overcoming the disturbance with the decrease of the integral of absolute error (IAE) by 40 % to 96%. Thus, there is a saving of utility (water) used is 0,015%. Since the utility is water, the economic value is low. This led to a considerable payback period (PBP) of 14.5 years, and net present value (NPV) of USD -846 in the feed flowrate disturbance scenario of 5%, so that the use of SMPC in the DME purification plant is economically unfeasible. However, the use of two multivariable MPCs (MMPCs) instead of the eight SMPCs will decrease the PBP and will increase the NPV significantly, therefore, the use of MMPC can be considered for further research.

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