

Optimization of control performance on CO₂ removal in subang field using model predictive control

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Abstract. A model predictive control (MPC) is used to optimize the control performance on CO₂ removal in Subang Field. MPC is implemented to control the feed gas pressure (PIC-1101), amine flow rate (FIC-1102), and makeup water flowrate (FIC-1103) to maintain CO₂ concentration in sweet gas. MPC is built using the first-order plus dead time (FOPDT) models. The control performance tests are used set point (SP) tracking and disturbance rejection with the performance indicator is the integral of square error (ISE). The result show that the optimum setting of prediction horizon (P), horizon (M) and Time Sampling (T) in MPC are 9, 1, 32 and 1 on PIC-1101; 34, 10 and 5 on FIC-1102 and 40, 10 and 5 on FIC-1103. Based on ISE values, the use of MPC can improve performance for set point tracking by 14.02% in PIC-1101, 76.74% in FIC-1102, and 16.31% in FIC-1103, the use of MPC can improve performance for disturbance rejection by 19.32% in FIC-1102, and 91.57% in FIC-1103, compared with the proportional-integral (PI) controller that used in the field.

1 Introduction

Indonesia as the largest country in Southeast Asia with economic growth per capita was recorded at 5.0% in 2016, up to 4.9% from the year earlier [1]. The increasing number of economic growth leads to an increase in the need for energy, the importance of energy mix in meeting those needs is very important one of which is the use of natural gas. Natural gas is widely used as fuel for power generation activities, both for household and office and industrial needs, besides the use of natural gas can also be used as raw material for the petrochemical industry [2].

Natural gas coming out from wells have the main content of CH₄ (Methane), C₂H₆ (Ethane), C₃H₈ (Propane), C₄H₁₀ (Butane), C₅H₁₂ (Pentane), CO₂ (Carbon dioxide), H₂S (Hydrogen Sulfide), and N₂ (Nitrogen) as well as small amounts of H₂ (Hydrogen), He (Helium), O₂ (Oxygen), and C₆H₁₄ (Hexane and other heavy hydrocarbons) (ISO 6974-1: 2000 - Natural gas). Sales gas have a requirement for a maximum of 5% -vol CO₂ and 8 ppmv H₂S to increase the calorific value and consider to the environment [3].

To fulfill the process is required process of removal of acid gas in order to reach the desired gas specification. The principle of the removal process is by absorbing the acid gas, but there is often a problem of the loss of a number of hydrocarbons in the process of the release of acid gas as an example of CO₂ removal unit at "X" Company in Subang Field. To overcome these problems, optimization of operating conditions and the addition of equipment required to achieve these operating conditions and the use of advance control.

Recently studies that discussed the control of the CO₂ removal unit is very limited to certain controlled variables

(CV). The configuration used in the control is a single control loop with the PI (Proportional - Integral) method, which consists of one transmitter, one controller, and a final control element. The goal is only to control the level on the absorber column [4], while controlling for pressure variable, previous study used single control loop with PI method, then for final control element controlled with control valve at output of KO drum sweet gas with the intention that pressure on absorber column can be maintained at optimum condition [5], whereas another study discuss about temperature control to maintain amine circulation temperature [6] which is not available in field because it is set by manual controlling. Therefore, in this research, the research is conducted to see the whole factory control system supported by the use of predictive control model (MPC) method to get control parameters and improve process performance in terms of control.

2 CO₂ Removal Unit

2.1 Process Control Target

General process flow for CO₂ Gas Removal Plant at "X" in Subang Field is shown in the scheme of the process, can be seen as in Fig.1. The image shows from the absorption process to the regeneration part. The scheme is slightly different from typical acid gas removal in general [7], in the regeneration section where there are only LP (Low Pressure) Flash columns with tray and packed configurations therein. Methyl diethanolamine solution with piperazine acceleration agent is used in this process due to its flexibility and availability, to maintain its strength (amine strength) in the absorption process, it is

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necessary to add water or makeup water in absorber column, the location of the inlet flow is also designed above the inlet solution amine or in the upper tray in order to capture the volatile amine solution to be excluded from the sweet gas stream. The main tools of concern are the absorber columns and LP Flash columns as well as associated pipelines, heat exchangers, and knock out drums.

2.2 Control Target

In this project, limitation of the variables that need to be maintained are the amine flow rate, the makeup water flow rate, and the pressure of feed gas to the absorber column. The control is intended to maintain the quality of the final product i.e the CO₂ content in the sweet gas, in addition some variables also need to be controlled for reasons of process safety [8].

Control system in CO₂ Removal Plant that used in this research shown in Fig 2 and tag number from each controllers shown in Table 1. The PIC-1101 controller is the process controller for controlling the pressure

difference between the bottom and top of the absorber column and maintaining sweet gas pressure. The pressure difference is maintained at about 3 psig.

The FIC - 1102 controller is the process controller for controlling the level in absorber and LP flash columns and amine strength, but in this study more focused on controlling amine strength. The amine solution used is a mixture of aMDEA and piperazine with water. Due to the amount of water that evaporates during the regeneration process, it is necessary to makeup water to keep the amine strength remains in the range of 45% [9]. It takes 2 – 4 m³/h makeup water to keep it up.

The FIC - 1103 controller is the process controller for controlling amine strength. The amine solution used is a mixture of aMDEA and piperazine with water. Due to its effect on the CO₂ removal process, the flow rate should be maintained at 650 – 700 m³/h to maintain a 45% amine strength concentration.

The controller currently used in the plant uses a P-I (Proportional - Integral) control mechanism. Then to compare it is done by using MPC (Model Predictive Control) in SISO system (Single Input Single Output).

Table 1. Control system on CO₂ Removal Unit

Type of Controller	Controlled Variable	Manipulated Variable
Pressure Control (PIC – 1101)	Feed gas to the absorber column	Sweet gas flow rate of KO drum output
Flow Control (FIC – 1102)	Makeup water flow rate to absorber column	Makeup water flow rate from utility
Flow Control (FIC – 1103)	Amine flow rate to the absorber column	Amine flow rate from amine pump

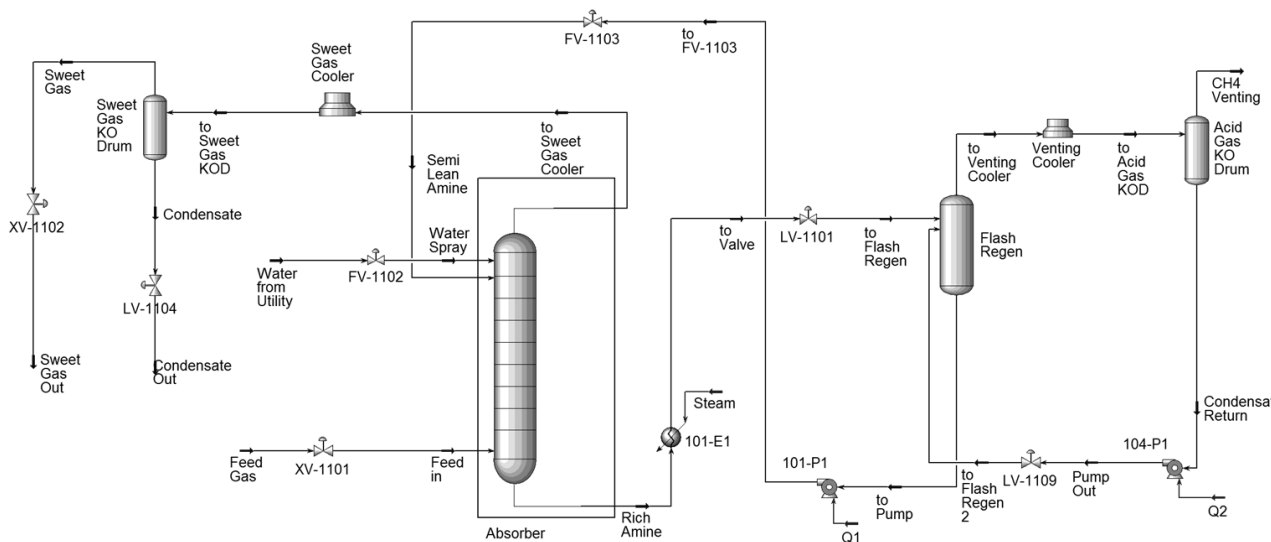


Fig. 1. CO₂ Removal Process Scheme

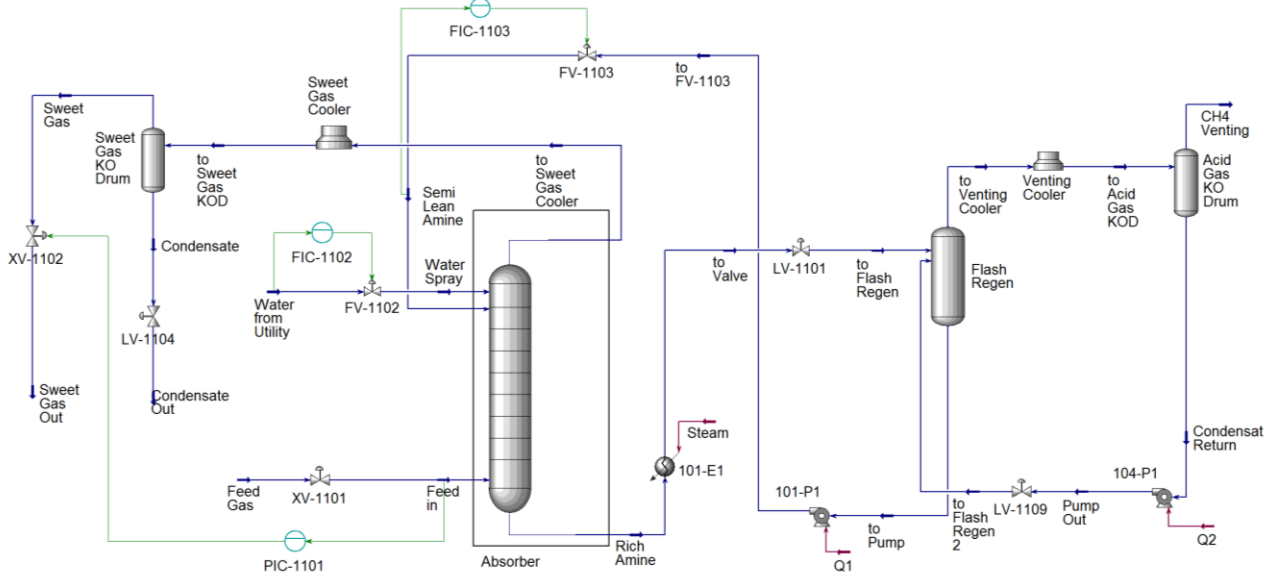


Fig. 2. Control System in CO₂ Removal Plant

3 Empirical Model of Process Control

The model used in obtaining the parameters of the empirical model is used First Order Plus Dead Time (FOPDT) approach in this research [10]. Eq. (1) shows FOPDT model that has dead time (θ), this number shows how much time the system needs to respond to step change. The equation also shows that the speed of the system in response to the interference (τ). While gain (K_p) shows the amount of system sensitivity.

$$G_p(s) = \frac{K_p e^{-\theta s}}{\tau s + 1} \quad (1)$$

The result of FOPDT will be obtained a Process Reaction Curve (PRC) through model testing, empirical models were developed as shown in Table 2.

Table 2. FOPDT Model of CO₂ Removal Unit

Controller	Model
PIC – 1101 Controller	$\frac{-0.199e^{-1.5s}}{31.5s + 1}$
FIC – 1102 Controller	$\frac{0.044e^{-0.543s}}{2.084s + 1}$
FIC – 1103 Controller	$\frac{3.330e^{-3.106s}}{0.528s + 1}$

4 Controller Tuning

As resulted empirical model, we have to find controller parameters with some tuning procedures [10]. Based on empirical model from FOPDT, we can calculate the control parameters of PI controller by using Eq. (2) and Eq. (3). The controllers is tuned using Ziegler-Nichols method [8]. However, the control parameters of PI

controller from actual is different than using Eq. (2) and Eq. (3) to get that parameters, so this step could be neglected.

$$K_c = \frac{0.9}{K_p} \left(\frac{\theta}{\tau}\right)^{-1} \quad (2)$$

$$T_i = 3.33 \theta \quad (3)$$

The modeling results from the previous step then tuned to get the control parameters. As in SISO system, the tuning of MPC Controller is based upon [11]. Approximate the process dynamics of all controller output to measured process variable pairs with FOPDT models, select the sample time (T) as close as possible with Eq. (4), compute the prediction horizon (P) with Eq. (5), and compute a control horizon (M) with Eq. (6).

$$\left\{ \begin{array}{l} T_{rs} = \text{Max}(0,1 \tau_{rs} ; 0,5\theta_{rs}) \\ T = \text{Min}(T_{rs}) \end{array} \right\} \quad (4)$$

$$P = \text{Max}\left(\frac{5\tau_{rs}}{T} + k_{rs}\right) \text{ where } k_{rs} = \left(\frac{\theta_{rs}}{T} + 1\right) \quad (5)$$

$$M = \text{Max}\left(\frac{\tau_{rs}}{T} + k_{rs}\right) \quad (6)$$

Tuned values of MPC and control parameter from actual i.e PI Controllers are shown in Table 3.

Table 3. Tuned values of CO₂ Removal Controller

Parameter	MPC Fine Tuning	MPC Dougherty & Cooper	Proportional-Integral
PIC – 1101			
P	91	54	-
M	32	12	-
T	1	3	-
Kc	-	-	7.2
Ti	-	-	46.1
FIC – 1102			
P	34	51	-
M	10	11	-
T	5	5	-
Kc	-	-	0.5
Ti	-	-	10
FIC - 1103			
P	40	51	-
M	10	11	-
T	5	5	-
Kc	-	-	0.37
Ti	-	-	10.6

5 Performance of Controller

Set point tracking and disturbance rejection are the way to test controller performance, reliable controller must be aggressive by set point changing and be able the regulator from disturbances [12].

5.1 Set Point Tracking

The first comparison is between Propotional – Integral, MPC – Dougherty & Cooper, MPC – Fine Tuning for set point (SP) tracking. Fig. 3 (a) shows PIC – 1101 performance from SP changing about 2 psig, controlling using the resultant constants from tuning using the MPC-fine tuning and proportional-integral method provides a fast response when compared to the constants of the MPC-Dougherty & Cooper tuning constants. The MPC-fine tuning method responds more slowly than proportional integral but the MPC-fine tuning method has an advantage over the proportional-integral in the process to achieve a more stability.

Fig. 3 (b) presents FIC – 1102 performance from set point change about 0.5 m³/h, and Fig. 3 (c) FIC – 1103 performance from set point change about 30 m³/h. We can see that controlling by using the resultant constants of the tuning using the MPC-fine tuning and Dougherty & Cooper method provides a fast response when compared to the proportional-integral. However, the MPC-fine tuning method has an advantage compared to MPC-

Dougharty & Cooper in the process speed to achieve stability. So that the tuned constant using MPC-fine tuning method is better to overcome set point changes compared to the constants of propotional-integral and MPC-Dougharty & Cooper.

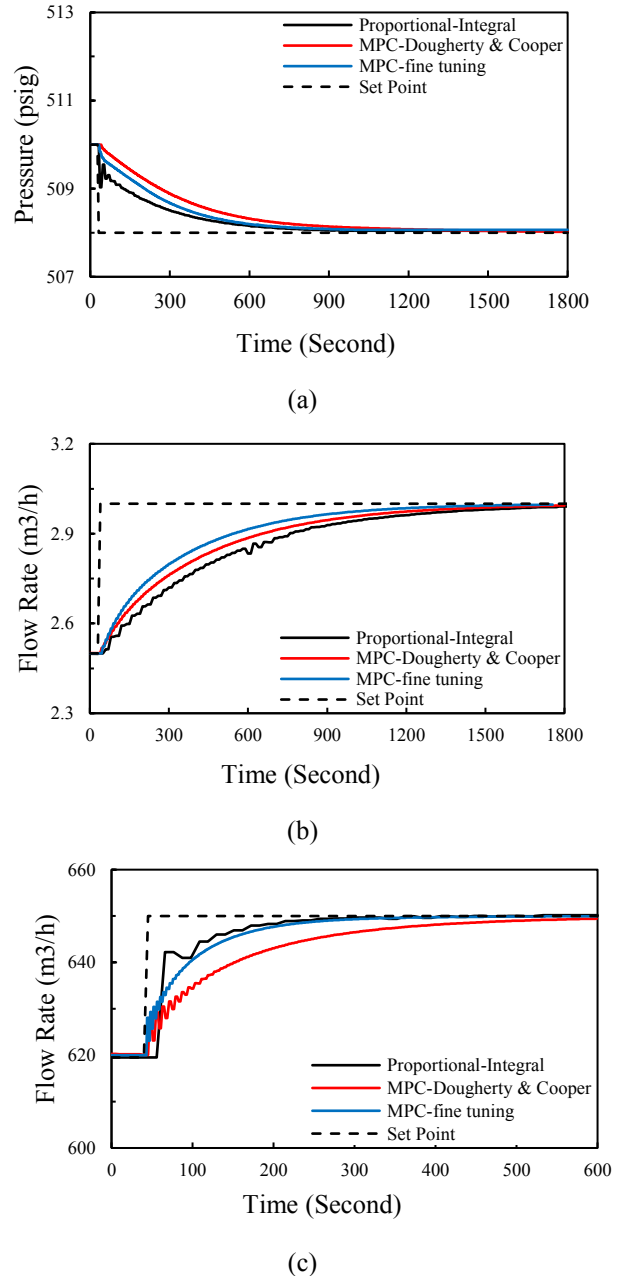


Fig. 3. Controllers response to set point changes: (a) PIC – 1101 (b) FIC – 1102 (c) FIC – 1103

ISE is the integral of the square error of controller. In the context of process control, the meaning of error is the difference between the value of the actual CV of the targeted CV value or so-called Set Point (SP) [13].

$$ISE = \int_0^{\infty} [SP(t) - CV(t)]^2 dt \tag{7}$$

ISE is one of the parameters that shows the performance of control. The small value of error, which also means the smaller value of Eq (7), then this indicates a good controller performance. ISE values from three controllers above are summarized in Table 4.

Table 4. Performance of PI controller and MPC controller by ISE calculation for SP tracking

Controller	Proportional-Integral	MPC-fine tuning	MPC-Dougherty & Cooper
PIC – 1101 Controller	8.946	7.692	11.377
FIC – 1102 Controller	0.834	0.194	0.346
FIC – 1103 Controller	380	318	665

5.2 Disturbance Rejection

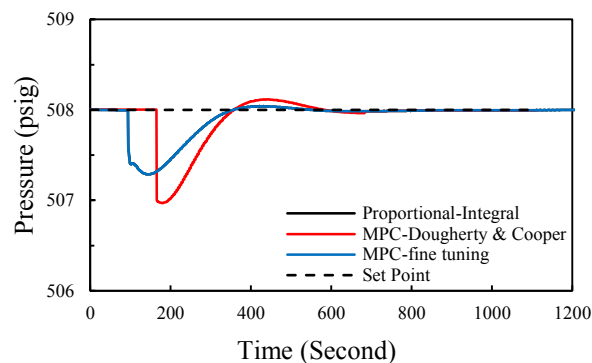
Controllers response to the effect of interference changes the flow rate of feed gas comparisons shown in Fig. 4. One controller to maintain pressure and two controller to maintain flow rate. The disturbance to test reliable controller is feed gas flow rate decreasing about 5 MMSCD. Fig. 4 (a) shows PIC – 1101 to reject disturbance, the tuning method uses proportional-integral and MPC-fine tuning has the same ability to overcome the interference. Seen from the duration of the MPC-Dougherty & Cooper method of control response to be able to stabilize then this adjustment is no better than the setting of the previous two methods.

Fig. 4 (b) presents FIC – 1102 to reject disturbance, and Fig. 4 (c) shows FIC – 1103 to reject disturbance. From both images it is seen that MPC is better to overcome the interference because it is more stable to reach its original condition, using fine tuning method and Dougharty & Cooper method. While the use of PI controllers shows fluctuations to achieve stable conditions.

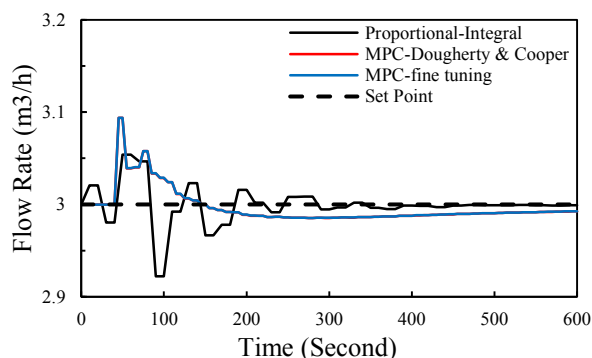
ISE values from three controllers above are summarized in Table 5.

Table 5. Performance of PI controller and MPC controller by ISE calculation

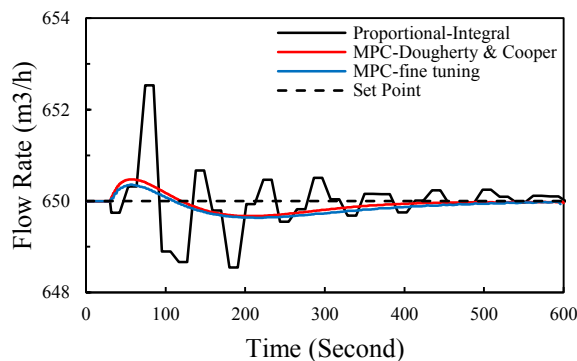
Controller	Proportional-Integral	MPC-fine tuning	MPC-Dougherty & Cooper
PIC – 1101 Controller	0.947	0.947	1.378
FIC – 1102 Controller	0.295	0.238	0.238
FIC – 1103 Controller	4.306	0.363	0.623



(a)



(b)



(c)

Fig. 4 Controllers response to the effect of interference changes the flow rate of feed gas: (a) PIC – 1101 (b) FIC – 1102 (c) FIC – 1103

6 Conclusion

Replacement of controller from Proportional-Integral to Model Predictive Control is very influential on the speed of process back to its stability. For that use of MPC can be an option in controlling the process in CO₂ Removal at "X" company in Subang field. The control response is based on the research that has been done by testing the reliability of the controller using the change of set point, the use of MPC can improve the control performance by 14.02% in PIC-1101 for control of absorber column pressure and keep pressure difference the top and bottom of the absorber column, 76.74% in FIC-1102 to maintain the flow rate of makeup water in order to maintain the desired strength of amine, and 16.31% in FIC-1103 to

maintain the semi-lean amine circulation. While on disturbance by changing of feed gas flow rate, the use of MPC can improve the control performance by 19.32% in FIC-1102 to maintain the flow rate of makeup water in order to maintain the desired strength of amine, and 91.57% in FIC-1103 to maintain the semi-lean amine circulation against the effect of rate change disturbances gas feed flow.

We express our gratitude to the Universitas Indonesia which has funded this research through the scheme of Hibah Publikasi Internasional Terindeks untuk Tugas Akhir Mahasiswa (PITTA) No.2359/UN2.R3.1/HKP.05.00/2018.

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