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Re-refinery Used Oil Vacuum Distillation Column Control by using Internal Model Control

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The purposes of this research are to make a steady state and dynamic process simulations and to analyse process dynamics as well as to calculate the performance of 1DOF IMC on re-refinery used oil distillation column control. The controller for this research is IMC (Internal Model Control), a model based controller. IMC structure used in this research is one degree of freedom-IMC, a type of controller that gives a very good response for set point change (servo problem). First step in this work is to set steady state and dynamic process simulations. Secondly, a simulation on 1DOF IMC controller having a set point change in tray temperature was carried out using software Simulink. Responses of 1DOF IMC on enriching temperature and stripping temperature show that the controller can give good responses for set point change. The integral absolute error (IAE) for 1DOF IMC for a set point change in the enriching temperature are 68.5 for enriching temperature response and 13.59 for stripping temperature response. For a set point change of stripping temperature are 68.12 for enriching temperature response and 35.48 for stripping temperature response respectively.

1. Introduction

One of the important processes in re-refinery used oil is distillation process (Speight and Exall, 2014). There are two types of distillation process in re-refinery used oil: vacuum distillation and final fractionation. Vacuum distillation is the first distillation in the re-refinery used oil that has a purpose to separate gasoil from the lube base oil.

Distillation column is a unit operation with multiple controlled variables and multiple manipulated variables. Control problem which has multiple controlled variables and multiple manipulated variables is called as MIMO (multiple input, multiple output) control problems. There are some controlled variables in the distillation column, such as: distillate and bottom product composition, column pressure, liquid level inside accumulator and liquid level in the bottom column. There are also some manipulated variables, such as: distillate flowrate, bottom product flowrate, reflux flowrate and heat duty for condenser and reboiler. Figure 1 shows the vacuum distillation of used oil completed with PID controller.

There are some desired performance criteria in a controller, such as: stable, minimum disturbance effect, rapid and smooth response for set point change, zero offset, moderate control action and robust control system (Seborg et al., 2011).

So many design and tuning methods have been developed on the controller in various chemical processes. PID controller cannot solve industrial process complexity and its quality of product specification. PID is usually designed in a feedback structure, which has some disadvantages such as: disturbance is known after output measurement, so that control action is done after a disturbance influences the process. This causes a significant problem for process with large time delay. The delay of control action makes the action sometimes inappropriate with the disturbance entering the process. Control by using PID also has other disadvantage which sacrifices performance in order to achieve robustness. It means to achieve robust controller, the response could be poor. Those were the reasons why IMC was developed. IMC is a model based controller, which has process model that stands as the real process itself. The development of IMC is aimed to solve the disadvantages in feedback control structures (Brosilow and Joseph, 2002). IMC can give a very good response for servo problems (set point change).

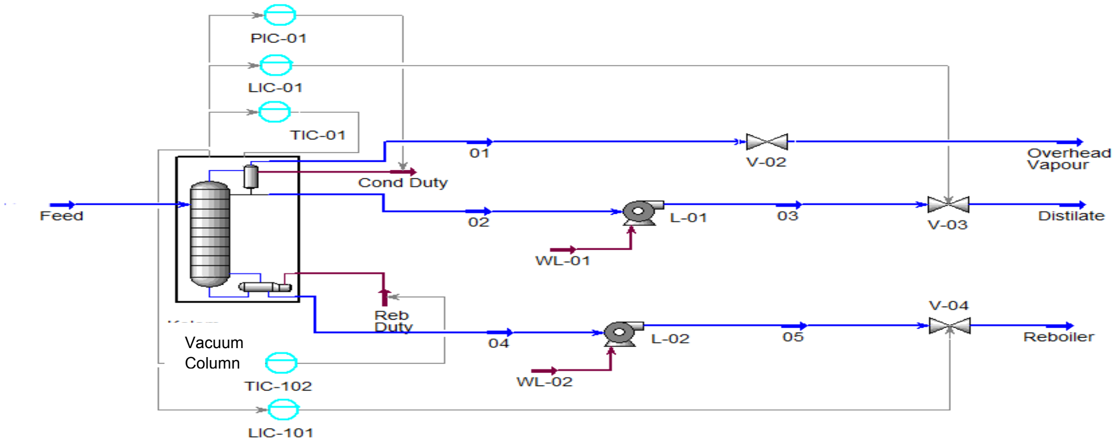

Figure 1: Control system configuration

The change of process variables in vacuum distillation column makes a need for designing control system which observes changes in the process. In this research, 1DOF IMC is used for solving those problems. Approach for these problems is done by simulating vacuum distillation column by using Aspen HYSYS. Simulation of controller structure and the calculation are done by using Simulink for MIMO 2x2, which controls enriching and stripping temperature.

2. Method

2.1 Steady State Simulation

Calculation was made for steady state model using Aspen HYSYS. The model needed some data on feed, including composition, temperature, pressure, and flow rate. They also needed to know the condition at top and bottom stage of the column.
Feed entered the column at 164.8 °C, 11.9 kPa, and the molar flowrate was 4,975 mol/h. The column had 32 stages, and the feed stage was at 17^{th}. This column used partial condenser and total reboiler.

2.2 Dynamic Simulation

The purpose of dynamic simulation is to get response of process. Column was installed with five controllers. They were basic controllers which needed in distillation system. They were pressure controller, condenser level controller, enriching temperature controller, stripping temperature controller, and reboiler level controller. Dynamic mode was simulated with Aspen HYSYS.

2.3 Identification of Transfer Function

To identify a transfer function, a step test was used. IMC was applied to TIC-01 and TIC-02. The process is initially at steady state, and the controller was on manual mode. Then, the controller output was changed (3-5). The response was recorded on the process reaction curve, which is the open loop step response (Seborg et al., 2011).

2.4 Design of 1DOF-IMC

1DOF-IMC was designed in two steps:
First, the process model was factored, being time delay and the right-half plane zeros, and all the left-half plane poles:

$$\tilde{G} = \tilde{G}_{+}\tilde{G}_{-} \quad (1)$$

Secondly, the controller was specified.

$$Gc^{*} = \frac{1}{\tilde{G}_{-}} f \quad (2)$$

where *f* is a low pass filter

$$f = \frac{1}{(\tau_c s + 1)^r} \quad (3)$$

r is positive integer, usually using 1. τ_c is the closed loop time constant and important as a tuning parameter in IMC. There were some guidelines to choose τ_c.

τ_c/θ > 0,8 dan τ_c > 0,1 τ (Rivera et al., 1986) (4)

$\tau > \tau_c > \theta$ (Chien and Fruehauf., 1990) (5)

$\tau_c = \theta$ (Skogestad, 2003) (6)

2.5 MIMO Simulation

Dynamic simulation was required to verify the design of 1DOF-IMC. It was simulated in MATLAB Simulink with a change in set point.

3. Result and Discussion

3.1 Steady State Simulation

Fluid package that was used in this simulation is Peng Robinson Equation of State (Chen and Mathias, 2002).

3.2 Dynamic Mode Simulation

Dynamic simulation was carried out to know the behaviour of the process. Before converting steady state into dynamic simulation, controllers are added to the column.
When controllers are added to system, the control valves action is also determined. Type of control valve used in Aspen HYSYS is air to open (fail close). There are five controllers that are added to the system with manipulated and controlled variables paired as can be seen in Table 1.

Table 1: Control structure of vacuum distillation and the result for auto-tuning

Controller	Controlled Variable	Manipulated Variable	Kc	τ_i	τ_d
PIC-01	Top stage pressure	Condenser duty	10.4	0.135	0.03
TIC-01	Enriching temperature	Reflux flowrate	14.5	31.8	7.06
TIC-02	Stripping temperature	Reboiler duty	14.8	1.07	0.239
LIC-01	Condenser level	Distillate flowrate	14.8	59.3	13.2
LIC-02	Bottom level	Bottom product flowrate	14.8	0.236	0.0524

Two control valves are added to the system; distillate flowrate valve and bottom product flowrate valve. Sizing control valve is done by using rating in Aspen HYSYS. This aims to determine the valve characteristic and to know the value of Cv.
After converting the steady state mode into dynamic mode, one has to assure that the controllers are in the manual mode. In this condition, all OP is set to 50 %. This is done until the process becomes stable or in steady state. After responses become stable, then one can change one by one of controllers from manual to auto mode. Type of controller that is used is PID controller.
In the auto mode, a set point change is given to the system until the process variables reach the desired set point. To achieve this condition, tuning is needed. PID tuning is used to get the controller's parameters (Kc, τi and τd) and also for FOPTD or SOPTD model (Ljung, 2002). The method used in this tuning is relay auto-tuning from Autotuner in Aspen HYSYS. For this method, feedback controller is temporary replaced by an on-off controller (relay). The value of relay is usually 5 - 10 % from controller output (Luyben, 2002). The result for Auto-tuning can be seen in Table 1.
Meanwhile, controller responses are shown by stripcharts. In these stripcharts, black shows OP, red shows SP and blue shows PV.
Figure 2 shows response of enriching temperature with time. The value of set point is 139 °C. The process variable is also 139 °C with valve of manipulated variable is 61.79 %. The result shows response is stable and can achieve the desired set point.
Figure 3 shows response of stripping temperature with time. The value of set point is 246.8 °C. The process variable is also 246.8 °C with valve of manipulated variable is 49.66 %. The result shows response is stable and can achieve the desired set point.

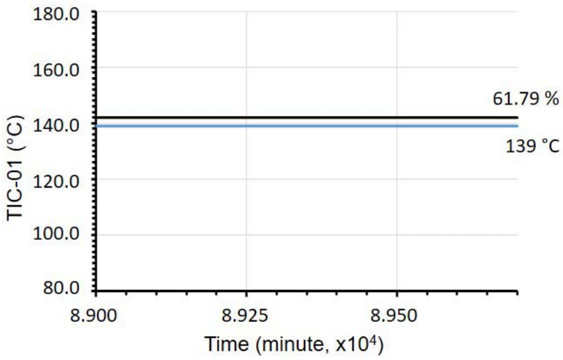

Figure 2: Stripchart of TIC-01

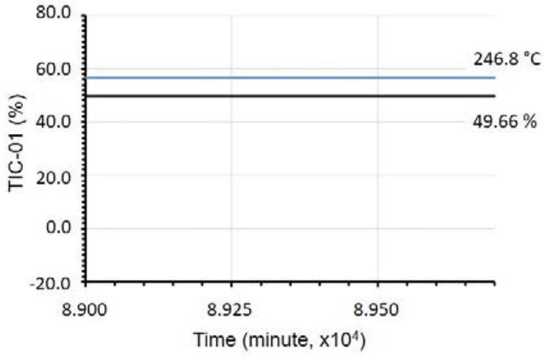

Figure 3: Stripchart of TIC-02

3.3 Identification of Transfer Function

Step test method was carried out to give four transfer functions (Rangaiah and Khrisnaswamy, 1994). They were Gp_{11}, Gp_{21}, Gp_{12} and Gp_{22}. Gp_{11} was a relation between enriching temperature and reflux flowrate. Gp_{21} was a relation between stripping temperature and reflux flowrate. Gp_{12} was a relation between enriching temperature and reboiler duty. Gp_{22} was a relation between stripping temperature and reboiler duty. The transfer functions were used to design of IMC for MIMO system.

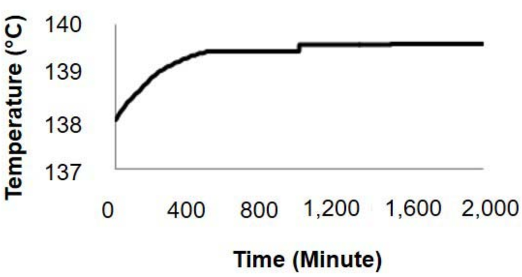

Figure 4: Enriching temperature open loop step response from reduction of reflux flowrate

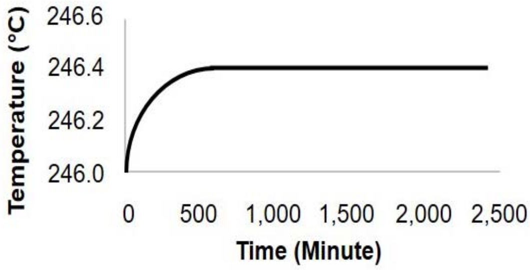

Figure 5: Stripping temperature open loop step response from reduction of reflux flowrate

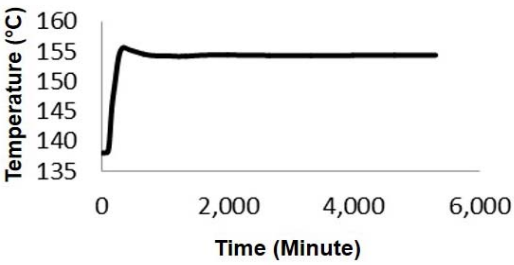

Figure 6: Enriching temperature open loop step response from increased of reboiler duty

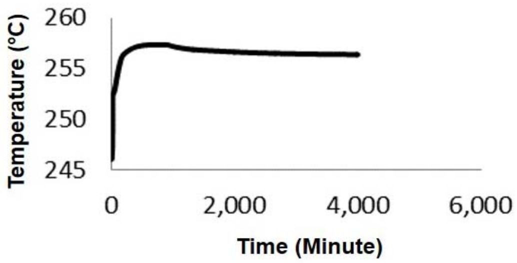

Figure 7: Stripping temperature open loop step response from increased of reboiler duty

The resulted FOPTD transfer function for Figure 4 is:

$$G_{p11} = \frac{0.312e^{-26.6s}}{106.7s + 1} \tag{7}$$

The resulted FOPTD transfer function for Figure 5 is:

$$G_{p21} = \frac{0.0666e^{-15s}}{30s + 1} \tag{8}$$

The resulted SOPTD transfer function for Figure 6 is:

$$G_{p12} = \frac{5.45e^{-81.2s}}{2819.61s^2 + 106.2s + 1} \tag{9}$$

The resulted SOPTD transfer function for Figure 7 is:

$$G_{p22} = \frac{5.44e^{-13.33s}}{81.9025s^2 + 44.707s + 1} \tag{10}$$

3.4 Design of 1DOF-IMC

There are two process variables that will be installed using IMC, which is the enriching temperature and the stripping temperature. τ_c parameter was chosen to be the same as *θ*. G was obtained from identification of transfer function. This research assumed perfect model, so the value of *G* would be the same as $\tilde{G}$. Gpm_{11} was the same as Gp_{11}. Gpm_{22} was the same as Gp_{22} (Seborg et al., 2011). Table 2 shows the IMC design transfer functions.

Table 2: IMC Design

Design	Transfer Function
$G_{c1}{}^*$	$\frac{106.7s + 1}{8.2992s + 0.312}$
$G_{c2}{}^*$	$\frac{43.98s + 1}{72.52s + 5.44}$
G_{pm11}	$\frac{0.312e^{-26.6s}}{106.7s + 1}$
G_{pm22}	$\frac{5.44e^{-13.33s}}{(42.79s + 1)(1.91s + 1)}$

3.5 Simulation of MIMO 2x2 1DOF IMC

After designing 1DOF 1MC for MIMO 2x2 control problems, then a simulation on MIMO 2x2 1DOF IMC was carried out to see the behaviour of the controlled variables for a set point change in the enriching and stripping tray temperature. Simulation responses for set point change in both enriching and stripping temperature can be seen in Figure 8 and Figure 9.

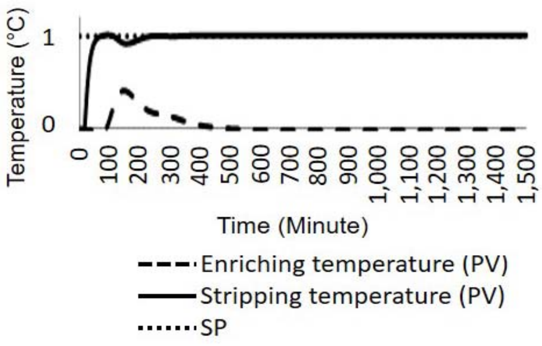

Figure 8: Response of 1DOF IMC for set point change in enriching temperature

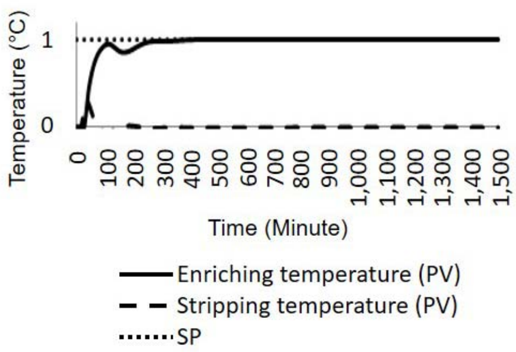

Figure 9: Response of 1DOF IMC for set point change in stripping temperature

In Figure 8, solid line represents PV for enriching temperature, dashed line represents PV for stripping temperature and dotted line represents set point for enriching temperature. At 0 min to 15 min, response shows that PV for stripping temperature is 0. For enriching temperature, response shows that PV for enriching temperature is 0 °C at 0 - 26.6 min. The reason is because the process has time delay 15 min for stripping temperature and 26.6 min for enriching temperature. From 26.6 min, PV of enriching temperature goes up to set point which has a value of 1. PV for stripping temperature oscillates a little bit and then back to 0 °C. From

Figure 8, at 500 min, PV of enriching temperature can achieve set point and both responses are stable until reach 1,500 min.
In Figure 9, solid line represents PV for stripping temperature, dashed line represents PV for enriching temperature and dotted line represents set point for stripping temperature. At 0 min to 81.2 min, response shows that PV for enriching temperature is 0 °C. For stripping temperature, response shows that PV for enriching temperature is 0 °C at 0 to 13.33 min. The reason is because the process has time delay 81.2 min for enriching temperature and 13.33 min for stripping temperature. From time at 13.33 min, PV of stripping temperature goes up to set point which has a value of 1. PV for enriching temperature oscillates a little bit and then back to 0 °C. From figure 9, at 500 min, PV of stripping temperature can achieve set point and both responses are stable until reach 1,500 min.

3.6 Calculation of IAE using 1DOF IMC

IAE is a value that is easy to calculate because it is just the sum of area above and under set point (Carlos and Armando, 1997). This method is used to determine the IAE of the controlled variables using 1DOF IMC that has been designed.
Based on the simulation, a set point change in enriching temperature for a time from 0 min to 1,500 min, IAE value is 68.5 for enriching temperature response and 13.59 for stripping temperature response. A set point change in stripping temperature for a time from 0 min to 1,500 min, IAE value is 68.12 for enriching temperature response and 35.48 for stripping temperature response.

4. Conclusion

Based on the investigation using 1 DOF IMC controller, it can be concluded that the simulation for both steady state and dynamic of vacuum distillation have been successfully carried out using Aspen HYSYS. Responses from MIMO 2x2 1DOF IMC controller for both enriching and stripping temperature show excellent result in set point changes. The IAE result is concluded as following:

Set point change in enriching temperature	Set point change in stripping temperature
Enriching temperature response = 68.5	Enriching temperature response = 68.12
Stripping temperature response = 13.59	Stripping temperature response = 35.48

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