Dynamic Performance Test of Fractionation Process within LNG Plant using INDISS

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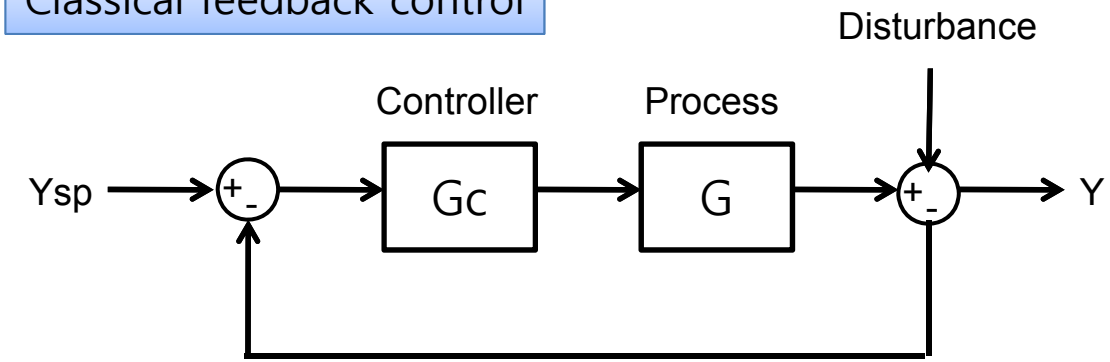
Introduction

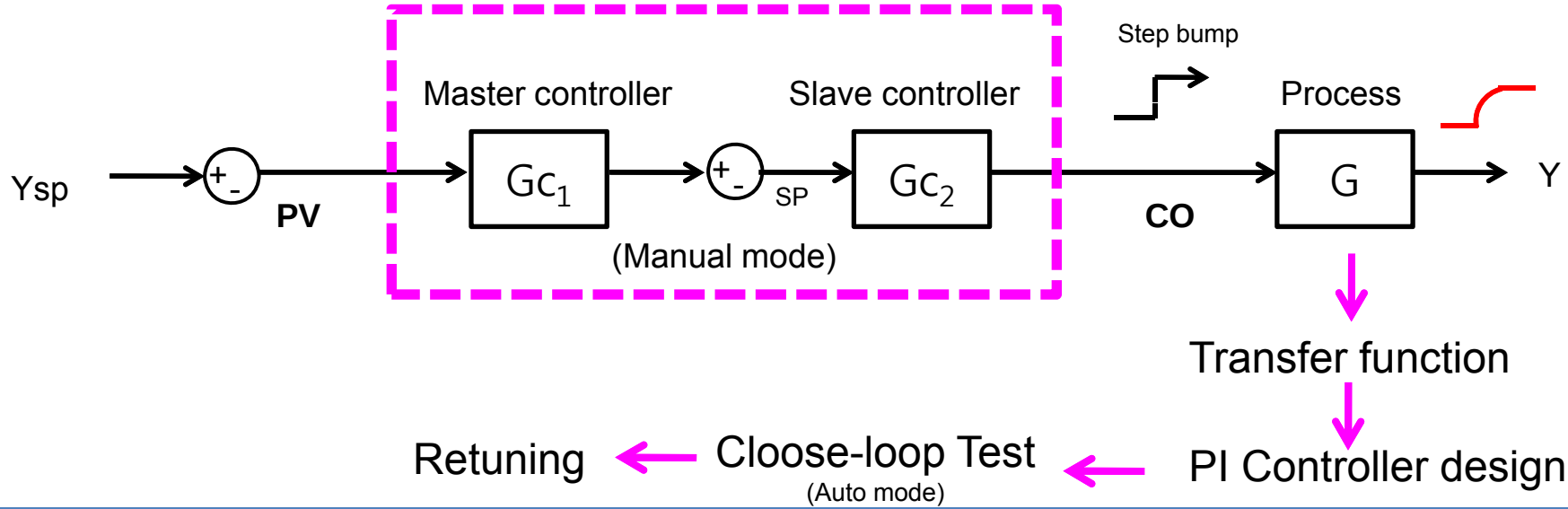
Classical feedback control



Concept of work

To considers dynamic performance of fractionation process using bump test and applies simplified transfer function model to design parameters tuning of PI controllers, especially casecade controller type.

Bump test: Open loop (manual mode) and consider cascade controller as one input to process



Process Description

There are 4 distillation towers in series:
Demethaniser, Deethaniser,
Depropaniser and Debutaniser.

we consider casecade controller type to design Kc and Ti using for PI controller setting.

Three main cascade controllers are considered in this work including column temperature, condenser level and column bottom level

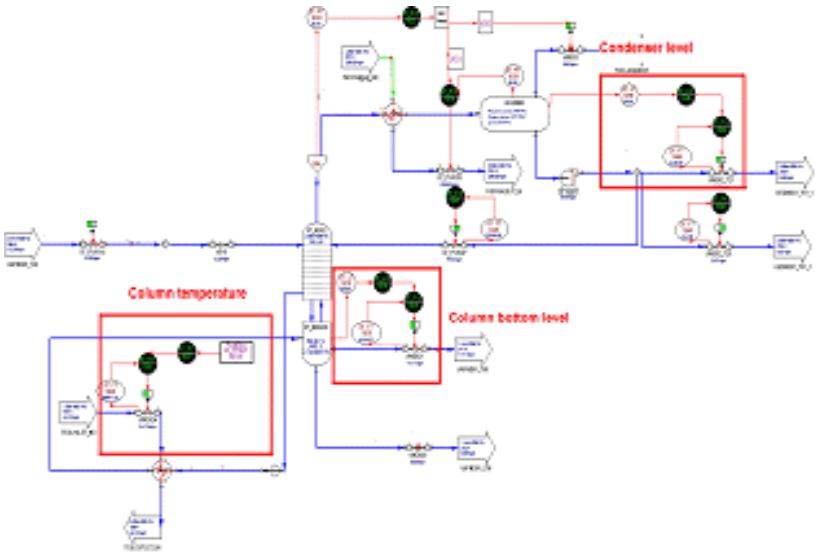
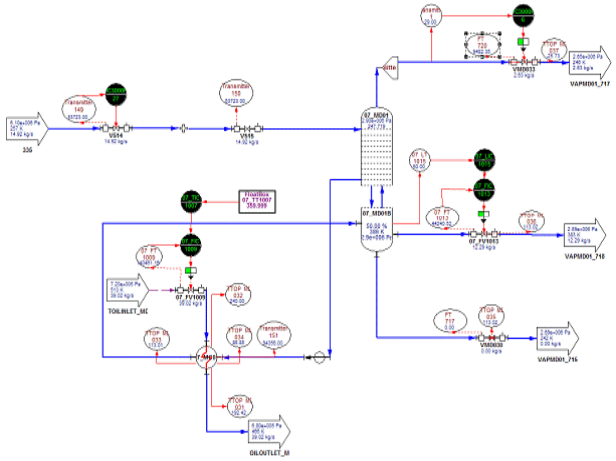


Table 1. Cascade controllers list

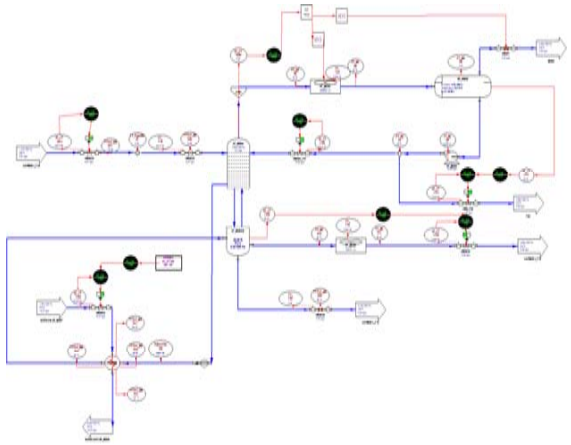
	Master Controller	Slave Controller
Demethaniser	Column temp. at 1st tray	Hot oil flowrate
	Bottom column level	Bottom product flowrate
Deethaniser	Column temp. at 1st tray	Hot oil flowrate
	Bottom column level	Bottom product flowrate
Depropaniser	Condenser level	Top product flowrate
	Column temp. at 5th tray	Reflux flowrate
	Bottom column level	Bottom product flowrate
Debutaniser	Condenser level	Top product flowrate
	Column temp. at 1st tray	Hot oil flowrate
	Bottom column level	Bottom product flowrate
	Condenser level	Top product flowrate

Fractionation process dynamic model using INDISS

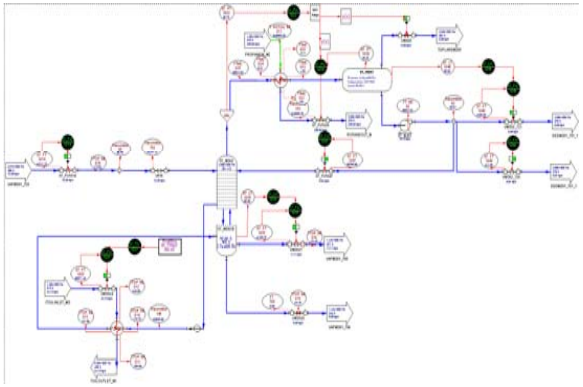
Demethaniser modeling



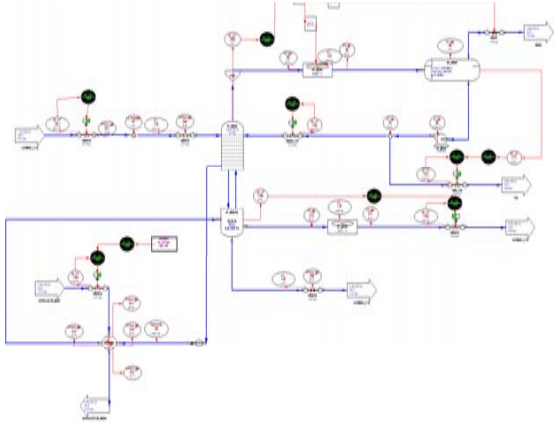
Depropaniser modeling



Deethaniser modeling



Debutaniser modeling



Demethaniser is a reboiled stripper type while others are reflux column type.

The dynamic process is performed using commercial simulator: INDISS.

INDISS (Industrial Integrated Simulation Sofware) is a program based on dynamic simulation, which is used to model fractionation process, and allowed the user to observe an operation through simulation.

Information for modeling is usually available on paper for PFDs, P&IDs, and Equipment data sheets.

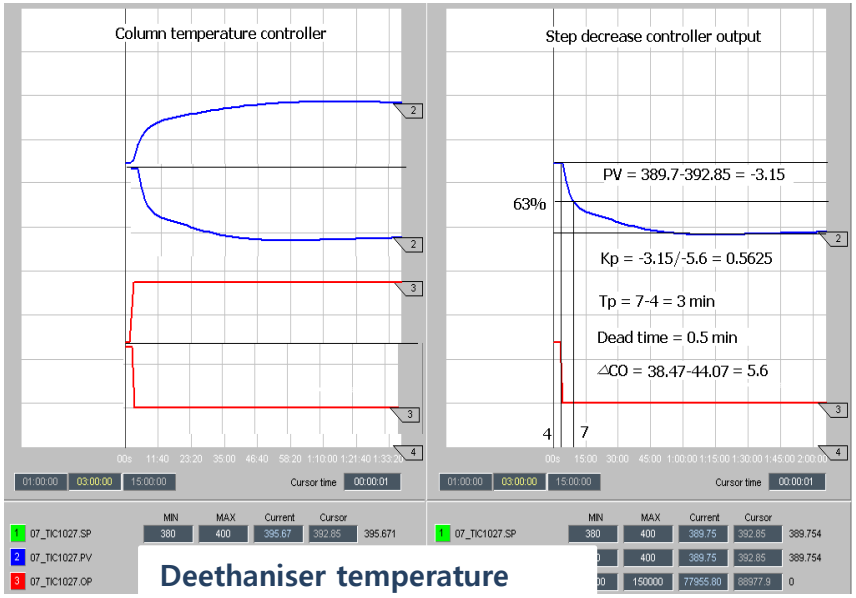
Bump Test Strategies

Step 1 Bump the process and collect controller output (CO) to process variable (PV).

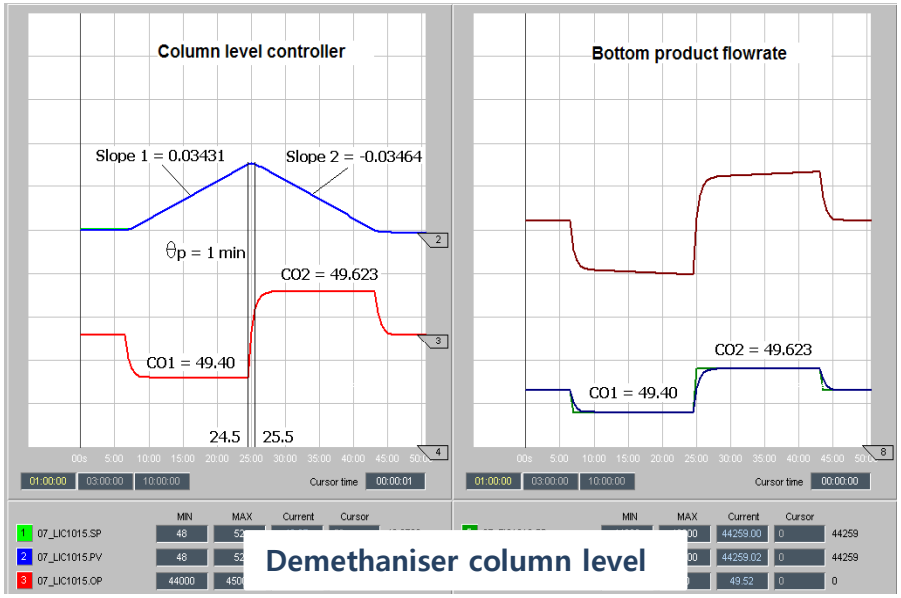
This method has done with open loop controller (manual mode). Step increase or decrease CO of slave controller and trace PV response of master controller until the new value is stable.

Both of increase and decrease CO step bump should be consider because their response are different sensitivity. More sensitive PV response is chosen to go on next step.

Step bump for FOPDT model: Column temperature controllers.

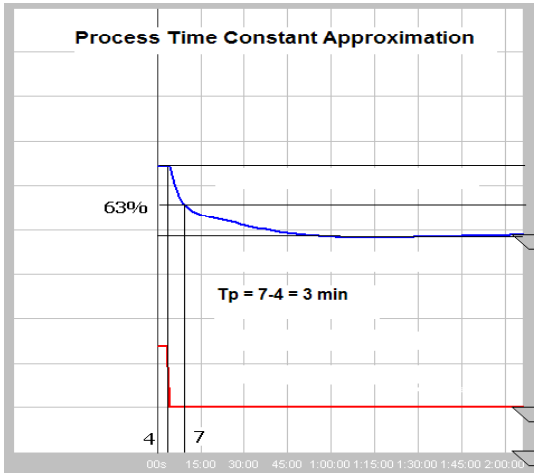


Step bump for Integrating model: Level controllers.



Step 2 Approximate the process data behavior with FOPDT dynamic model or integrating process plus dead time dynamic model.

In this step, Kp, Tp and Θ are determined to generise as transfer functions, G(s).



Kp is the direction PV moves and how far it travels in response to a change in CO.

Tp is a time constant shown how fast the PV moves in response to a change in the CO. It can be read with step 1 result at the time where PV moving to 63%of ∆ PV.

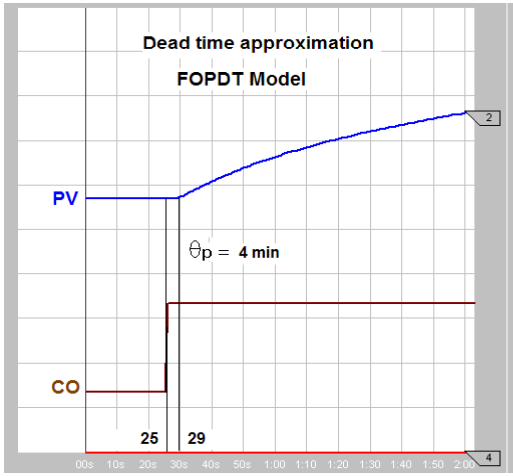
Θ is the different in time of CO achieve stepped new value and PV start a clear responses.

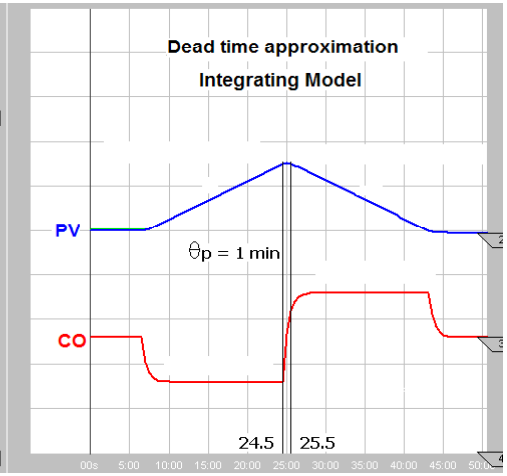
for FOPDT

$$Kp = \frac{\Delta PV}{\Delta CO} \qquad G(s) = \frac{K_p e^{-\varpi}}{\varpi + 1}, \tau = T_i$$

for Integrating

$$Kp^* = \frac{slope2 - slope1}{CO2 - CO1} \qquad G(s) = \frac{K_p^* e^{-\varpi}}{s}$$





	Controllers	Transfer functions	Model types
Demeth.	Column temp.	$0.33e^{-0.01s}/(6.25s+1)$	FOPDT
	Bottom level	$0.31e^{-0.01s}/s$	Integrating
Deeth.	Column temp.	$0.56e^{-0.5s}/(3s+1)$	FOPDT
	Bottom level	$1.66^{e-0.5s}/s$	Integrating
	Cond. level	$0.02e^{-2s}/s$	Integrating
Deprop.	Column temp.	$9.05e^{-4s}/(271s+1)$	FOPDT
	Bottom level	$0.21e^{-0.5s}/s$	Integrating
	Cond. level	$0.04e^{-2s}/s$	Integrating
Debut.	Column temp.	$1.36e^{-0.5s}/(82s+1)$	FOPDT
	Bottom level	$0.08e^{-s}/s$	Integrating
	Cond. level	$0.05e^{-3s}/s$	Integrating

Determined Transfer Functions of Cascade Controllers

	Controllers	Transfer functions	Model types
Demethaniser	Column tempemperature at last tray	$0.33e^{-0.01s}/(6.25s+1)$	FOPDT
	Bottom column level	$0.31e^{-0.01s}/s$	Integrating
Deethaniser	Column tempemperature at last tray	$0.56e^{-0.5s}/(3s+1)$	FOPDT
	Bottom column level	$1.66^{e-0.5s}/s$	Integrating
	Condenser level	$0.02e^{-2s}/s$	Integrating
Depropaniser	Column tempemperature at fifth tray	$9.05e^{-4s}/(271s+1)$	FOPDT
	Bottom column level	$0.21e^{-0.5s}/s$	Integrating
	Condenser level	$0.04e^{-2s}/s$	Integrating
Debutaniser	Column tempemperature at last tray	$1.36e^{-0.5s}/(82s+1)$	FOPDT
	Bottom column level	$0.08e^{-s}/s$	Integrating
	Condenser level	$0.05e^{-3s}/s$	Integrating

Column temperatures are referred as large process time constant (Tp or τ). They means process variable moves in slowly response to a change in the CO. This results relate to design Ti in next step. The model presented slow response consist demethaniser column temperature, depropaniser column temperature and debutaniser column temperature.

Step 3 Use the model parameters from step 2 in rules and correlations to complete the controller design and tuning.

Below quations are used for PI controller tuning design. They are generised from process model and designed transfer functions.

for FOPDT model

$$Kc = \frac{1}{K^*}\frac{2Tc+\theta}{(Tc+\theta p)^2}, Ti = 2Tc+\theta$$

for Integrating plus dead time model

$$Kc = \frac{1}{Kp}\frac{Tp}{(Tc+\theta p)}, Ti = \tau$$

Tc is the desired colsed-loop time constant, it is a key decision to design controller parameters. In general, increasing Tc produces a more conservative controller because Kc decreases while Ti increases.

Several IMC guidelines for Tc have been published for the FOPTD model following:
1. $Tc/\theta > 0.8$ and $Tc > 0.1\tau$ (Rivera et al., 1986)
2. $\tau > Tc > \theta$ (Chien and Fruehauf, 1990)
3. $Tc = \theta$ (Skogestad, 2003)

Table 3 shows Kc and Ti designed based on IMC model.

Tc Selections using for PI controller design

Integrating plus dead time

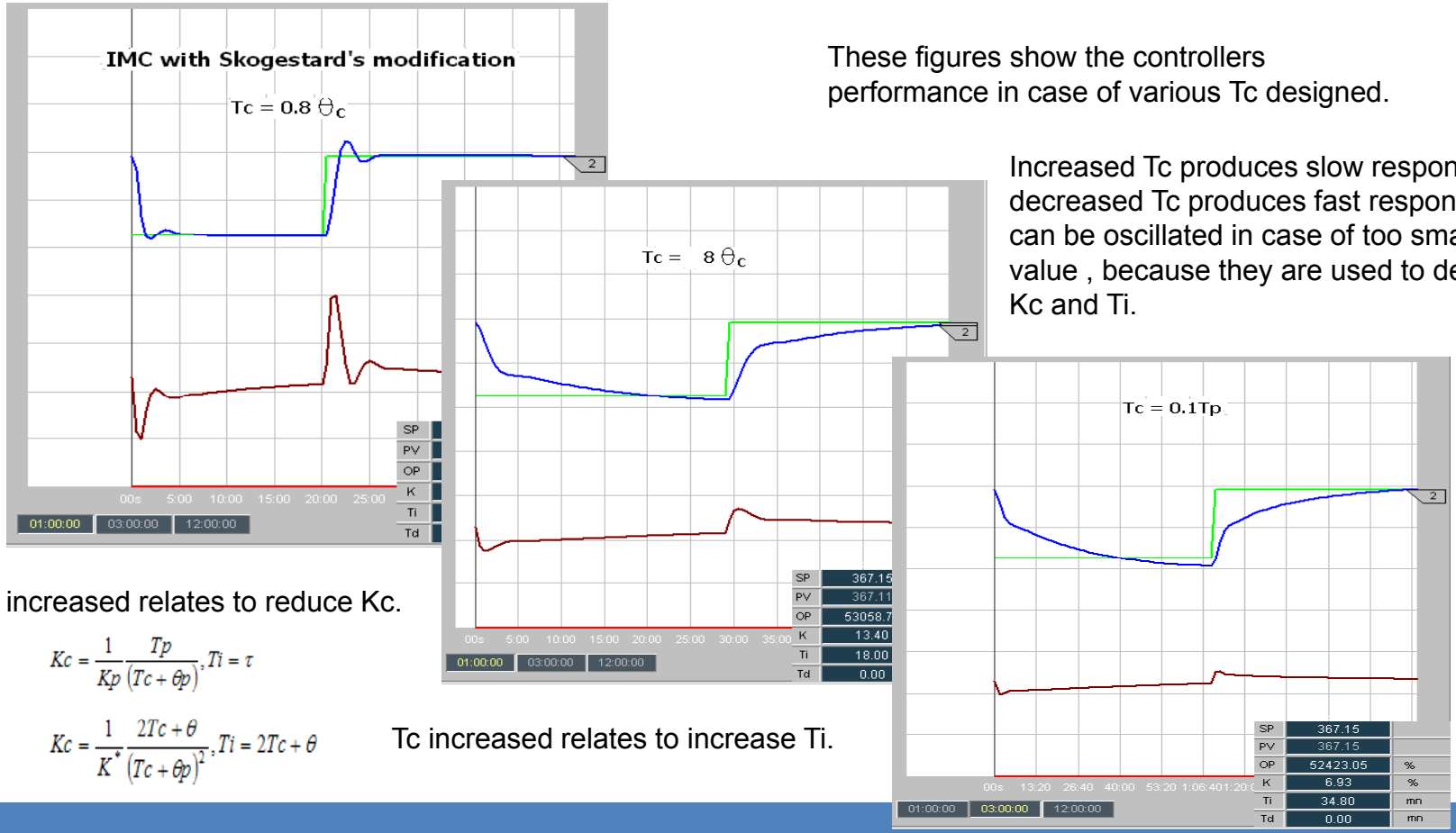
1. Tc = 3θ (http://www.controlguru.com/pages/table.html)

FOPDT model

1. Tc/θ > 0.8 and Tc > 0.1Tp (Rivera et al., 1986)
2. Tp > Tc > θ (Chien and Fruehauf, 1990)
3. Tc = θ (Skogestad, 2003)

These figures show the controllers performance in case of various Tc designed.

Increased Tc produces slow response while decreased Tc produces fast response and it can be oscillated in case of too small Tc value , because they are used to determined Kc and Ti.



Tc increased relates to reduce Kc.

$$Kc = \frac{1}{Kp}\frac{Tp}{(Tc+\theta p)}, Ti = \tau$$

$$Kc = \frac{1}{K^*}\frac{2Tc+\theta}{(Tc+\theta p)^2}, Ti = 2Tc+\theta$$

Tc increased relates to increase Ti.

Lag-Dominant Model method to reduce Ti

In case of very large Tp, it needs to reduce value because the large value of Ti is too slow responds. The way to reduce Ti is used Lag-Dominant Model [1] method. There are 2 ways using in this work including:

1. Approximate the lag-dominant model by an integrating model and calculate K^*_p from K_p/Tp (Chien and Fruehauf, 1990).
2. Limit the value of Ti as min{Tp, 4(Tc+θ)} (Skogestad, 2003).

Three cases are presented to design PI controller tuning . In case 1 is used to design for normal process variable response.

In case 2 and 3 are used to generise Ti in case of very slow process variable reponse, we can choose the best choice when the method is going on to next step (tuning).

Case1: IMC based PID controller setting

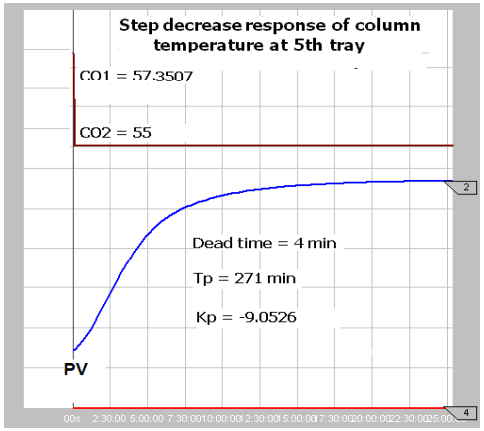
$$Kc = \frac{1}{Kp}\frac{Tp}{(Tc+\theta p)} \qquad Ti = Tc$$

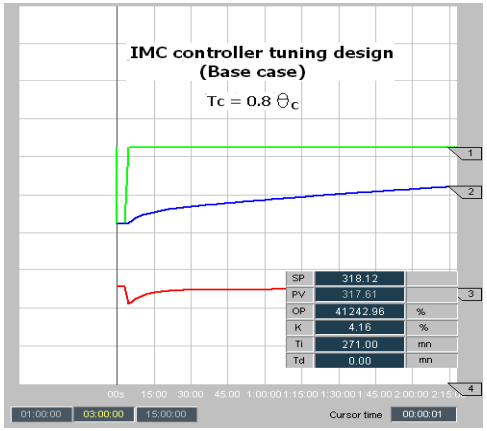
Case2: IMC based on the integrator approximation

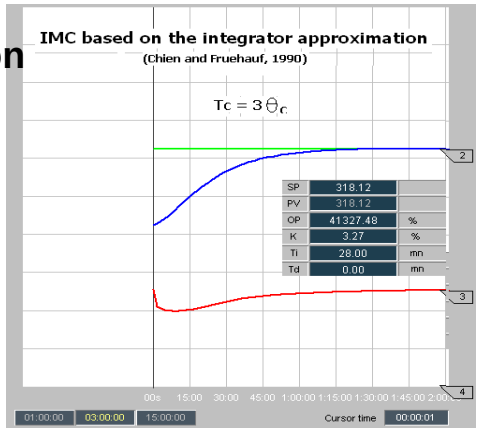
$$Kc = \frac{1}{K^*}\frac{2\tau_c+\theta}{(Tc+\theta p)^2} \qquad Ti = 2Tc+\theta p$$

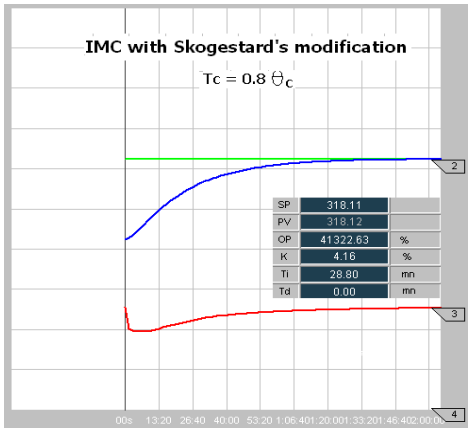
Case3: IMC with Skogestard's modeification

$$Kc = \frac{1}{Kp}\frac{Tp}{(Tc+\theta p)} \qquad Ti = \min\{\tau_1, 4(\tau_c+\theta)\} \qquad K^* = \frac{Kp}{Tp}$$









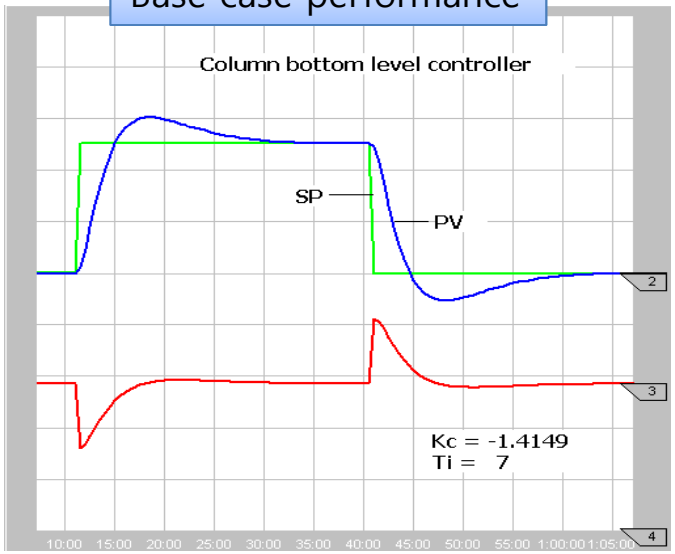
Step 4 PI Controller Tuning

After control parameters designed, they are used to set controller tuning with closed loop model (auto mode). Kc and Ti are re-tuned to choose more proper values.

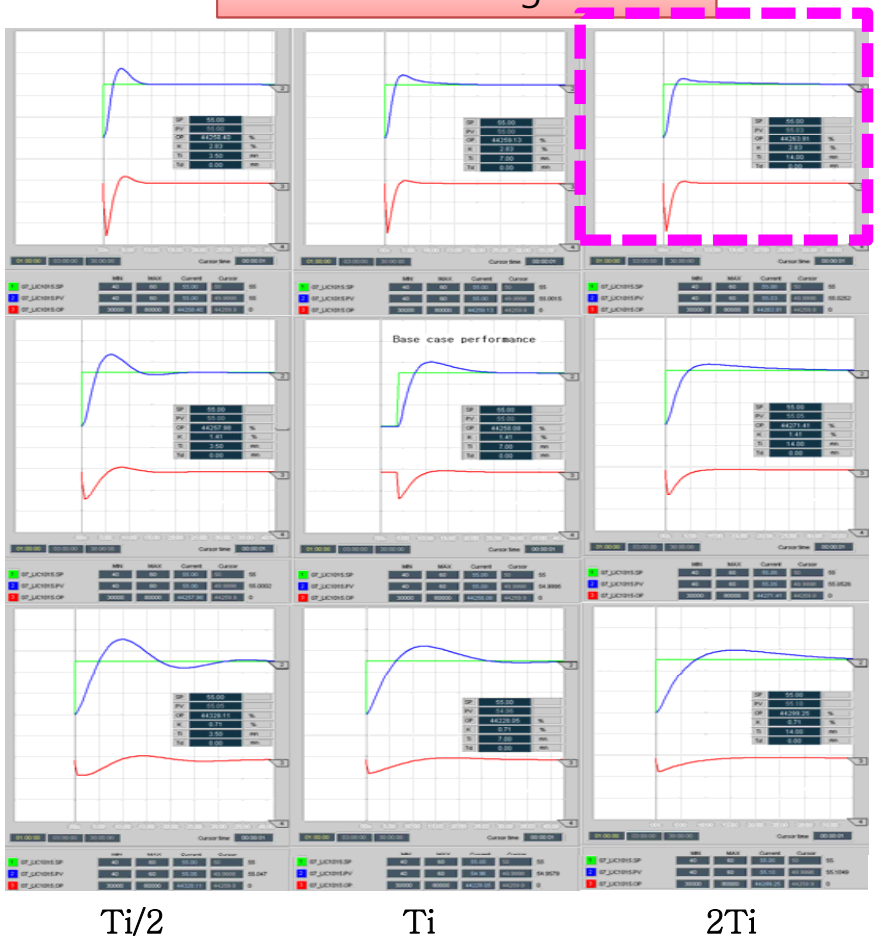
These show base case PI controller desiged with re-tuning various cases

Transfer function $G(s) = \frac{-0.30919}{s} e^{-s}$ $Tc = 3\theta_p$

Base case performance



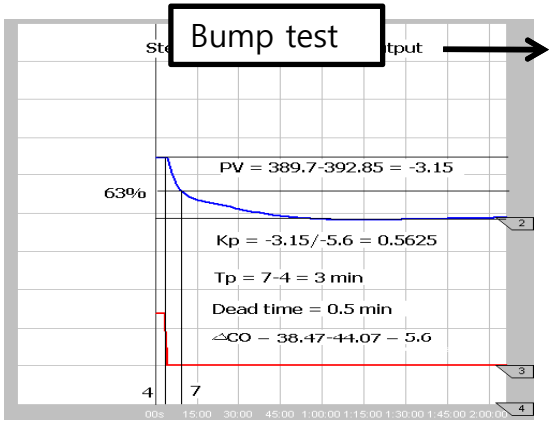
Retuning



Selected controller tuning: Kc = 2.8, Ti = 14

Summarized overall step of PI controller design

Demethaniser column temperature PI controller tuning

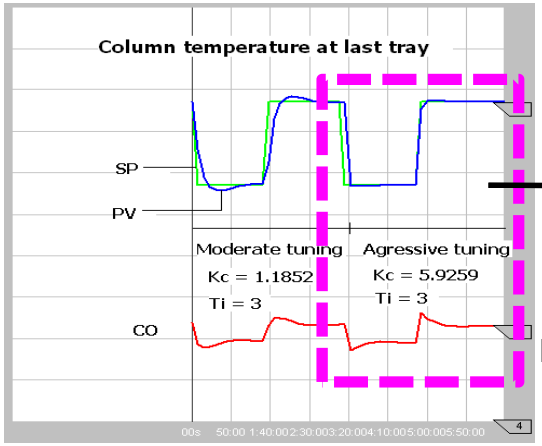


Design transfer function

$$G(s) = \frac{0.8233}{37s+1} e^{-0.5s}$$

Design PI controller

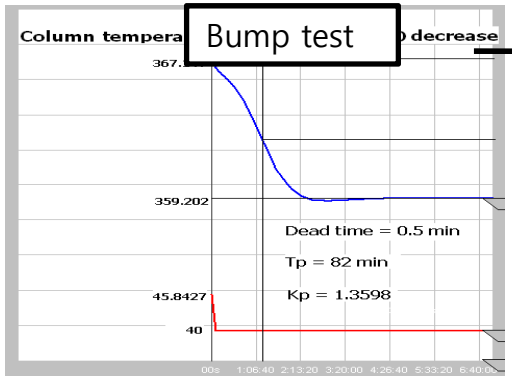
Re-tuning



Select Kc, Ti

Kc = 5.93, Ti = 3

Debutaniser column temperature PI controller tuning



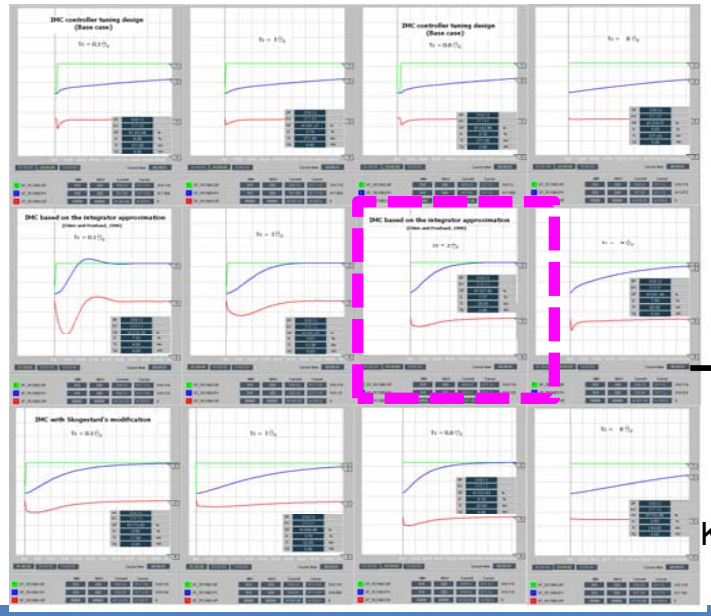
Design transfer function

$$G(s) = \frac{1.3598}{82s+1} e^{-0.5s}$$

Generise Tp

Design Kc, Ti

Re-tuning



Select Kc, Ti

Kc = 25.32, Ti = 8.5

Base case PI controllers design and re-tuning selection

This table show the PI controller designed with base case and re-tuning selection

Columns	Controllers	Base case design	After re-tuning
		Kc, Ti	Kc, Ti
Demethaniser	Column temperature at last tray	3.02, 6.25	20.08, 7.9
	Column bottom level	1.41, 7	2.83, 14
Deethaniser	Column temperature at last tray	5.93, 3	5.93, 3
	Column bottom level	0.53, 3.5	1.06, 7
	Condenser level	9.26, 14	18.52, 14
Depropaniser	Column temperature at fifth tray	5.61, 12	5.61, 12
	Column bottom level	5.38, 3.5	10.77, 7
	Condenser level	6.05, 20	12.10, 28
Debutaniser	Column temperature at last tray	67, 3.6	25.32, 8.5
	Column bottom level	0.08, 3	10.79, 14
	Condenser level	3.12, 22	6.24, 42

Conclusion

❖ Bump test are presented as strategies in this work, it is useful to learn about the dynamic behavior of a process and design controller tuning paramters based on model.

❖ The process behavior are descriped as transfer functions (FOPDT and Integrating model, they are applied to design PI controllers with simplified transfer functions.

❖ The key of this method is to design initial controller settings that can subsequently be fine tuned on-line, if necessary. Because on-line tuning can be time-consuming, it is very useful to have good initial controller settings in order to minimize the required time and effort.

❖ If a reasonably accurate, dynamic model of the process is available, it is advantageous to base the controller design on the process model.

❖Furthermore, parameters from the dynamic model are not only used in correlations to compute tuning values, but also provide insight into controller design parameters such as loop sample time and whether dead time presents a performance challenge.

Acknowledgement

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References

1. Dale E., Tomas F. and Duncan A., 2003, Process Dynamics and Control, pp.297-311.
2. http://www.controlguru.com/pages/table.html
3. http://www.bin95.com/PID_Controller_Design.htm