Design of an Internal Model Control for SISO Binary Distillation Column

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Abstract– **The prime objective of any industrial process is to perform efficiently with variable cost reduction. Internal Model Control (IMC) is a commonly used technique that provides a transparent mode for the designing and tuning of various types of control architecture. In this paper, we have designed the internal model control for binary distillation column for SISO process. The transfer function has been taken from Wood and Berry model. The internal model control has been designed considering three strategies namely, process perfect, process mismatch with disturbances and process model with disturbance only. It has also been tried to reduce the disturbance created in the system by varying tuning parameter (λ).**

Keywords- Internal Model Control; Binary Distillation Column; SISO; Disturbance; Wood and Berry

I. INTRODUCTION

In industrial system, internal model control and model Predictive control (model based control) has proven to be successful controller design strategies.Internal Model Control (IMC) is a commonly used technique that provides a transparent mode for the designing and tuning of various types of control architecture. Simultaneously it allows good set point tracking along with sulky disturbance response especially for the process with a small time-delay or time-constant ratio. But for many process control applications, disturbance rejection for the unstable process is of extreme priority than the set point tracking. Hence the controller design that emphasizes disturbance rejection rather than the set point tracking is an important criterion that must be taken into consideration. Internal model control is an advance control technique in which process model is used in order to compute the value of control variable. In internal model control process model is connected in parallel with the actual process, with the help of this we compare both of process [1].Hear, to design a liner controller based on a linearized model for chemical processes all model- based control strategies is used. Compare to open loop control, internal model control is able to compensate for disturbance and model uncertainty. Internal model control provides a useful range of all stable controllers for open loop stable systems [2]. For the perfect model assumption, the design of a stable internal model control becomes an insignificant task for close-loop stability. Although most of the process is nonlinear in nature, the internal model controller performs acceptable result for this process. This paper will present a SISO (single input single output) process for binary distillation column using internal model control and how we can reject the disturbance.

II. INTERNAL MODEL CONTROL ALGORITHM

The block diagram of internal model control is given below (fig.1). [3]

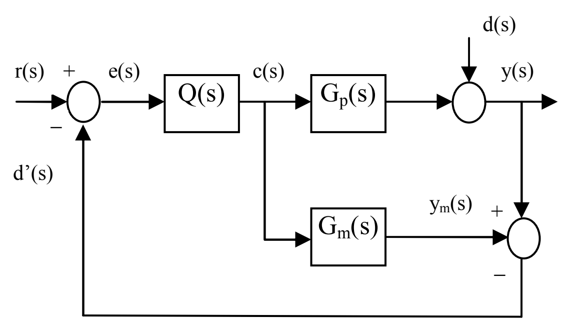

Figure1. Internal Model Control structure

Where Q(s) is the primary controller (IMC) transfer function, $G_p(s)$ is the process transfer function, $G_m(s)$ is the process model transfer function, r(s) is set point, e(s) is error, c(s) is manipulated variable, d(s) is disturbance, $y_m(s)$ is model output and y(s) is controlled variable (process output).

We know that dynamic controller gives faster response than the static controller so we use dynamic control law.

Hence

$$Q(s) = \frac{1}{G_P(s)} \quad (1)$$

This is only valid with stable process with no time delay. Now we have focus to design the IMC for time delay system.
The controller design procedure has been generalized to the following step [5].

1. First we have identified the process model into good stuff and bad stuff by using all pass formulation or using simple factorization.
2. Invert the (good stuff) invertible portion of the process model and to make proper add the filter.

$$Q(s) = \frac{f(s)}{G_{m\_}(s)} \quad (2)$$

Internal model control works with different condition which we given below.

When Model Perfect, No Disturbances [$G_p(s) = G_m(s)$ & $d(s)=0$]:

$$y(s) = G_p(s)\, Q(s)\, r(s) \quad (3)$$

Model Perfect, Disturbance Effect:

$$y(s) = [G_P(s)\, Q(s)\, r(s) + \{1 - G_m(s)\, Q(s)\}\, d(s)] \quad (4)$$

With only Disturbance & Disturbance Rejection:

$$y(s) = [1 - G_m(s)\, Q(s)]d(s) \quad (5)$$

$$d(s) = G_d(s)\, L(s)$$

L(s) is load disturbance.
For IMC design we have taken filter

$$f(s) = \frac{1}{(1+\lambda s)^n} \quad (6)$$

For disturbance rejection we have use the filter in the form of

$$f(s) = \frac{\Upsilon s + 1}{(1+\lambda s)^n} \quad (7)$$

Where Υ is constant selected to achieve good disturbance rejection.

III. THE DISTILLATION COLUMN

Distillation is a separation method in the petroleum and chemical industries for purification of final products. A general distillation column consists of a vertical column, where plates or trays are used to increase the component separations. A condenser is used to cool and condense the vapor and a reboiler is used to provide heat for the necessary vaporization from the bottom of the column. A reflux drum is used to hold the condensed (liquid) vapor to recycle the liquid reflux to back from top of the column. According to L-B, Shinskey approach [6] the distillation column (fig.2) has control variable (L) (reflux flow) is used to control the output variable such as propylene and the bottom flow (B) is used to control the bottom composition such as propane.

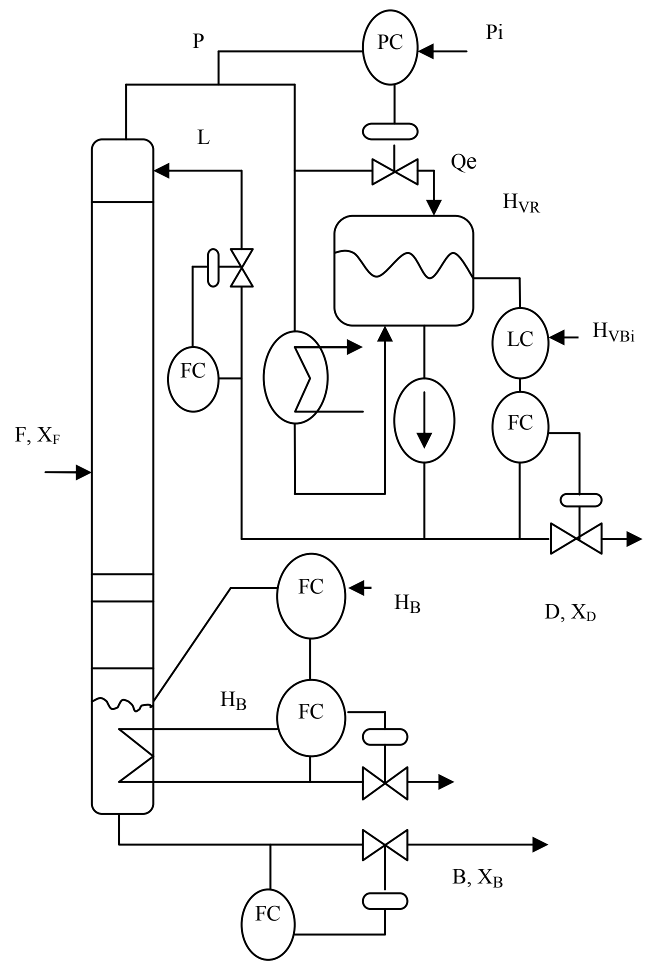

Figure2. Propylene (C3')/Propane (C3) distillation column

Where PC is pressure controller, FC is flow controller, LC is level controller, AT is composition transducer, L is reflux flow, P is pressure, B is bottom product flow ,H_{VR} is reflux tank level, HB is bottom column level, F is feed flow, xF is feed composition, xB is bottom composition, and xD is top composition.

Distillation column process has two output top X_D (the propylene)and bottom X_B(the propane) composition and four input such as two disturbance feed flow(F) and feed composition (X_F) and two controlled variable reflux(L)and bottom product flow (B).

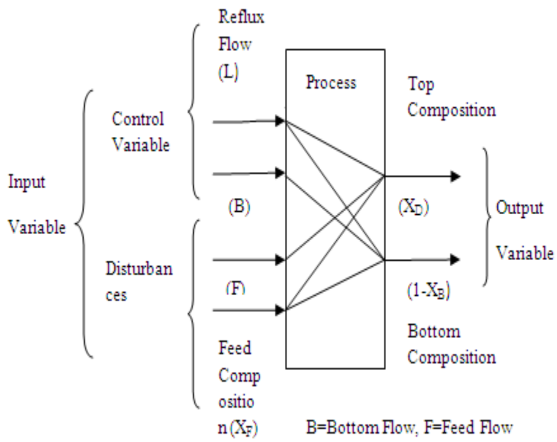

Figure3. Distillation process block diagram.

The process model is described by first order transfer function with dead time (8) having gain constant and time constant for process channel [4].

$$G = \frac{K_m e^{-\tau s}}{Ts+1} \quad (8)$$

K_m is the process gain, T is the time constant and τ is the dead time.

The process model is a nonlinear and represented by using several parameters given below in table I.

TABLE I. MODEL PARAMETERS

Channel	K_m(process gain)	T(time in min.)	τ(dead time)
L-x_D	12.8	16.7	1
F-x_D	3.8	14.9	8.1

IV. INTERNAL MODEL CONTROL FOR DISTILLATION COLUMN

We know that distillation method is a nonlinear process, hence there is a need of model based control such as internal model control, which can take account of the process nonlinearities by changing the process model according to the operating point [7].

We have done MATLAB programming and found out control variable (reflux flow 'L') response, output variable response (top product 'X_D'), output response with disturbance and output response using only disturbance and how to reject the disturbance.

The first condition i.e. when model is perfect and no disturbance effect on the process is shown in figure below. Figure (4) indicates the controller output also known as manipulated variable response (Reflux flow L).

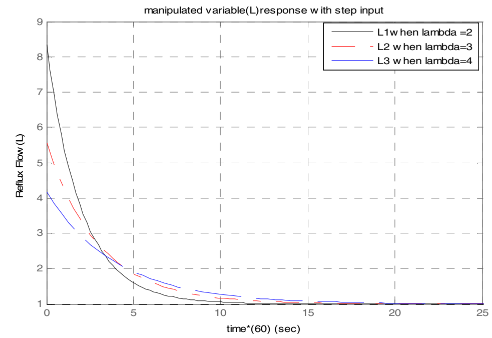

Figure4. Manipulated Variable Response (reflux ratio L).

Fig (4) shows the controller output for different tuning parameter λ. As λ increases, the manipulated variable response decreases. So we need a proper range of λ for better operation.

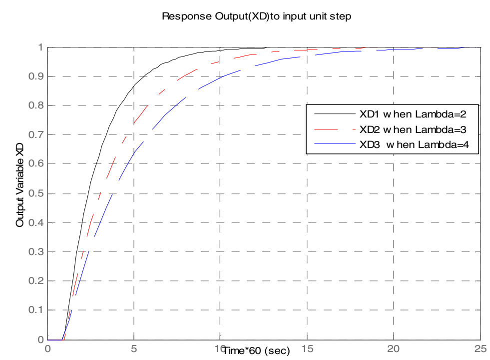

Figure5. Output Variable Response (top product X_D).

Fig (5) shows the process output (top product X_D) for different tuning parameter λ. Above result shows that with increase in the value of λ, the set point tracking increases and we find accurate result after a long time, but for small value of λ the transient and saturation time decreases and better set point tracking is achieved. For small values of λ the speed of response increases.

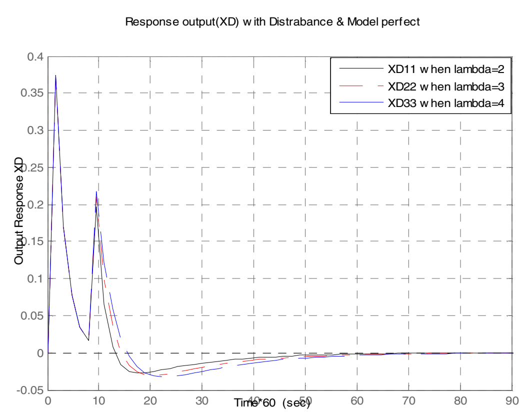

Figure6. Output Variable Response with disturbance (top product X_D).

Fig (6) shows the result when model is perfect and disturbance is affecting the process. It indicates that when the value of λ increases, peak overshoot and settling time also increases. For small value of λ, spike is small compare to larger values.

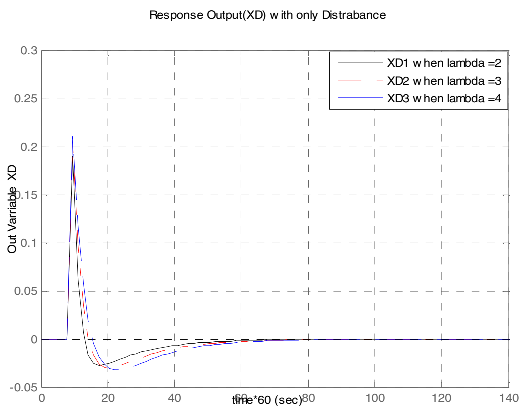

Figure7. Output Variable Response with only disturbance (top product X_D)

Fig (7) shows the result by considering only disturbance which is affecting the process. Using simple filter f(s) = $\frac{1}{(1+\lambda s)^n}$ and different tuning parameter λ we have tried to remove the disturbance and find the value of λ so that disturbance is easily removed from the process.

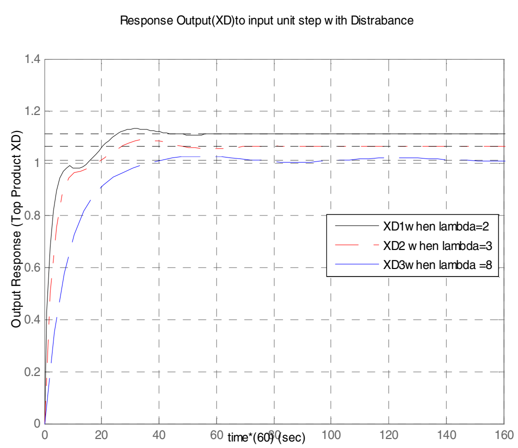

Figure8. Output Variable Response Disturbance Rejection (top productXD)

Fig (8) shows the output variable response. It indicates the rejection of disturbance after introducing the filter with different tuning parameter (λ). The different type of a filter for designing this model controller is given below:

$$f(s) = \frac{\Upsilon s + 1}{(1+\lambda s)^n}$$

$$\text{Where } \Upsilon = \frac{33.4\lambda - \lambda^2}{16.7} \qquad (9)$$

It shows that the disturbance rejection has taken place when λ=8 min. With decrease in λ, the distortion is taking place in control output (X_D) and offset is increased.

V. Conclusion

This paper deals with a solution for controlling a binary distillation column. We have used IMC controller for controlling only top product (x_D) and with the help of above method we can also design the IMC for bottom product (X_B). We are taking single input single output (SISO) process by considering only top product.

The internal model control structure is widely used in tuning and implementation because of its simplicity. This work has been done considering only the tuning parameter, also called as time constant (λ), by taking constant controller gain. The speed of response and the transient response both increases for small value of λ, and hence transient time decreases. When we use new design of filter (7), disturbance rejection happens with increase of λ.

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