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Dynamic Response of Tray to Tray Temperature to Sudden Changes in Reflux Flow Rate in a Binary Distillation Column

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Abstract: - This paper focusses on the strategic steps in the design, operation and response of tray to tray temperature in a binary distillation column to changes in the reflux flow rate. The temperature profile of a distillation column is an important parameter in the determination of the column performance. A model for the tray dynamics in distillation column is developed and used to determine the temperature profile of a binary distillation column that have been subjected to sudden changes in reflux flow rate. These equations were forward tested and the results obtained were compared with those from literature and was discovered that the percentage error ranges from 0–10.Thus, thebinary distillation column equations presented in this paper for the response of tray to tray temperature due to sudden changes in reflux flow rate can be used to predict the tray to tray temperature in multi-component distillation column that result from sudden changes in the reflux flow rate in such column. Hence, the developed model is suitable for the prediction of tray to tray temperature changes in any distillation column due to changes in reflux flow rate.

Keywords: - *binary, distillation, reflux, temperature, transfer function*

I. INTRODUCTION

Distillation is probably the most widely used separation process in the chemical and allied industries [1]. It is applicable in almost all separation of liquid mixtures into their various components such as rectification of alcohols, which has been practiced since antiquity and fractionation of crude oil. In processing industries, the demand for purer products coupled with the need for greater efficiency has encouraged continuous research into the principles and techniques governing the operation of the distillation unit [1].

The operation of the distillation column is governed by the principles of mass and energy balances in separating liquid mixtures into various components using their bubble point as a major criterion in determining the purity of separation [2]. The temperature profile of a distillation column may deviate from that of the designed temperature profile either by alteration in feed composition, reboiler flow rate or reflux flow rate. When these changes occur it is expected that the temperature profile (i.e. tray to tray temperature) of the column changes also. In this paper, we shall concentrate on the disturbance of reflux flow rate and its effect on tray to tray temperature in the binary distillation column.

The temperature profile of a distillation column is a measure of performance of the column [3], a means for monitoring these changes in tray to tray temperature is essential. Furthermore, for petroleum refinery (multi-component) column operation where side streams are withdrawn at a particular tray temperature, a monitoring of tray to tray temperature may enable (without leading necessarily to a shut-down of the column) the operator determine which trays now hold the new temperature (due to sudden change in reflux flow rate) from which side streams can be withdrawn [4], [5]. When such sudden change occurs (and remains constant for a while), the dynamics of operation of the column changes too. In this paper, we will track these changes in the dynamics of tray to tray temperature using the principles of mass and energy balance, and Taylor series expansion in linearizing non-linear terms.

Distillation columns are designed with a larger range in capacity than any other type of processing equipment with, single column 0.3-10m in diameter and a height of about 3-75m [6]. Designers and process control operators are aimed at achieving the desired product quality at minimum cost and also to provide constant purity of product even though there may be varieties in feed composition (especially in crude oils) and alteration in reboiler and reflux flow rate [7]. A distillation unit is normally considered with its associated control systems and it is often operated in association with several other separate units.

The operations of a distillation column is governed by the principles of mass and energy balances in the separation of liquid mixtures into various components using their bubble point as a major parameter in the separation process [8]. The temperature profile of the distillation column is an important parameter in the determination of the column performance; therefore a means for monitoring and controlling the temperature profile is very essential [9]. However, the temperature profile of a distillation column may vary from that of the designed temperature profile either by modification and/or disturbance(s) in feed composition, reboiler flow rate and/or reflux flow rate [10]. When these sudden changes occur, it is expected that the temperature profile (tray to tray temperature) of the column changes also. In this paper, we shall consider the disturbance of reflux flow rate (only), and its effect on tray to tray temperature in the binary distillation column.

This paper shows the strategic steps in the design, operation and response of a binary distillation column to changes in the reflux flow rate. The column comprises of 25 trays or plates, a reflux drum, a condenser and a reboiler. The thirteenth tray is considered as the feed tray. In such distillation column, when there is sudden change in reflux flow rate its results in a change in tray to tray temperature, then, the methods proposed in this paper may be used for quick estimate of the tray temperature, so as to determine the new tray to which side stream can be withdrawn. Therefore, binary distillation column equations presented here for the response of tray to tray temperature due to sudden changes in reflux flow rate can be used to predict the tray to tray temperature in multi-component distillation column that result from sudden changes in the reflux flow rate in such column.

II. MODEL DEVELOPMENT

In this paper, a mathematical model for the dynamic response of tray to tray temperature to sudden changes in reflux flow rate in a binary distillation column is developed and perturbations equations are analysed.

Let us consider the Fig. 1 to develop a mathematical model to describe the dynamics of a single tray in the distillation column.

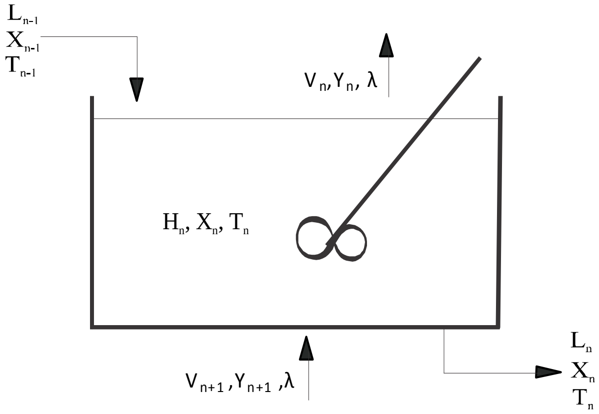

Fig. 1: A continuously stirred tank heater as a tray in the column

Where

H_n = volume of liquid hold-up in moles in tray n
L_{n-1} = the molar flow rate of liquid in to tray n from tray n-1.
X_{n-1} = mole fraction of the more volatile components in L_{n-1}
T_{n-1} = temperature of liquid L_{n-1}
V_n = molar flow rate of vapour exiting tray n
Y_n = mole fraction of the more volatile component in V_n
λ = latent heat of vaporization
L_n = molar flow rate of liquid out of tray n
X_n = mole fraction of the more volatile components in L_n
T_n= temperature of liquid L_n
V_{n+1} = molar flow rate of vapour in to tray n from tray n+1
Y_{n+1} = mole fraction of the more volatile component in V_{n+1}

2.1 MODEL ASSUMPTIONS

Some basic assumptions are considered to simplify the mathematical model of the dynamic response of the tray to tray temperature in a binary distillation column as follow:

1. Liquid hold-up in each plate is constant. Regardless of whether sudden changes occur, the rate at which liquid enters the tray will be the same as the rate at which liquid leaves the tray. Thus ensuring that liquid hold-up is constant.
2. Total pressure and temperature are uniform throughout the entire binary distillation column.
3. The binary distillation column is perfectly insulated. This is to ensure that there is no heat loss or gain between the column and its surroundings, thus enabling the distillation column operate adiabatically.
4. The feed is introduced as a saturated liquid. If the volume of liquid in the reboiler changes as a result of sudden changes in the reflux flow rate, it is expected that the controller action on the reboiler would responds fast enough so as to the supply of the heat necessary to cause the number of moles of vapour travelling from the stripping section to the rectifying section to remain constant from tray to tray. Thus, Equimolar overflow and Equimolar vaporization.
5. Hold-up of vapour in any tray in the binary distillation column is relatively small compared to liquid hold-up, and thus can be neglected.
6. Vapour bubbles through the liquid hold-up on each tray at a rate that is fast enough to enhance thorough agitation of the liquid hold-up. As a result, each tray together with its hold-up may be considered as a continuously stirred tank heater in which heat is supplied by the vapour releasing its heat of condensation to the liquid hold-up, and into which liquid flows in and out at the same rate.
7. All heats of solution are negligible.

2.2 MODEL DEVELOPMENT

The unsteady state energy balance consideration yields:

$$L_{n-1}X_{n-1}T_{n-1}C_p + V_{n+1}Y_{n+1}\lambda - L_{n-1}X_nT_nC_p - V_nY_n\lambda = \frac{d}{dt}H_nX_nT_nC_p \quad (1)$$

Based on equimolar vaporization and equimolar overflow, equation 1 can be written as:

$$L_{n-1}X_{n-1}T_{n-1}C_p + V\lambda(Y_{n+1}+Y_n) - L_{n-1}X_nT_nC_p = \frac{d}{dt}H_nX_nT_nC_p \quad (2)$$

The steady state energy balance equation is then:

$$\overline{L}_{n-1}\overline{X}_{n-1}\overline{T}_{n-1}C_p + V\lambda(Y_{n+1}+Y_n) - \overline{L}_{n-1}\overline{X}_n\overline{T}_nC_p = 0 \quad (3)$$

It is important to note that non-linear terms $L_{n-1}X_{n-1}T_{n-1}$, $L_{n-1}X_nT_n$ appear in equation2. Using a Taylor series expansion to linearize these non-linear terms yields the following two expressions after neglecting terms of higher powers:

$$L_{n-1}X_{n-1}T_{n-1} = \overline{L}_{n-1}\overline{X}_{n-1}\overline{T}_{n-1} + \overline{L}_{n-1}\overline{X}_{n-1}(T_{n-1}-\overline{T}_{n-1}) + \overline{L}_{n-1}\overline{T}_{n-1}(X_{n-1}-\overline{X}_{n-1}) + \overline{T}_{n-1}\overline{X}_{n-1}(L_{n-1}-\overline{L}_{n-1}) \quad (4)$$

A similar linearization gives,

$$L_{n-1}X_nT_n = \overline{L}_{n-1}\overline{X}_n\overline{T}_n + \overline{L}_{n-1}\overline{X}_n(T_n-\overline{T}_n) + \overline{L}_{n-1}\overline{T}_n(X_n-\overline{X}_n) + \overline{T}_n\overline{X}_n(L_{n-1}-\overline{L}_{n-1}) \quad (5)$$

Substituting equations 4 and 5 into 2, dividing through by C_p and subtracting the steady state energy balance equation yields the following linearized unsteady state energy balance equation:

$$\overline{X}_{n-1}\overline{T}_{n-1}L_{n-1} + \overline{L}_{n-1}\overline{T}_{n-1}X_{n-1} + \overline{L}_{n-1}\overline{X}_{n-1}T_{n-1} - 3\overline{X}_{n-1}\overline{T}_{n-1}\overline{L}_{n-1} - \overline{X}_n\overline{T}_nL_{n-1} - \overline{L}_{n-1}\overline{X}_nT_n - \overline{T}_n\overline{L}_{n-1}X_n + 3\overline{X}_n\overline{T}_n\overline{L}_{n-1} = \overline{H}n\frac{d}{dt}X_nT_n \quad (6)$$

Introducing the perturbation variables

$$L_{n-1} = \overline{L}_{n-1} + \Delta L_{n-1} \quad (i)$$
$$X_{n-1} = \overline{X}_{n-1} + \Delta X_{n-1} \quad (ii)$$
$$T_{n-1} = \overline{T}_{n-1} + \Delta T_n \quad (iii)$$
$$X_n = \overline{X}_n + \Delta X_n \quad (iv)$$
$$T_n = \overline{T}_n + \Delta T_n \quad (v)$$

into the linearized unsteady state energy balance equation yields the equation of perturbations

$$\overline{X}_{n-1}\overline{T}_{n-1}\Delta L_{n-1} + \overline{L}_{n-1}\overline{X}_{n-1}\Delta T_{n-1} + \overline{T}_{n-1}\overline{L}_{n-1}\Delta X_{n-1} - \overline{X}_n\overline{T}_n\Delta L_{n-1} - \overline{L}_{n-1}\overline{X}_n\Delta T_n - \overline{T}_n\overline{L}_{n-1}\Delta X_n = \overline{H}_n\frac{d}{dt}(\overline{X}_n\Delta T_n + \overline{T}_n\Delta X_n) \quad (7)$$

The consequence that a change in reflux would have on composition is obtained by setting $\Delta T_n = 0$ in equation 7. Likewise the effect of a change in reflux on temperature is obtained by setting $\Delta X_n = 0$ in equation 7. In this way equation 7 is uncoupled so as to get two equations of perturbation:

$$\frac{\overline{H}_n}{\overline{L}_{n-1}}\frac{d}{dt}\Delta X_n + \Delta X_n = \frac{\overline{X}_{n-1}}{\overline{T}_n}\Delta T_{n-1} + \frac{\overline{T}_{n-1}}{\overline{T}_n}\Delta X_{n-1} + \frac{\overline{X}_{n-1}\overline{T}_{n-1}-\overline{X}_n\overline{T}_n}{\overline{L}_{n-1}\overline{X}_n}\Delta L_{n-1} \quad (8)$$

$$\frac{\overline{H}_n}{\overline{L}_{n-1}}\frac{d}{dt}\Delta T_n + \Delta T_n = \frac{\overline{X}_{n-1}}{\overline{X}_n}\Delta T_{n-1} + \frac{\overline{T}_{n-1}}{\overline{X}_n}\Delta X_{n-1} + \frac{\overline{X}_{n-1}\overline{T}_{n-1}-\overline{X}_n\overline{T}_n}{\overline{L}_{n-1}\overline{T}_n}\Delta L_{n-1} \quad (9)$$

Let $\tau = \frac{\overline{H}_n}{\overline{L}_{n-1}}$ defined the time constant for the consequence of change in reflux on temperature. This same time constant gives the consequence of change in reflux on composition. Thus, equations 8 and 9 can be written as:

$$\tau\frac{d}{dt}\Delta X_n + \Delta X_n = \frac{\overline{X}_{n-1}}{\overline{T}_n}\Delta T_{n-1} + \frac{\overline{T}_{n-1}}{\overline{T}_n}\Delta X_{n-1} + \frac{\overline{X}_{n-1}\overline{T}_{n-1}-\overline{X}_n\overline{T}_n}{\overline{L}_{n-1}\overline{T}_n}\Delta L_{n-1} \quad (10)$$

$$\tau\frac{d}{dt}\Delta T_n + \Delta T_n = \frac{\overline{X}_{n-1}}{\overline{X}_n}\Delta T_{n-1} + \frac{\overline{T}_{n-1}}{\overline{X}_n}\Delta X_{n-1} + \frac{\overline{X}_{n-1}\overline{T}_{n-1}-\overline{X}_n\overline{T}_n}{\overline{L}_{n-1}\overline{X}_n}\Delta L_{n-1} \quad (11)$$

2.3 SOLUTION TO PERTURBATION EQUATIONS

Equations 10 and 11 are the equations of perturbation that are solved using Laplace transformation to obtain transfer functions that relates changes in temperature and changes in composition to changes in reflux. Also, it is important to note that sudden changes in reflux do not have any effect on mole fraction and temperature of liquid hold-up in the reflux drum and consequently the reflux temperature remains constant and so does reflux composition. Therefore ΔT_0 and ΔX_0 are negligible. Furthermore, based on the assumptions that these sudden changes in reflux does not change with time, so that, $\Delta L_{n-1} = \Delta R$.

On tray n = 1, equation 10 yields:

$$\tau\frac{d}{dt}\Delta X_1 + \Delta X_1 = \left(\frac{\overline{X}_0\overline{T}_0-\overline{X}_1\overline{T}_1}{\overline{L}_0\overline{T}_1}\right)\Delta R$$

whose Laplace transformation yields the transfer function:

$$\frac{\Delta X_1(S)}{\Delta R(s)} = \left(\frac{\overline{X}_0\overline{T}_0-\overline{X}_1\overline{T}_1}{\overline{L}_0\overline{T}_1}\right)\frac{1}{\tau S+1} \quad (12)$$

Likewise substituting n = 1 into equation 11 yields:

$$\tau\frac{d}{dt}\Delta T_1 + \Delta T_1 = \left(\frac{\overline{X}_0\overline{T}_0-\overline{X}_1\overline{T}_1}{\overline{L}_0\overline{X}_1}\right)\Delta R$$

whose Laplace transformation yields:

$$\frac{\Delta T_1(S)}{\Delta R(s)} = \left(\frac{\overline{X}_0\overline{T}_0-\overline{X}_1\overline{T}_1}{\overline{L}_0\overline{X}_1}\right)\frac{1}{\tau S+1} \quad (13)$$

On tray 2, equation 10 yields:

$$\tau\frac{d}{dt}\Delta X_2 + \Delta X_2 = \frac{\overline{X}_1}{\overline{T}_2}\Delta T_1 + \frac{\overline{T}_1}{\overline{T}_2}\Delta X_1 + \frac{\overline{X}_1\overline{T}_1-\overline{X}_2\overline{T}_2}{\overline{L}_1\overline{T}_2}\Delta R$$

on Laplace transformation it yields:

$$\Delta X_2(S)(\tau S+1) = \frac{\overline{X}_1}{\overline{T}_2}\Delta T_1(S) + \frac{\overline{T}_1}{\overline{T}_2}\Delta X_1(S) + \frac{\overline{X}_1\overline{T}_1-\overline{X}_2\overline{T}_2}{\overline{L}_1\overline{T}_2}\Delta R(S) \quad (14)$$

Substituting equations 12 and 13 into 14 and simplifying gives:

$$\frac{\Delta X_2(S)}{\Delta R(S)} = \frac{\overline{X}_1\overline{T}_1-\overline{X}_2\overline{T}_2}{\overline{L}_1\overline{T}_2}\frac{1}{(\tau S+1)} + 2\left(\frac{\overline{X}_0\overline{T}_0-\overline{X}_1\overline{T}_1}{\overline{L}_0\overline{T}_2}\right)\frac{1}{(\tau S+1)^2} \quad (15)$$

Likewise putting n = 2 into equation 11 gives

$$\tau\frac{d}{dt}\Delta T_2 + \Delta T_2 = \frac{\overline{X}_1}{\overline{X}_2}\Delta T_1 + \frac{\overline{T}_1}{\overline{X}_2}\Delta X_1 + \frac{\overline{X}_1\overline{T}_1-\overline{X}_2\overline{T}_2}{\overline{L}_1\overline{X}_2}\Delta R$$

applying Laplace transform gives

$$(\tau S+1)\,\Delta T_2(S) = \frac{\overline{X}_1}{\overline{X}_2}\Delta T_1(S) + \frac{\overline{T}_1}{\overline{X}_2}\Delta X_1(S) + \frac{\overline{X}_1\overline{T}_1-\overline{X}_2\overline{T}_2}{\overline{L}_1\overline{X}_2}\Delta R(S) \quad (16)$$

Substituting equations 12 and 13 into 16 yields:

$$\frac{\Delta T_2(S)}{\Delta R(S)} = \frac{\overline{X}_1\overline{T}_1-\overline{X}_2\overline{T}_2}{\overline{L}_1\overline{X}_2}\frac{1}{(\tau S+1)} + 2\left(\frac{\overline{X}_0\overline{T}_0-\overline{X}_1\overline{T}_1}{\overline{L}_0\overline{X}_2}\right)\frac{1}{(\tau S+1)^2} \quad (17)$$

On tray 3, equation 10 yields:

$$\tau\frac{d}{dt}\Delta X_3 + \Delta X_3 = \frac{\overline{X}_2}{\overline{T}_3}\Delta T_2 + \frac{\overline{T}_2}{\overline{T}_3}\Delta X_2 + \frac{\overline{X}_2\overline{T}_2-\overline{X}_3\overline{T}_3}{\overline{L}_2\overline{T}_3}\Delta R$$

upon Laplace transform yields:

$$(\tau S+1)\,\Delta X_3(S) = \frac{\overline{X}_2}{\overline{T}_3}\Delta T_2(s) + \frac{\overline{T}_2}{\overline{T}_3}\Delta X_2(s) + \frac{\overline{X}_2\overline{T}_2-\overline{X}_3\overline{T}_3}{\overline{L}_2\overline{T}_3}\Delta R(s) \quad (18)$$

Substituting equations 15 and 17 into 18 and simplifying gives:

$$\frac{\Delta X_3(S)}{\Delta R(S)} = \left(\frac{\overline{X}_2\overline{T}_2-\overline{X}_3\overline{T}_3}{\overline{L}_2\overline{T}_3}\right)\frac{1}{\tau S+1} + 2\left(\frac{\overline{X}_1\overline{T}_1-\overline{X}_2\overline{T}_2}{\overline{L}_1\overline{T}_3}\right)\frac{1}{(\tau S+1)^2} + 4\left(\frac{\overline{X}_0\overline{T}_0-\overline{X}_1\overline{T}_1}{\overline{L}_0\overline{T}_3}\right)\frac{1}{(\tau S+1)^3} \quad (19)$$

Also on tray 3, equation 11 yields:

$$\tau\frac{d}{dt}\Delta T_3 + \Delta T_3 = \frac{\overline{X}_2}{\overline{X}_3}\Delta T_2 + \frac{\overline{T}_2}{\overline{X}_3}\Delta X_2 + \frac{\overline{X}_2\overline{T}_2-\overline{X}_3\overline{T}_3}{\overline{L}_2\overline{X}_3}\Delta R$$

upon Laplace transform yields:

$$(\tau S+1)\,\Delta T_3(s) = \frac{\overline{X}_2}{\overline{X}_3}\Delta T_2(s) + \frac{\overline{T}_2}{\overline{X}_3}\Delta X_2(s) + \frac{\overline{X}_2\overline{T}_2-\overline{X}_3\overline{T}_3}{\overline{L}_2\overline{X}_3}\Delta R(s) \quad (20)$$

Substituting equations 15 and 17 into 20 and simplifying gives:

$$\frac{\Delta T_3(S)}{\Delta R(S)} = \left(\frac{\overline{X}_2\overline{T}_2-\overline{X}_3\overline{T}_3}{\overline{L}_2\overline{X}_3}\right)\frac{1}{\tau S+1} + 2\left(\frac{\overline{X}_1\overline{T}_1-\overline{X}_2\overline{T}_2}{\overline{L}_1\overline{X}_3}\right)\frac{1}{(\tau S+1)^2} + 4\left(\frac{\overline{X}_0\overline{T}_0-\overline{X}_1\overline{T}_1}{\overline{L}_0\overline{X}_3}\right)\frac{1}{(\tau S+1)^3} \quad (21)$$

In like manner $\Delta X_4(S)$, $\Delta T_4(S)$, $\Delta X_5(S)$, and $\Delta T_5(S)$ are solved to yield the following four equations:

$$\frac{\Delta X_4(S)}{\Delta R(S)} = \left(\frac{\overline{X}_3\overline{T}_3-\overline{X}_4\overline{T}_4}{\overline{L}_3\overline{T}_4}\right)\frac{1}{\tau S+1} + 2\left(\frac{\overline{X}_2\overline{T}_2-\overline{X}_3\overline{T}_3}{\overline{L}_2\overline{T}_4}\right)\frac{1}{(\tau S+1)^2} + 4\left(\frac{\overline{X}_1\overline{T}_1-\overline{X}_2\overline{T}_2}{\overline{L}_1\overline{T}_4}\right)\frac{1}{(\tau S+1)^3} + 8\left(\frac{\overline{X}_0\overline{T}_0-\overline{X}_1\overline{T}_1}{\overline{L}_1\overline{T}_4}\right)\frac{1}{(\tau S+1)^4} \quad (22)$$

$$\frac{\Delta T_4(S)}{\Delta R(S)} = \left(\frac{\bar{X}_3\bar{T}_3-\bar{X}_4\bar{T}_4}{\bar{L}_3\bar{X}_4}\right)\frac{1}{\tau S+1} + 2\left(\frac{\bar{X}_2\bar{T}_2-\bar{X}_3\bar{T}_3}{\bar{L}_2\bar{X}_4}\right)\frac{1}{(\tau S+1)^2} + 4\left(\frac{\bar{X}_1\bar{T}_1-\bar{X}_2\bar{T}_2}{\bar{L}_1\bar{X}_4}\right)\frac{1}{(\tau S+1)^3} + 8\left(\frac{\bar{X}_0\bar{T}_0-\bar{X}_1\bar{T}_1}{\bar{L}_1\bar{X}_4}\right)\frac{1}{(\tau S+1)^4} \quad (23)$$

$$\frac{\Delta X_5(S)}{\Delta R(S)} = \left(\frac{\bar{X}_4\bar{T}_4-\bar{X}_5\bar{T}_5}{\bar{L}_4\bar{T}_5}\right)\frac{1}{\tau S+1} + 2\left(\frac{\bar{X}_3\bar{T}_3-\bar{X}_4\bar{T}_4}{\bar{L}_2\bar{T}_5}\right)\frac{1}{(\tau S+1)^2} + 4\left(\frac{\bar{X}_2\bar{T}_2-\bar{X}_3\bar{T}_3}{\bar{L}_2\bar{T}_5}\right)\frac{1}{(\tau S+1)^3} + 8\left(\frac{\bar{X}_1\bar{T}_1-\bar{X}_2\bar{T}_2}{\bar{L}_1\bar{T}_5}\right)\frac{1}{(\tau S+1)^4} + 16\left(\frac{\bar{X}_0\bar{T}_0-\bar{X}_1\bar{T}_1}{\bar{L}_0\bar{T}_5}\right)\frac{1}{(\tau S+1)^5} \quad (24)$$

$$\frac{\Delta T_5(S)}{\Delta R(S)} = \left(\frac{\bar{X}_4\bar{T}_4-\bar{X}_5\bar{T}_5}{\bar{L}_4\bar{X}_5}\right)\frac{1}{\tau S+1} + 2\left(\frac{\bar{X}_3\bar{T}_3-\bar{X}_4\bar{T}_4}{\bar{L}_2\bar{X}_5}\right)\frac{1}{(\tau S+1)^2} + 4\left(\frac{\bar{X}_2\bar{T}_2-\bar{X}_3\bar{T}_3}{\bar{L}_2\bar{X}_5}\right)\frac{1}{(\tau S+1)^3} + 8\left(\frac{\bar{X}_1\bar{T}_1-\bar{X}_2\bar{T}_2}{\bar{L}_1\bar{X}_5}\right)\frac{1}{(\tau S+1)^4} + 16\left(\frac{\bar{X}_0\bar{T}_0-\bar{X}_1\bar{T}_1}{\bar{L}_0\bar{X}_5}\right)\frac{1}{(\tau S+1)^5} \quad (25)$$

In order to calculate the temperature changes, these S-space transfer functions for the changes in temperature as a consequence of reflux changes (only) are transformed to real time space using inverse Laplace transform.

III. RESULTS AND DISCUSSION

The transfer functions were transformed to real time space equations and the solution for the tray to tray temperature changes of the distillation column are calculated.The real time equations obtained are used in conjunction with data obtained from [14], to predict the tray by tray temperatures for the distillation column due to sudden changes in reflux from 40.5 lbmol /100 lbmol of feed to 33.5 lbmol /100 lbmol. Thus, the S-space transfer functions that were obtained in the previous section are converted into real time space using the inverse Laplace transformation techniques, assuming that transient effects due to a change in reflux have arrived at a new steady state; we let t → ∞ in real time space solution. The results are presented and discussed in following figures.

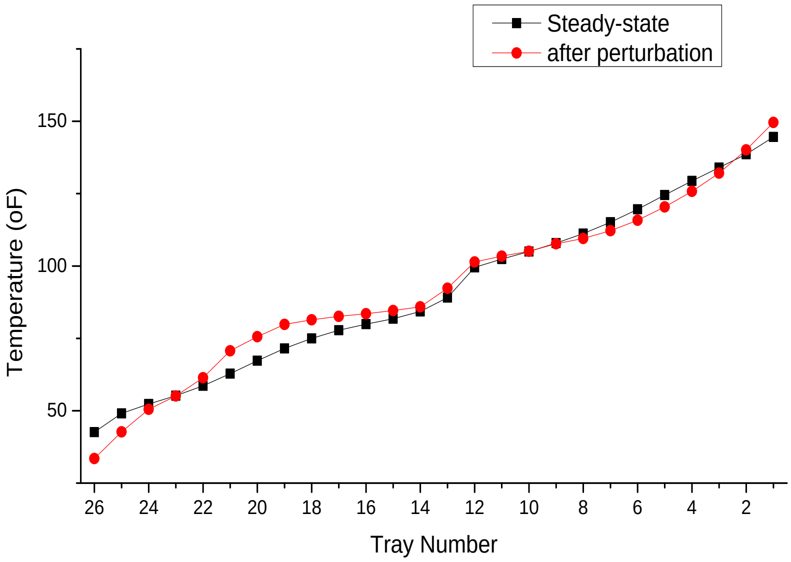

Fig. 2: Tray to tray temperature profile down the column

Fig. 2 shows the tray to tray dynamic temperature profile down the column to a sudden change in reflux flow rate. The steady-state temperature profile of the column increases at uniform rate from top to bottom. The sudden change of reflux flow rate from 40 lbmol/100 lbmol to 33.5 lbmol/100 lbmol introduced a perturbation to the temperature profile. As such, the sudden decrease in temperature below the steady-state temperature in the top three trays was observed, this may be as a result of the introduction of a colder reflux temperature into the column. The temperature then increases in the seventh tray above the steady-state temperatures until the feed tray where its falls back to the steady-state temperature. This temperature profile of the distillation column is an important parameter in the determination of the column performance; therefore a means for monitoring and controlling the temperature profile is very essential.

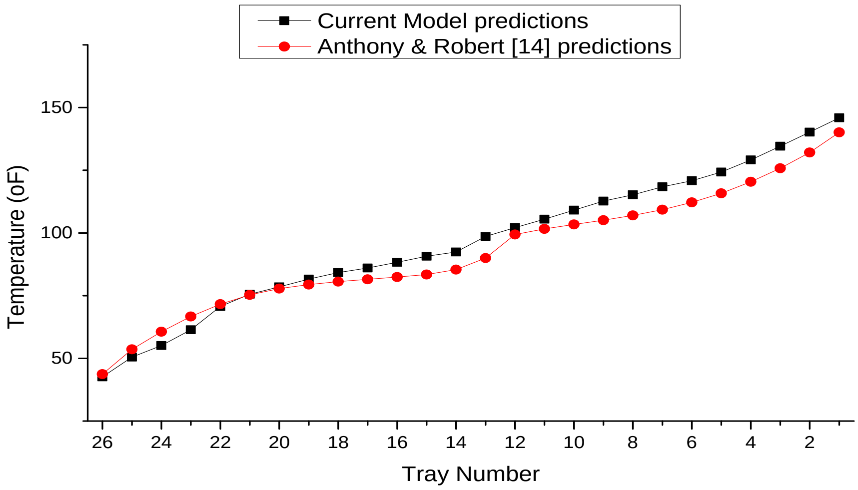

Fig. 3: Tray to tray temperature profile down the column

Fig. 3 shows a comparison of the predicted results of the current model with those predicted by Anthony & Robert [14] for the same operating conditions. Both predictions were similar, although the current model predicted lower temperatures for the first four trays and slightly higher temperatures down the column. This tray to tray dynamic temperature response is essential for the prediction of side stream to which new temperature of the required range now falls.

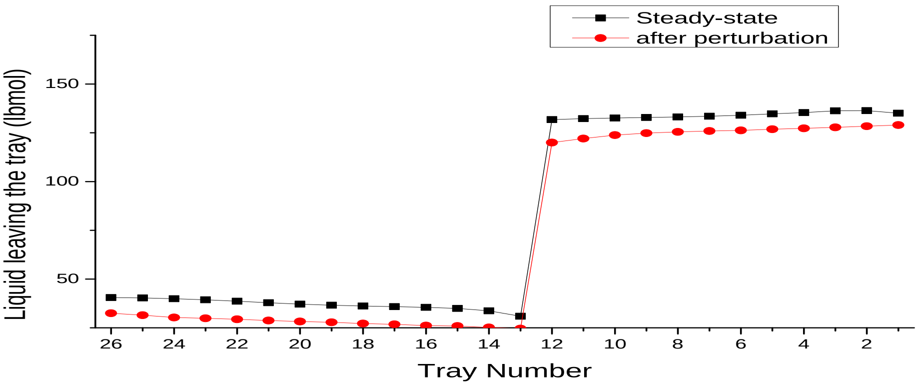

Fig. 4: Liquid hold-up from tray to tray down the column

Fig. 4 shows the level of liquid in the column from tray to tray. The liquid hold-up is lower above the feed tray and rises rapidly above at the feed tray showing the introduction of more liquid into the column. The level of liquid at steady-state is higher compared with the one after perturbation because of the reduction in the reflux. Hence, the current model shows high percentage reliability and applicability for the prediction of tray to tray temperature changes in a distillation column due to changes in reflux flow rate.

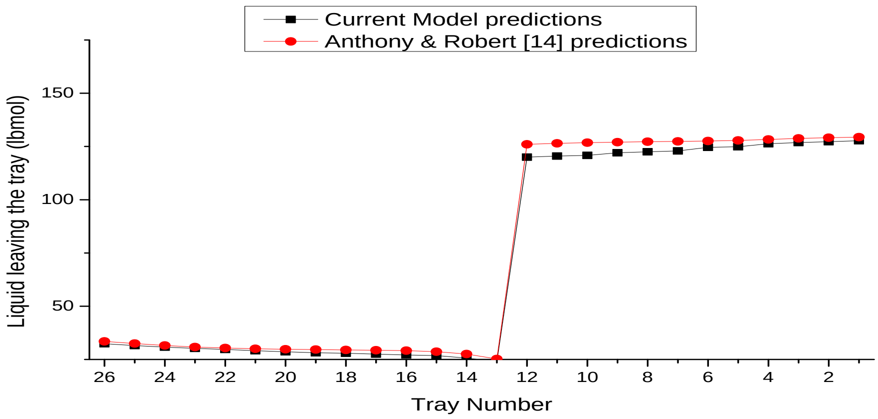

Fig. 5: Liquid hold-up from tray to tray down the column

Fig. 5 shows the liquid hold-up predictions down the column after perturbation comparing those of Anthony & Robert [14] and the current model. The liquid hold-up is lower above the feed tray and rises rapidly above at the feed tray showing the introduction of more liquid into the column. Similar observations were shown in both cases with lesser liquid-hold predicted by the current model. Hence, the current model shows high percentage reliability and applicability for the prediction of tray to tray temperature changes in a distillation column due to changes in reflux flow rate.

IV. CONCLUSION

This paper becomes applicable when quick estimates for changes in temperature due to sudden change in reflux flow rate are required for a distillation column, then it is recommended that the method discussed in this paper can be used since the errors predicted in this paper falls within the users allowable tolerances (0% - 10%). Thus, this paper may be relevant in multi-component distillation column operations were side streams are withdrawn from trays that are at particular temperature. In such distillation column, a sudden change in reflux flow rate causes a change in tray to tray temperature, then the methods proposed in this paper may be used for quick estimate of the tray temperature, so as to determine the new tray to which side stream can be withdrawn. Therefore, binary distillation column equations presented in this paper for the response of tray to tray temperature due to sudden changes in reflux flow rate can be used to predict the tray to tray temperature in multi-component distillation column that result from sudden changes in the reflux flow rate in such column.

V. REFERENCES

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