Developing Empirical Model & Investigating Relation Between Design Characteristics Of Continuous Distillation (CASCADE) For Methanol-Water System

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Abstract—Developing model equation, consider binary mixture of methanol-water system and using a continuous distillation (Stage wise operation - cascade), various assumption data are number of stages including reboiler are 5. Feed plate is 3rd from top. Efficiency Of each stage: 100%. Various runs are operated between various parameters and tabulated data. And model has been developed in the form of empirical equation. Heat duty and condenser duty along with rectification section and stripping section are reported in tabulation data. A changing reflux ratio with respect to internal reflux ratio for rectification and stripping section; Result has been concluded for achievement of energy saving goal because of heat duty.

Keywords--Cascade, Empirical Model, Reboiler Duty, Rectification, Reflux ratio, stripping.

I. INTRODUCTION

There are various methods of liquid-liquid separations employed in industries. Distillation is one of the important one; though it involve the considerable amount of thermal (heat) energy consumption. In pharmaceutical industry, the costly ingredient from its solvent mixture & other components is required to separate; that is to purify. As purification is required to 100% also, disposal of waste solvent is an environment problem. Distillation operation is preferred over other. Also, as the prices of the utilities-fuel oil (for heating or steam generation) and electrical energy (for running the equipment’s in the distillation operation) are increasing rapidly, their quantities should be minimized or optimized in order to economize the operation.

Distillation is generally carried out using packed column or plate column. Packed column is frequently competitive in cost.

McCabe Thiele method is used to design the distillation equipment. In this method, we assume the constant molar overflow and L/V ratio is equated with R/(R+1) ratio. The numbers of ideal stages are calculated assuming 100% efficiency.

An actual efficiency & stages are calculated by applying practical correction to ideal situation. This efficiency can be further improved through the addition of inter-boilers and intermediate condensers.

Binary systems with extreme purity are analyzed by Smoker. All efficiencies are term into a single factor as Murphree efficiency.

II. MATERIAL AND METHODS

A.R. Grade chemicals and Brocil make glassware are used for investigation. McCabe Thiele method and Lewis Sorel method is used.

Assumptions/Data

Number of stages including reboiler are 5.

Feed plate is 3rd from top. Feed at bubble point. Efficiency of each stage: 100%.

Molar flow rates of Vapour & Liquid in Rectification as well as in Stripping section are equal.

\[ \text{i.e. } L_1 = L_2 \text{ & } V_1 = V_2 \text{ in Rectifying Section and } L_3 = L_4, \]
\[ V_3 = V_4 = V_{reb} \text{ in Stripping Section.} \]
III. Calculation Of Design Characteristics

To find out: Relation between External Reflux Ratio ($n$), Internal Reflux Ratio in Rectification ($L/V_n$), & in stripping section ($L/V_m$), Condensate duty ($Q_c$) and Reboiler duty ($Q_R$). (Model Equation)

i.e. $f$ (External R.R, Internal R.R, reboiler duty & condensate duty) = 0

Assumptions/Data

Number of stages including rebuilder are 5.

Feed plate is 3rd from top.

Efficiency Of each stage: 100%. Feed at bubble point.

Mc be Thiele method and Lewis Sorel method is used.

Molar flow rates of Vapor & Liquid in Rectification as well as in Stripping section are equal.

i.e. $L_1=L_2$ & $V_1=V_2$ in Rectifying Sec.

& $L_3=L_4$, $V_3=V_4=V_{reb}$ in Stripping Section

Internal reflux ratio in rectification section means $L_{n}/V_{n+1}$

& internal reflux ration in Stripping section means $L_{m}/V_{m+1}$

IV. Observation Table

Table 1

<table>
<thead>
<tr>
<th>STAGE</th>
<th>$X_r$</th>
<th>F</th>
<th>D</th>
<th>B</th>
<th>R</th>
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<td>1.3</td>
</tr>
<tr>
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<td>0.3</td>
<td>1</td>
<td>0.2143</td>
<td>0.7857</td>
<td>1.3</td>
</tr>
<tr>
<td>5</td>
<td>0.3</td>
<td>1</td>
<td>0.2143</td>
<td>0.7857</td>
<td>1.3</td>
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<td>1.5</td>
</tr>
</tbody>
</table>

Fig 1. Schematic Diagram for Experimental Setup
Model Equation

Relation between External Reflux Ratio (n), Internal Reflux Ratio in Rectification (L/V)_R, Internal Reflux Ratio in stripping section (L/V)_S, Condensate duty (Q_c) & Reboiler duty (Q_R).

\[ f(n, (L/V)_R, (L/V)_S, Q_c, Q_R) = 0 \]

\[ f(X_1, X_2, X_3, X_4) = 0 \]
Table 3

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Reflux ratio (n)</th>
<th>Internal Reflux ratio in Rect. Sec. (L/V)R</th>
<th>Internal Reflux ratio in Strip. Sec. (L/V)s</th>
<th>Reboiler Load KJ/hr per Kg mole of Feed (Q_R)</th>
<th>Condenser Load KJ/hr per Kg mole of Feed (Q_C)</th>
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<tbody>
<tr>
<td>1</td>
<td>1.3</td>
<td>0.565</td>
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<td>52633.114</td>
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<td>2</td>
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<td>0.600</td>
<td>2.467</td>
<td>54299.211</td>
<td>19994.19</td>
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<td>3</td>
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<td>0.643</td>
<td>2.309</td>
<td>56732.801</td>
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<td>0.667</td>
<td>2.222</td>
<td>58342.012</td>
<td>23993.028</td>
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<td>5</td>
<td>2.5</td>
<td>0.714</td>
<td>2.048</td>
<td>62361.512</td>
<td>27991.866</td>
</tr>
</tbody>
</table>

Model Equation

\[ X_1 = f(X_2, X_3, X_6) \]

\[ X_1 = -3.53345 -4.06203* X_2 + 0.176069* X_3 + 19.10034 * X_6 \]

(Regression coefficient: 0.999973)

OR-

\[ n = -3.53345 -4.06203*(L/V)_R + 0.176069* (L/V)_S + 19.10034 * (Q_C/Q_R) \]

Table 4

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Reflux ratio (n)</th>
<th>Condenser duty(Q_C) KJ/hr</th>
<th>Reboiler duty (Q_R) KJ/hr</th>
<th>Internal Reflux Ratio in Rectification Section Av.(L/V)_R</th>
<th>Internal Reflux Ratio in Stripping Section Av.(L/V)_s</th>
<th>Heat Duties Q_C/Q_R</th>
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<tr>
<td>1</td>
<td>1.3</td>
<td>2564.81</td>
<td>2256.12</td>
<td>0.363</td>
<td>2.92</td>
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<td>1.5</td>
<td>2722.83</td>
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<td>0.397</td>
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<td>1.8</td>
<td>2945.21</td>
<td>2604.85</td>
<td>0.432</td>
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<td>3083.49</td>
<td>2753.08</td>
<td>0.460</td>
<td>2.65</td>
<td>1.1200</td>
</tr>
</tbody>
</table>

V. CONCLUSIONS

A table show design characteristics data for various reflux ratios n = 1.3, 1.5, 1.8, 2.0 quantities for Condensate Duty (Q_C), Reboiler duty, Internal Reflux Ratio in Rectification and Stripping Section can be calculated and Results are tabulated as under:

Table 5

REFERENCES

[1] Jia Xiao-Ping, a.b Wang Fang a Xiang Shu-Guang a Han Fang Yu a Minimum energy consumption process synthesis for energy saving 2008


