UNIVERSITI PUTRA MALAYSIA

COMPOSITION CONTROL OF THE CSTC PACKED-TYPE BINARY DISTILLATION COLUMN.

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BY

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LIST OF SYMBOLS AND ABBREVIATIONS

Latin Symbols

$\underline{A}$, $\underline{B}$	State dependent matrix of a system model
B	Bottom product flow rate
C	Cost function
D	Distillate rate except in Chapter 4
$\underline{D}$	Feedback matrix in On-line Riccati Control
F	Feed rate
H	Normalised molar capacitance p.u. length
H_a, H_b	Accumulator and reboiler holdups
h'	Distance along column measured from feed and end points
h	Normalised distance
$\underline{J}$	Disturbance matrix
k_r ,k_s	Coefficient of cross-flow p.u. length in rectifier and stripper (=k)
K, K_c	Proportional gain, c denotes critical value
L_r, L_s, l	Flow rates of liquid in rectifier and stripper and small changes therein
L	Dimensionless normalised column length of a section of the tower (=L'k/V)
L'_1 , L'_2	Lengths of entire rectifier and stripper (=L' where identical)
L'	Identical length of rectifier and stripper
$\underline{P}$	Solution of Riccati equation

$R\ (=\lambda)$	Cost weighting factor
S, S_r	Separation (=Y-X') and its reference value
S_e	Separation in the column operated in thermodynamic equilibrium ($=Y_e-X'_e$) and is fictitious
$S_e(1)$	Separation that would exist between vapour in equilibrium with the accumulator liquid and liquid in equilibrium with reboiler vapour ($=Y_e(1)$ - and is also fictitious.
T	Normalised time constant of the end vessels
T_n	Base time (=H/k)
T	Time
u	Control input signal ($=(v+l)/V=2v/V$)
u'	Control input signal (in Chapter 6, $=V_s(t)$).
$V_r\ (=V)$, V_s	Molar flows of vapour in rectifier and stripper
V	Small changes in V_r and V_s about means $\overline{V}_r\ (=V)$, $\overline{V}_s$
W	Bottom product rate
X, (X')	Liquid compositions in rectifier (stripper)
X_e, (X'_e)	Composition of liquid in equilibrium with vapour in rectifier (stripper)
x, (x')	Small changes in X, (X')
Y, (Y')	Vapour compositions in rectifier (stripper)
Y_e, (X'_e)	Composition of vapour in equilibrium with liquid in rectifier (stripper)
y, (y')	Small changes in Y, (Y')
z	Feed vapour composition
Z	Feed liquid composition
DU,DX	$=V_s(t)$, Composition with small changes x.

Greek Symbols

α (α^{-1})	Slope of piecewise linear approximation of equilibrium curve in stripper (rectifier) section
β	Relative volatility of mixture to be separated
ε	$= \alpha - 1$

Subscript

C	Critical value
E	Equilibrium value
L	Liquid
R	Variables associated with the rectifier
Ref	Reference value
S	Variables associated with the stripper
Sref	Reference value of the variables associated with stripper
V	Vapour
r	Reference value.

Abbreviations

CSTC	Continuous Stirred Tank Column
CSTR	Continuous Stirred Tank Reactor
DE	Differential Equation
PID	Proportional-Integral-Derivative Control

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COMPOSITION CONTROL OF THE CSTC BINARY DISTILLATION COLUMN

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January 1999

Chairman: Dr. Samsul Bahari Mohd Noor

Faculty: Engineering

The economic performance of most processes and certainly their safety and operability depend to a large extend on how well they are controlled. That is why finding control means for the complicated Binary Distillation Column process has been attracting the efforts of many researchers and scientists interested in modeling, simulating and designing controls for the process.

The CSTC binary distillation column in the form of six DE's has been studied. Simulations have been carried out to validate the model. Further testing on the Open Loop and Closed-Loop was done. The model was formulated in the matrix form and converted to the error coordinate form in order to apply the On-line Riccati control method, which has been successfully implemented and found to be very satisfactory.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains.

KANDUNGAN KAWALAN DI DALAM CSTC "BINARY DISTILLATION" LAJUR

Oleh

ASAAD ABDALLAH YOUSUF MALIK

Januari 1999

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Perlakuan ekonomi kebanyakan proces dan tentu sekali keselamatan dan kebolehkendalian bergantung secara amnya terhadap bagaimana proces tersebut dikawal. Yang demikian, mencari kaedah-kaedah pengawalan untuk proces Turus Penyulingan Binari yang rumit telah menarik usaha dari penyelidik-penyelidik dan saintis yang berminat dalam permodelan, penyelakuan dan merekabentuk kawalan-kawalan untuk proces-proces berkenaan.

Turus Penyulingan Binari CSTC dalam bentuk enam persamaan kebezaan telah dikaji. Penyelakuan-penyelakuan telah dijalankan untuk mengesahkan model tersebut. Pengujian lanjutan pada gelung-buka dan gelung tertutup telah dilakukan. Model-model telah dirumuskan dalam bentuk matriks dan ditukarkan ke bentuk kordinat ralat dalam merangka untuk menggunakan kaedah Kawalan Riccati Dalam Talian yang telah dilaksanakan dengan berjayanya dan didapati amat memuaskan.

CHAPTER I

INTRODUCTION

Computer has been used as an essential tool in many control applications, especially in simulation, after modeling, of processes that have complicated and different set of parameters.

Distillation is a method of separating miscible components of a solution that have different boiling points. The fundamental principle underlying distillation is that vapour created by boiling a mixture is richer in the more volatile component. Distillation systems can be run in either batch or continuous mode. A batch is charged to the reboiler and the more volatile component is boiled away. Combining many of these batch distillations into a column causes the enrichment process to occur continuously in stages, thus producing a better separation possible than obtained just by a single batch distillation stage. We call the ratio of the condensate returned to the column over that removed from the column the reflux ratio.

The maximum separation is obtained when all the liquid from the condenser is returned to the column. When no product is drawn off this is called total reflux. Taking off some of the reflux as a product reduces the degree of separation obtained.

Distillation process is important in many industries and applications especially in product separation. The process was very complicated even when it is reduced to its minimal representation because of its nonlinearity, spatial distribution and unusual dynamics that can cause enormous apparent differences in the behaviour of the process under different operating conditions and under only slight design change that is why it attracts the efforts of many researchers seeking for control means for the process.

A distillation never occurred at equilibrium; i.e. equilibrium between the vapour and the liquid phase is never obtained, although it is approached. Even working within limits of minimal order of complexity there remains a considerable choice of options as regards the type of system to be modeled, the modeling method and exactly where to make the idealizations of the process in order that analytical progress can be made.

Edwards (1979) derived a lumped-parameter model, for the packed type distillation column, from the differential equations describing the variation of liquid and vapour compositions within distillation column separating binary mixtures.

The distillation process remains the most important separation method in chemical and petroleum industry. It ranges from a single column, separating ideal binary mixtures, to complex, multi-staged columns separating multi-component mixtures.

Various studies on the design, steady-state behaviour as well as dynamic characteristics of distillation columns have been carried out. At the same time, studies on modeling, simulation and control have also been progressing.

All studies on distillation columns aim at improving the process so that it can be run effectively and efficiently i.e. to yield better quality product with a lower energy consumption. In achieving this there are always conflict between chemical engineers and control engineers in such a way that, the former have been trying to include every details of the process in order to get a better representation of the process, whilst the later tend to simplify and generalize the model and use various control strategy to overcome any discrepancies between the model developed and the real process.

Previous researchers considered columns of both the packed and tray varieties and studied their similarities and differences. There are five main components in the distillation column, namely, the reboiler, stripper, rectifier, condenser and accumulator. Each component plays an important role in the process. Figure 2 shows packed distillation column, figure 3 shows tray type whilst figure 1 shows the basic distillation column.

This research concentrates on the packed type distillation column, formulating the equations that describe the system behaviour, based on splitting the column into six hypothetical sections. These six sections are the rectifying vapour section, the rectifying liquid section, the stripping vapour section, the stripping liquid section, the reboiler and the accumulator.

The main objectives of this research are:

(1) To rearrange the CSTC model proposed by Edwards and Mohd Noor (1995(a)) in a six-equation form in such a way that it can be simulated using MATLAB (a powerful simulation package).

(2) Run simulation tests on the composition model, which are very important as model validation before control design attempt can be done.

(3) Finally application of an appropriate control method onto the model.

General outlines of this thesis are:

(1) The packed type binary distillation column, objective and general outlines of this thesis are focussed in Chapter 1.

(2) The distillation process, basic distillation column, modeling and computer simulation are focussed in Chapter 2.

(3) Modeling and formulation the DE's (Differential Equations) of the process is focussed in Chapter 3.

(4) Simulation of the obtained equations that represent the system, as a step of system realization, for validation of the process is focussed in Chapter 4.

(5) Application of the linear proportional control technique to the process, simulating and obtaining results is focussed in Chapter 5.

(6) Application of the Riccati control technique to the process and comparing it with the mentioned linear proportional control technique is focussed in Chapter 6.

(7) Conclusions and suggestions for future work are presented in Chapter 7.

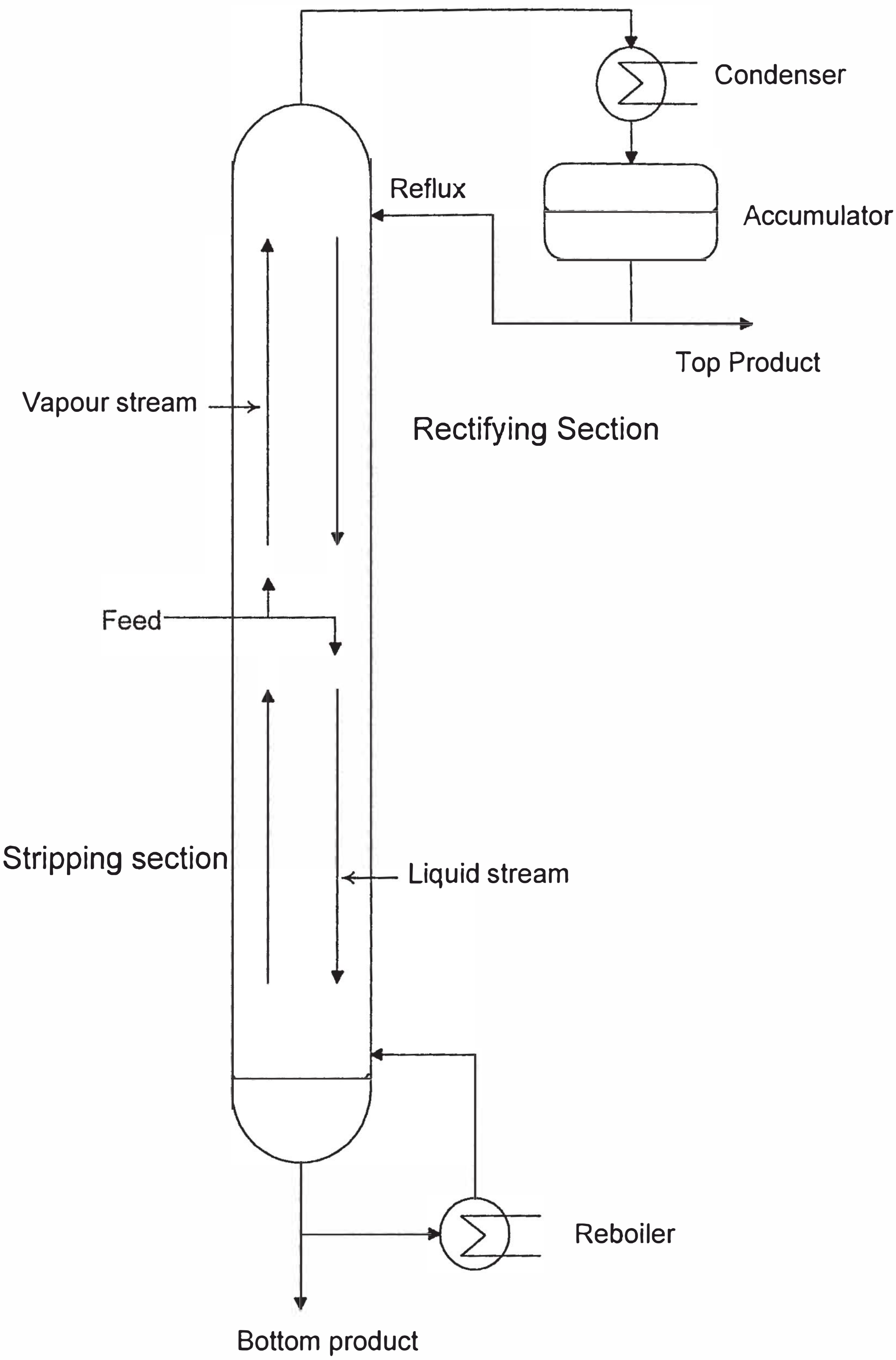

Figure 1: Basic Distillation Column

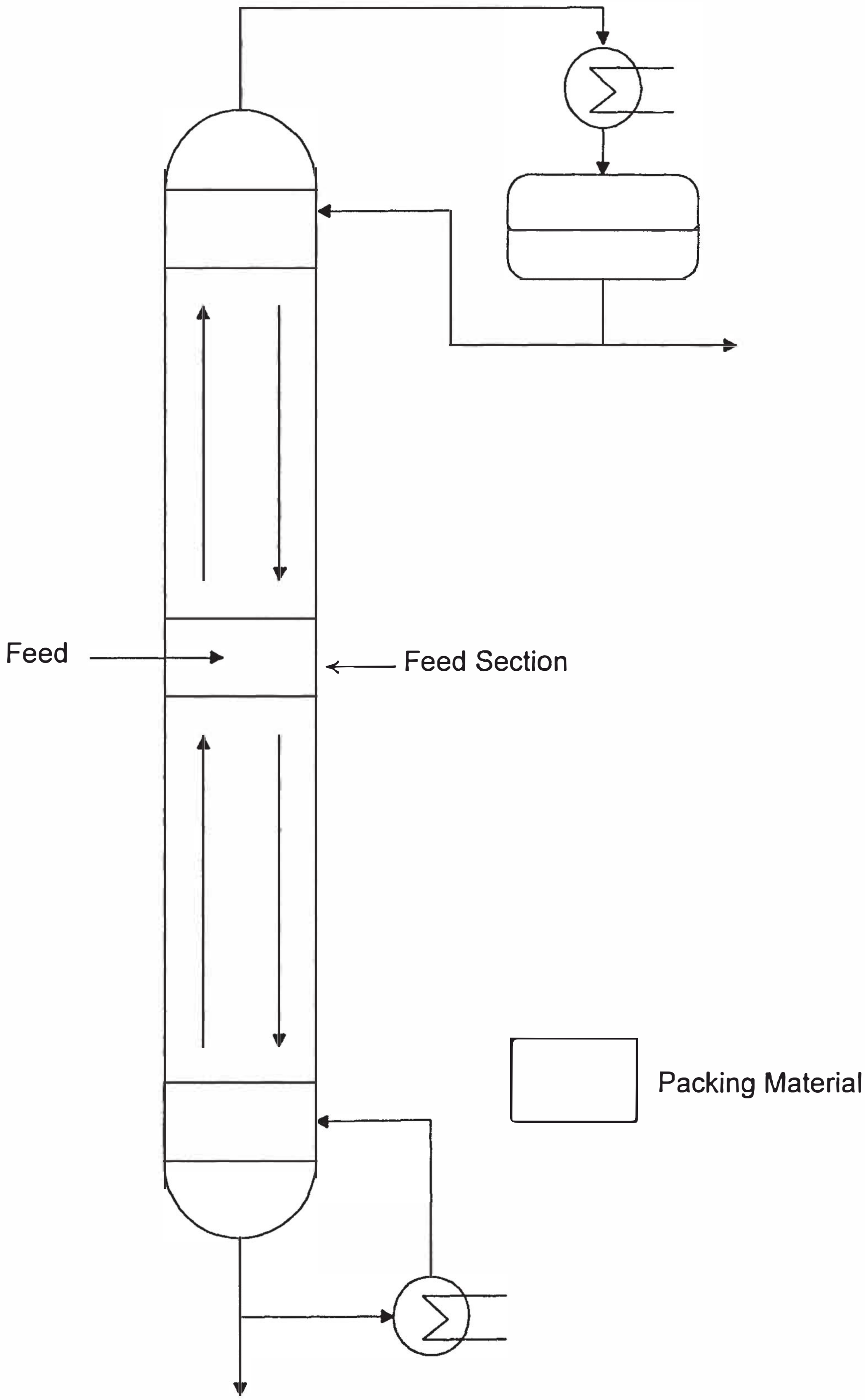

Figure 2: Packed Distillation Column

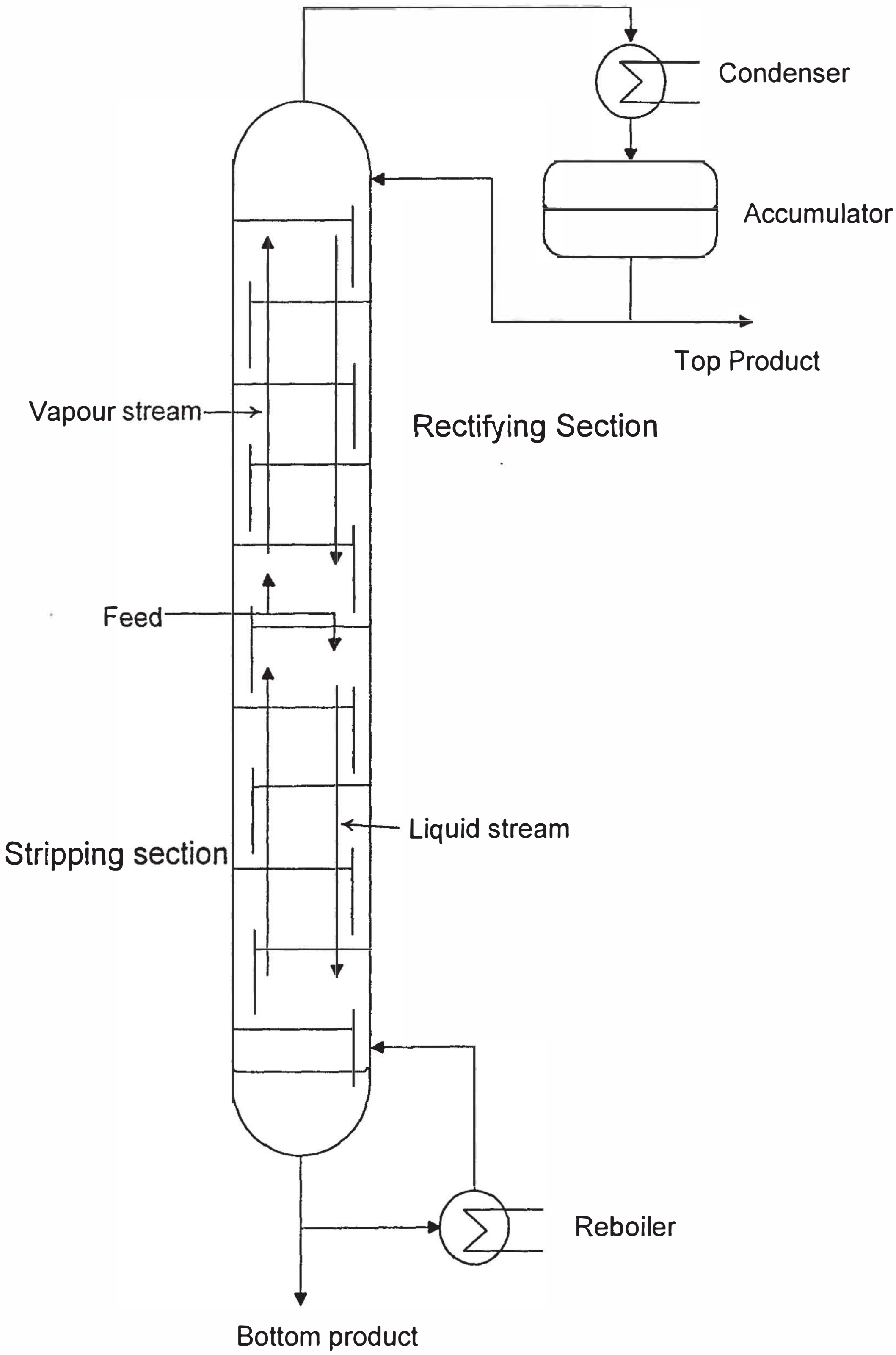

Figure 3: Tray-Type Distillation Column

CHAPTER II

LITERATURE REVIEW

Distillation

Distillation is a highly interacting multivariable process; successful application of controls requires a detailed analysis of loop interaction using models. It has received more attention from control engineers, both academic and industrial. It is very common in chemical plants and petroleum refineries. It is used for the final stages of purification where products are most valuable and quality specifications most rigid. But it is also most difficult to control owing to long dead times and time lags.

Distillation is also difficult to understand, leading many theoreticians and practitioners to come to different conclusion as to how it should be controlled. But this controversy is partly due to its many faces. The severity of interaction depends on many factors, and a control system that works well on one separation may be unsatisfactory on another. Response to disturbance is also quite variable from one column to another, so that there is no general solution to distillation-column control. Yet there are general principals, which if followed, will lead to successful control systems.

Basic Distillation Column

Different substances have different molecular sizes and hence different volatility. This then leads to different boiling points. Evaporation occurs from a given liquid under a given pressure of surroundings at a rate that increases with temperature. This is due to the increase with temperature of the so-called saturation vapour pressure (SVP) of the liquid.

The behaviour of the mixture is quite complicated and merits a somewhat deeper examination for present purpose: In the case of a binary mixture, for instance, having components 1 and 2, the more volatile being say component 1 then at a given temperature, the SVP, P1 of pure component 1 will exceed P2 of component 2. However the actual vapour pressures exerted by the components 1 and 2 by a liquid mixture of mole-fraction X (of the light component) will be only XP1 and (1-X) P2 respectively according to Raoult's law of vapour pressure because of the dilution of each. Now, as regards the vapour above the liquid under pressure P, at the same temperature, then, according to Dalton's low, the partial pressures of each component vapour 1 and 2 will be YP and (1-Y) P, respectively if Y is the mole-fraction of component 1 in the vapour, assuming ideal vapours and the absence of other gases. Hence, for equilibrium between the liquid and vapour mixtures, it follows that, for each component, there must be a balance of SVP's of the liquids and the partial pressures of the vapours(Mohd Noor, 1996).

i.e.

$$YP = XP1 \tag{2.1}$$