

Title	Batch rectification optimum number of theoretical plates when operated with constant distillate concentration
Sub Title	
Author	Hibino, Shinichi
Publisher	慶應義塾大学藤原記念工学部
Publication year	1950
Jtitle	Proceedings of the Fujihara Memorial Faculty of Engineering Keio University Vol.3, No.10 (1950.) ,p.84(24)- 89(29)
JaLC DOI	
Abstract	For batch rectification of two component mixture which is operated with constant distillate concentration, the relation between the yield of the lighter component Y and the reflux ratio R is calculated for various values of number of the plates n and relative volatility α , initial charge composition and distillate composition being taken as 0.50 and 0.95 respectively throughout the calculation. From the results of this, the graph showing the relation between n and the distillation time, which is obtained by the graphical integration of the Y vs. R curve, is constructed. Using this graph, the optimum value of n and its optimum range are determined.
Notes	
Genre	Departmental Bulletin Paper
URL	https://koara.lib.keio.ac.jp/xoonips/modules/xoonips/detail.php?koara_id=KO50001004-00030010-0024

慶應義塾大学学術情報リポジトリ(KOARA)に掲載されているコンテンツの著作権は、それぞれの著作者、学会または出版社/発行者に帰属し、その権利は著作権法によって保護されています。引用にあたっては、著作権法を遵守してご利用ください。

The copyrights of content available on the Keio Associated Repository of Academic resources (KOARA) belong to the respective authors, academic societies, or publishers/issuers, and these rights are protected by the Japanese Copyright Act. When quoting the content, please follow the Japanese copyright act.

Batch Rectification

Optimum Number of Theoretical Plates When Operated with Constant Distillate Concentration

(Received May 30, 1952)

Shinichi HIBINO*

Abstract

For batch rectification of two component mixture which is operated with constant distillate concentration, the relation between the yield of the lighter component Y and the reflux ratio R is calculated for various values of number of the plates n and relative volatility α , initial charge composition and distillate composition being taken as 0.50 and 0.95 respectively throughout the calculation. From the results of this, the graph showing the relation between n and the distillation time, which is obtained by the graphical integration of the Y vs. R curve, is constructed. Using this graph, the optimum value of n and its optimum range are determined.

I. Introduction

Batch rectification becomes important in small scale industrial applications, but since it is essentially an unsteady operation, its calculations are more involved compared with a continuous rectification. For this reason, useful studies for design purpose on batch rectification are rather meager.

There can be considered two distinct operations in batch rectification. One is the operation with constant reflux ratio, and another is with constant overhead product concentration. In the former case the distillate concentration changes with time and in the latter the reflux ratio must be increased continuously to maintain constant distillate concentration. For both cases, it is desirable to have some method of estimating the number of theoretical plates and reflux ratio to be used to obtain some specific degree of separation. On the batch rectification of two component mixture with constant reflux ratio, A. Rose¹⁾ and his collaborators have studied extensively and determined the optimum value of the number of theoretical plates and reflux ratio to give the standard separation (i. e., the separation in which the first 40% distillate has average concentration of more than 95%) as a function of the relative volatility. In the case of constant overhead product concentration, J. C. Chu²⁾ has developed the calculation methods for various conditions, but he gave no numerical results. It is the purpose of this paper to give some numerical results for this case to aid in selecting the number of theoretical plates and reflux ratio range.

II. Method of calculation of yield

In the following, only two component mixture is considered. The mixture is assumed to be ideal, and its equilibrium line is represented by

* Assistant Professor at Keio University

1) Ind. Eng. Chem., 33, 594 (1941)

2) Chem. Eng. Progress, 46, 215 (1950)

$$y = \frac{\alpha x}{1 + (\alpha - 1)} \quad (1)$$

where x : mole fraction of lighter component in liquid
 y : mole fraction of lighter component in vapor
 α : relative volatility

If hold-up is neglected, the following material balances hold at any time t in the course of the operation.

$$F = L + D \quad (2)$$

$$Fx_f = Lx_B + Dx_D \quad (3)$$

where F : initial charge, mole
 L : quantity of liquid remaining in the still, mole
 D : quantity of liquid distilled over, mole
 x_f, x_B, x_D : mole fraction of lighter component in charge, still and distillate, respectively

If the reflux ratio at any time is R , the equation of the operating line is

$$y = \frac{R}{R + 1} x + \frac{x_D}{R + 1} \quad (4)$$

In Eqns. (2), (3) and (4), L, D, R and x_B change with time, while F, x_f and x_D are constant.

Since the yield of the lighter component Y is

$$Y = \frac{Dx_D}{Fx_f} \quad (5)$$

we obtain

$$Y = \frac{x_D}{x_f} \frac{x_B - x_f}{x_B - x_D} \quad (6)$$

using (2) and (3).

x_B is calculated using Smoker's³⁾ equation in the form

$$x_B = x_k + \frac{x_D - x_k}{[1 - N] \left(\frac{\alpha}{rc^2} \right)^n + N} \quad (7)$$

where x_k : x coordinate of the intersection of the equilibrium line (1) and operating line (4)

$$r = R / (R + 1)$$

$$c = 1 + (\alpha - 1) x_k$$

n : equivalent number of the theoretical plates

$$N = \left[\frac{rc(\alpha - 1)}{\alpha - rc^2} \right] (x_D - x_k)$$

Using (6) and (7), we can obtain the relation between R and Y for the fixed values of x_D, x_f, α and n .

3) Trans. Amer. Inst. Chem. Engrs., 34, 165 (1938)

Calculations to obtain this relation were made for various values of α and n . x_D and x_f are taken as constant at 0.95 and 0.50 respectively throughout the calculation. As an example, the results when $\alpha = 1.5$ is shown in Fig. 1.

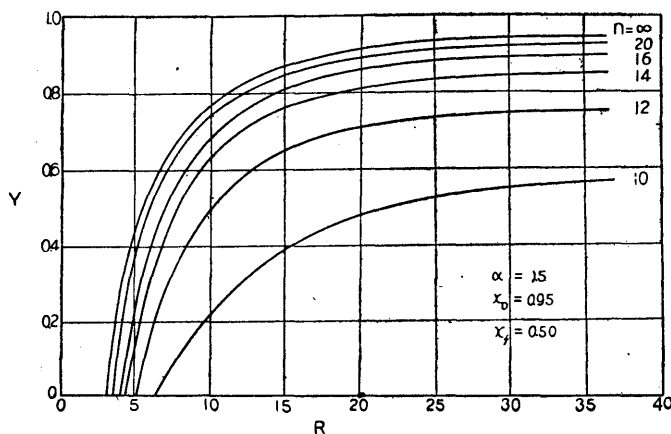


Fig. 1. Relation Between Y and R

III. Distillation time

In the case of constant reflux ratio, the calculation of distillation time is simple. But in the case of constant x_D , the distillation time must be obtained by integration since reflux ratio must be changed with time.

If we assume constant vapor rate V [mole/hr], the material balance in the differential time interval dt [hr] is,

$$Vdt = (R + 1) dD \quad (8)$$

On the other hand, from (5)

$$dY = \frac{x_D}{Fx_f} dD \quad (9)$$

Combining (8) and (9), we obtain

$$dt = \frac{Fx_f}{Vx_D} (R + 1) dY \quad (10)$$

Integrating

$$\theta = \frac{x_f}{x_D} \left[\int_0^Y R dY + Y \right] \quad (11)$$

where

$$\theta = \frac{V}{F} t \quad (12)$$

Hence, if we have the relation between R and Y , the distillation time can be calculated by graphical integration. The curve, showing the relation between reflux ratio and distillation time thus obtained, indicates how to change reflux ratio with time

to maintain constant x_D .

Fig. 2 shows such a relation of θ and R which is calculated by graphical integration of R vs. Y curve in Fig. 1.

IV. Minimum value of n and θ .

If we calculate the value of the yield when $R = \infty$ for a fixed value of n and α , this is the upper limit of the yield that is obtainable with those n and α . Therefore, to obtain a definite yield, there exists a lower limit of n to be used. On the other hand, when the rectifying column with $n = \infty$ is used, the distillation time to obtain a specified value of Y is minimum.

The calculations in both extreme cases are rather simple, and minimum values of n and θ (denoted by n_{min} and θ_{min}) to obtain a specified yield are tabulated in Table 1.

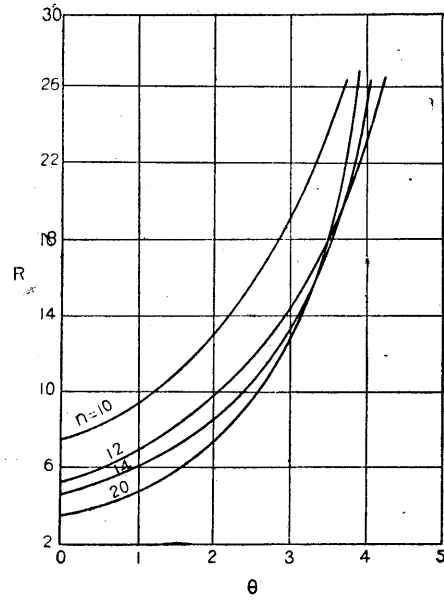


Fig. 2. Relation Between R and θ

Table 1. Values of n_{min} and θ_{min}

$\alpha \backslash Y$		n_{min}				θ_{min}			
		0.7	0.8	0.9	0.95	0.7	0.8	0.9	0.95
2.0	2.0	6.0	6.5	7.6	8.6	1.25	1.54	1.97	2.35
1.5	1.5	10.1	11.1	12.8	14.5	2.13	2.67	3.48	4.40
1.25	1.25	18.3	20.2	23.2	26.0	3.88	4.88	6.66	8.16
1.1	1.1	43.2	47.5	54.5	61.	9.4	11.9	15.7	—
1.05	1.05	84.	92.	106.	121.	18.6	23.4	31.1	—

In practice, somewhat larger value of n than n_{min} must be used and consequently some what larger value of θ than θ_{min} is required.

V. Optimum value of n

As known from the inspection of Fig. 1, to obtain a specified value of Y , any value of n larger than n_{min} may be used, but as n increases, both initial reflux ratio and cutting reflux ratio decrease and hence distillation time decreases. This relation between n and θ is calculated for various values of Y and α and the graph when $Y = 0.9$ is represented in Fig. 3. They resemble equilateral hyperbola with $n = n_{min}$ and $\theta = \theta_{min}$ as asymptotes. It is clear from this figure that, in the range of the curve near the asymptote $n = n_{min}$, θ increases strongly with decrease

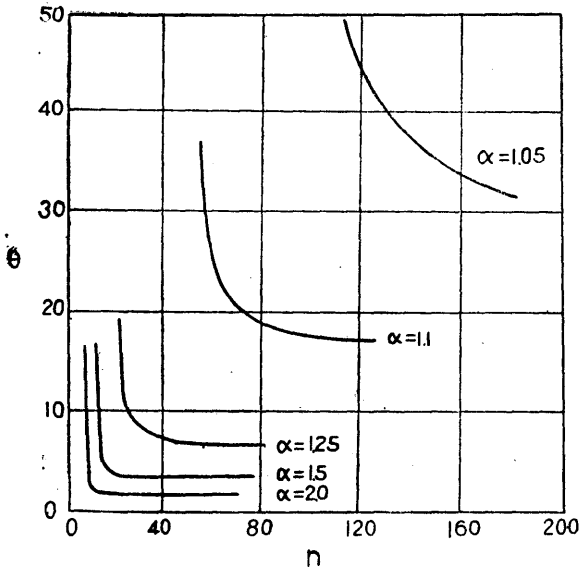
Fig. 3. Relation between θ and n to obtain 90% yield

Table 2. Optimum number of theoretical plates

$\alpha \backslash Y$	0.7	0.8	0.9	0.95
2.0	7.5	8.5	9.5	10.5
1.5	14.	15.	16.	18.
1.25	25.	27.	29.	31.
1.1	56.	63.	69.	(74.)
1.05	115.	123.	134.	(145.)
C	2.43	2.61	2.85	3.1

figures in () are obtained using Eqn. (13)

$$n_{opt} = \frac{C}{\log_{10}\alpha} \quad (13)$$

The values of C are also given in Table 2.

The upper and lower limits of the optimum range of n (denoted by n' and n'') and corresponding values of θ (θ' and θ'') are determined here in somewhat arbitrary way by the following expressions.

$$\left. \begin{aligned} n' &= n_{opt} - a_1 \\ n'' &= n_{opt} + a_2 \\ \theta' &= \theta_{min} + d_1 \\ \theta'' &= \theta_{min} + d_2 \end{aligned} \right\} \quad (14)$$

The values of a_1 , a_2 , d_1 , d_2 are independent of the value of Y and listed in Table 3.

in n and that near the asymptote $\theta = \theta_{min}$, shortening in distillation time is little even if we increase n considerably. Since large θ and n means high operating cost and high fixed charge respectively, the operation in these ranges of n is unpracticable. From these considerations, the existence of optimum range of n is obvious. The central value of this range n_{opt} is determined as the value of n at the intersection of each θ vs. n curve and the line drawn 45° to the n axis from the intersection of two asymptotes of that curve. n_{opt} and corresponding θ_{opt} for other values of Y are determined in the same way and tabulated in Table 2.

Since a plot of n_{opt} and $1/\log_{10}\alpha$ fits very closely on a straight line, the relation between n_{opt} and α for various values of Y can be expressed as

Table 3. Values of constants in Eqn. (14)

a	a_1	a_2	d_1	d_2
2.0	1	3	1.0	0.1
1.5	2	5	1.6	0.2
1.25	4	7	3.5	0.5
1.1	10	20	8.5	0.8
1.05	20	40	18.	1.5

Though the final selection of n must be decided by the economic balance in each specific case, the value of n to be used will probably lie within the optimum range here determined.