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McCabe-Thiele modifications

Batch reflux policies

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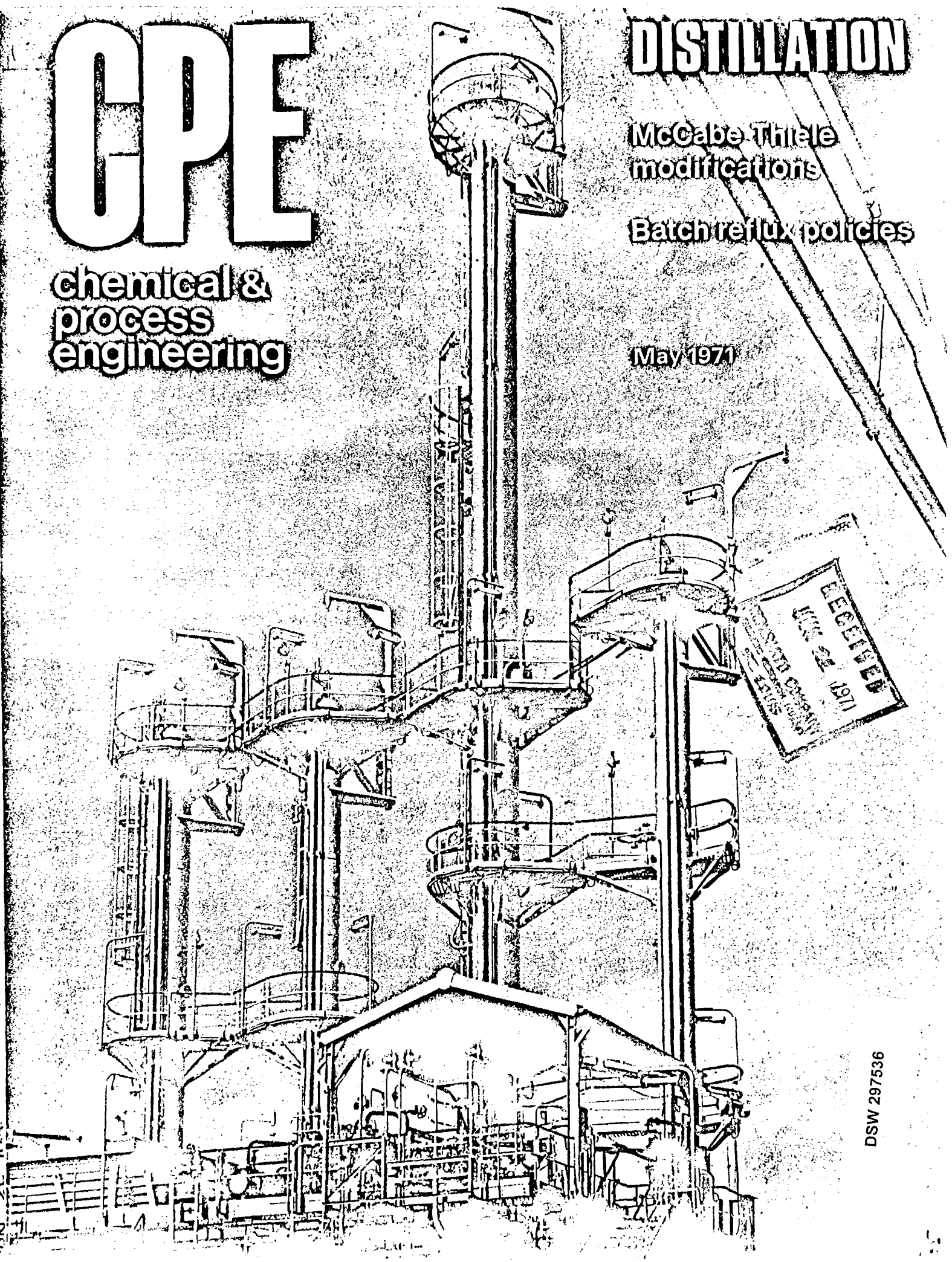

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Modified McCabe-Thiele Method

Ning Hsing Chen* Ph.D., M.S., B.Ch.E.

A new method for determining the number of theoretical plates required for a binary separation removes the restriction in the McCabe-Thiele method of equal latent heats of vaporisation. A feature of the method is that curved rather than straight operating lines are obtained. The equations used are simple, but the results obtained are accurate. Worked examples include those for open steam, multiple feeds and side streams.

ONE of the important assumptions in the McCabe-Thiele[11] method for determining the number of theoretical plates required in the separation of a binary mixture is that the components of the mixture must have equal latent heats of vaporisation. Under this condition, the vapour and the liquid flowrates within the column would be constant from plate to plate in both enriching and stripping sections. Then in the McCabe-Thiele diagram, the loci representing the enriching and stripping sections would be straight lines. However, in actual practice only a few mixtures have constant molal latent heats of vaporisation. For these mixtures, although the Ponchon-Savarit method[15,18] can be used, the lack of enthalpy-concentration diagram in many cases restricts its application. Another disadvantage is that this graphical method of calculation frequently needs large graph paper for the location of the distillate and residue delta points.

In order to take the varying latent heats of vaporisation in rectification into account, modification of the McCabe-Thiele method is necessary. During recent years, quite significant work has been done.[1,3–10,14,17]

In this article, the previous method described by the author[3] is reviewed and remodified, and is extended to the cases of open steam, multiple feeds and side streams. No enthalpy concentration diagram is needed, but instead, the latent heats of vaporisation at boiling points of the components are required. Those at other temperatures can be estimated by the Watson correlation[20] or by the Chen equation.[2] It is much easier to look up or estimate the latent heats of vaporisation than the enthalpy concentration diagram. As in the McCabe-Thiele diagram, the vapour/liquid equilibrium data should be known. The assumptions used in the derivation are:

(*a*) heat losses, heat of solution and sensible heats, which are small in comparison with the latent heat of vaporisation, are neglected;

(*b*) average values of the latent heat at the feed temperature and the distillate temperature are used for the enriching section, and the corresponding values for the stripping section; and

(*c*) consequently, the same average values of the ratios of the latent heats of the two components at these temperatures are used for the corresponding sections.

Enriching section

The balances around the envelope *1* in Fig. 1 are:

Total material $V_{n+1} = L_n + D$ .....(1)

More volatile component *A* $V_{n+1}y_{n+1} = L_n x_n + Dx_D$ ....(2)

Enthalpy $V_{n+1}H_{n+1} = L_n h_n + Dh_D^{en}$ ..(3)

where $h_D^{en} = h_D + (Q_c/D) + Q_{ln}/D)$

Eliminating V_{n+1}, L_n, D and rearranging gives

$$y_{n+1} = \frac{(h_D^{en} - H_{n+1})x_n + (H_{n+1} - h_n)x_D}{h_D^{en} - h_n} \quad .....(4)$$

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NOMENCLATURE

$\bar{C}_A$ = vapour specific heat of component *A*
$\bar{c}_A$ = liquid specific heat of component *A*
D = flowrate of distillate
F = flowrate of feed
f = fraction of vapour in feed
g = ratio of latent heats of less volatile to more volatile component (λ_B/λ_A)
H = vapour enthalpy
h = liquid enthalpy
L = flowrate of liquid overflow from one plate to the next
m = number of theoretical trays in stripping section
n = number of theoretical trays in enriching section
q = fraction of liquid in feed
R = reflux ratio L_o/D
S = boil-up ratio V_b/W
t = liquid temperature
T = vapour temperature
V = flowrate of vapour
W = flowrate of residue waste
x = mole fraction of more volatile component *A* in liquid
y = mole fraction of more volatile component *A* in vapour
z = mole fraction of more volatile component *A* in feed
λ = latent heat of vaporisation

Subscripts

A = component *A*
B = component *B* or reboiler
c = critical or condenser
D = distillate
F = feed
f = intersection of equilibrium curve and feed line
m = m^{th} plate
n = n^{th} plate
W = waste residue
A,D = component *A* and distillate
A,F = component *A* and feed
A,W = component *A* and waste
en = enriching
sp = stripping
os = open steam
mf = multiple feed
ss = side stream
lm = loss in stripping section
ln = loss in enriching section

Superscripts

en = enriching
sp = stripping
os = open steam
mf = multiple feed
ss = side stream

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The enthalpies of the vapour and liquid are expressed, respectively, as

$$H = [y\lambda_A + (1-y)\lambda_B] + [\bar{C}_A y + (1-y)\bar{C}_B](T - t_b) + H_m \quad \ldots\ldots\ldots(5)$$

$$h = [\bar{c}_A x + (1-x)\bar{c}_B](t - t_b) + h_m \quad \ldots\ldots\ldots(6)$$

Neglecting heat losses and sensible heats, an energy balance around a total condenser gives

$$h_D^{en} = Q_c/D = (R+1)[y\lambda_A + (1-y)\lambda_B] \quad \ldots\ldots\ldots(7)$$

Substituting Equation (7) into Equation (4) with the previous assumptions leads to

$$\frac{y_{n+1} - x_n}{x_D - x_n} = \frac{(1-g_{n+1})y_{n+1} + g_{n+1}\lambda_{A,n+1}}{(R+1)[(1-g_D)x_D + g_D]\lambda_{A,D}} \quad \ldots(8)$$

where g_{n+1} and g_D are the ratios of the latent heats of vaporisation of the less volatile component to that of the more volatile component at plate $n+1$ and in the distillate, respectively. Despite the variation of the latent heats of vaporisation of the two components from plate to plate, an arithmetic mean value of these ratios at feed temperature and distillate temperature will be used for the enriching section, and those at feed temperature and bottom temperature for the stripping section. Furthermore, by taking arithmetic mean values of latent heats of vaporisation at the feed temperature and the distillate temperature, Equation (8) can be simplified to

$$y_{n+1} = \frac{(\theta^{en} - g^{en})x_n + x_D g^{en}}{(x_D - x_n)(g^{en} - 1) + \theta^{en}} \quad \ldots\ldots\ldots(9)$$

where

$$\theta^{en} = (R+1)[(1-x_D)g^{en} + x_D][2\lambda_{A,D}/(\lambda_{A,F} + \lambda_{A,D})] \quad \ldots\ldots\ldots(10)$$

and

$$g^{en} = (g_D + g_F)/2$$

It is interesting to note that for equal molal latent heats of vaporisation, $g = 1$. Assuming latent heats constant from plate to plate, i.e. $\lambda_{A,F} = \lambda_{A,D}$, Equation (9) reduces to

$$y_{n+1} = (Rx_n + x_D)/(R+1) \quad \ldots\ldots\ldots(11)$$

which is the well-known operating equation in the enriching section used in the McCabe-Thiele method.

Stripping section

The balances around envelope *2* in Fig. 1 are

Total material $V_{m+1} = L_m - W$ .....(12)

More volatile component *A* $V_{m+1}y_{m+1} = L_m x_m - W x_W$ ..(13)

Enthalpy $V_{m+1}H_{m+1} = L_m h_m - W h_W^{sp}$ ..(14)

where $h_W^{sp} = h_W - (Q_B/W) - (Q_{lm}/W)$

Eliminating V_{m+1}, L_m, W and rearranging gives

$$y_{m+1} = \frac{(h_W^{sp} - H_{m+1})x_m + (H_{m+1} - h_m)x_W}{h_W^{sp} - h_m} \quad \ldots\ldots(15)$$

With the same assumptions used in the enriching section, for a total reboiler and average value of the latent heats of vaporisation at feed and bottom temperatures, Equation (15) is simplified to

$$y_{m+1} = \frac{(\theta^{sp} - g^{sp})x_m + x_W g^{sp}}{\theta^{sp} + (x_W - x_m)(g^{sp} - 1)} \quad \ldots\ldots\ldots(16)$$

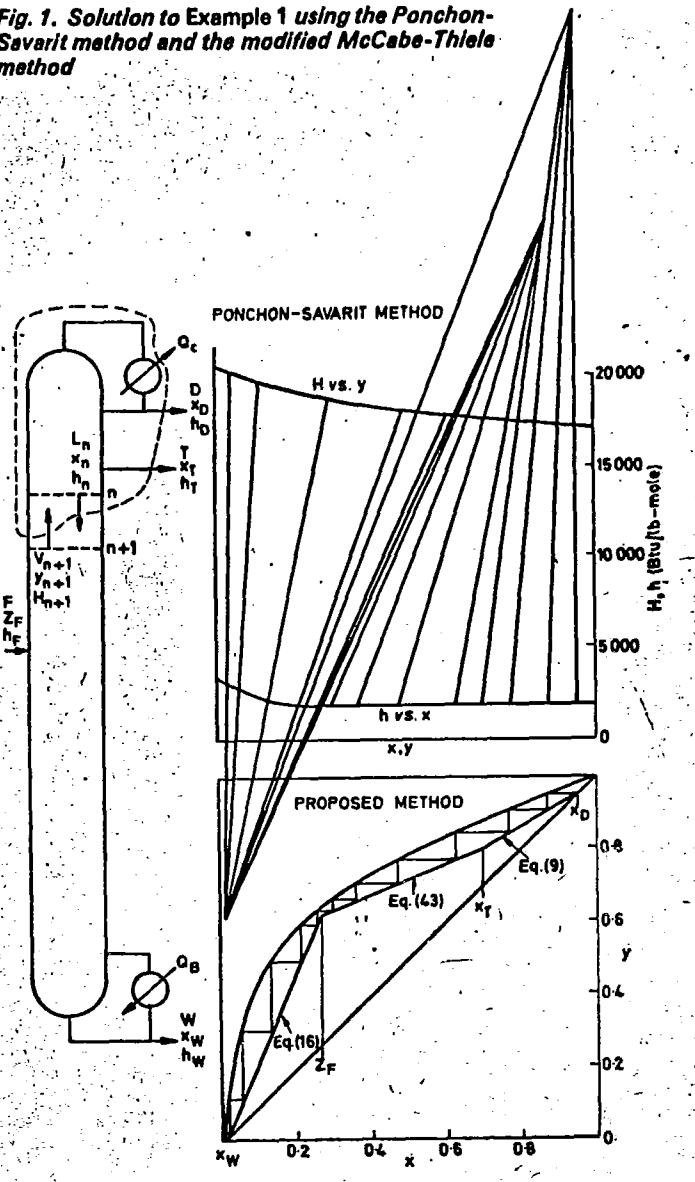
where

$$\theta^{sp} = -S[(1-x_W)g^{sp} + x_W][2\lambda_{A,W}/(\lambda_{A,F} + \lambda_{A,W})] \quad \ldots\ldots\ldots(17)$$

and

$$g^{sp} = (g_F + g_W)/2$$

Fig. 1. Solution to Example 1 *using the Ponchon-Savarit method and the modified McCabe-Thiele method*



The value of S can be calculated by the following equations:

$$F\theta_F = D\theta_D + W\theta_W \quad \ldots\ldots\ldots(18)$$

$$\theta_F = (1-q)[g_F - (g_F - 1)y_F] \quad \ldots\ldots\ldots(19)$$

$$\theta_D = (R+1)[g_D - (g_D - 1)x_D] \quad \ldots\ldots\ldots(20)$$

$$\theta_W = -S[g_W - (g_W - 1)x_W] \quad \ldots\ldots\ldots(21)$$

For equal latent heats of vaporisation, $g^{sp} = 1$. If the inequality of the latent heats from plate to plate is neglected, Equation (16) reduces to

$$y_{m+1} = (L_m x_m - W x_W)/V_m \quad \ldots\ldots\ldots(22)$$

which is the same operating equation in the stripping section used in the McCabe-Thiele method. All these equations, especially Equations (18)–(21), have been shown in a previous article.[3]

Minimum reflux ratio

For minimum reflux ratio, the enriching operating curve should meet the intersection of the feed line (Equation (23))

$$y = [(f-1)x + Z_F]/f \quad \ldots\ldots\ldots(23)$$

and the equilibrium curve. This point is x_f, y_f as shown in Fig. 1. Substituting this point into Equation (9) and rearranging gives

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$$\theta^{en} = \frac{g^{en}(x_D - x_f) - y_f(x_f - x_D)(1 - g^{en})}{y_f - x_f} \quad \ldots\ldots\ldots(24)$$

Substituting θ^{en} from Equation (24) into Equation (10) gives

$$R_{min} + 1 = \frac{y_f(x_f - x_D)(1 - g^{en}) + g^{en}(x_f - x_D)}{(x_f - y_f)[g^{en} - (g^{en} - 1)x_D][2\lambda_{A,D}/(\lambda_{A,F} + \lambda_{A,D})]} \quad \ldots\ldots(25)$$

For equal molal latent heats of vaporisation, $g^{en} = 1$. If the inequality of the latent heats of vaporisation is neglected, Equation (25) reduces to

$$R_{min} = (y_f - x_D)/(x_f - y_f) \quad \ldots\ldots\ldots(26)$$

which is the equation for minimum reflux ratio given in many references.

Modified McCabe-Thiele diagram

With the two operating Equations (9) and (16) and the feed line (Equation (23)), the number of theoretical plates required for the separation can be determined by:

(1) plotting the equilibrium curve;
(2) drawing in the feed line (Equation (23)) and locating x_D, Z_F, and x_W;
(3) plotting the operating curved lines by Equations (9) and (16);
(4) stepping off the triangles.

Example 1

Determine the number of theoretical plates required to separate methanol from water in a column at 1 atm equipped with a total condenser and a total reboiler. Reflux returns to the column at its boiling temperature at a ratio of 1·615 times the minimum. Feed enters as a saturated liquid at a rate of 110 lb-mole/hr with a composition of 30·9 mole% methanol. The composition of the distillate and residue are 95·0 mole% and 1·0 mole% methanol, respectively. Both are saturated liquids.

Solution.

It is necessary to look up the data for vapour/liquid equilibrium,[13] enthalpy-concentration diagram,[19] latent heats of vaporisation at boiling temperatures, and boiling and critical temperatures.[16]

The temperatures of the feed, distillate and residue can be obtained from the temperature-composition diagram.[19] The latent heats of vaporisation at these temperatures are then estimated by the Watson correlation.[20] The data is given in Table 1. From a material balance, it is found that $D = 35$ lb-mole/hr and $W = 75$ lb-mole/hr.

Because the feed is a saturated liquid, the feed line intersects the equilibrium curve at $x_f = 0{\cdot}309$ and $y_f = 0{\cdot}67$. Since $g^{en} = 0{\cdot}5(g_D + g_f)$, $g^{en} = 0{\cdot}5(1{\cdot}205 + 1{\cdot}226) = 1{\cdot}216$. From Equation (25), therefore

$$R_{min} = 0{\cdot}85$$

In the enriching section, $R = (1{\cdot}615)(0{\cdot}85) = 1{\cdot}374$, and from Equation (10) $\theta^{en} = 2{\cdot}44$. From Equation (9)

$$y_{n+1} = \frac{1{\cdot}224x_n + 1{\cdot}156}{2{\cdot}6452 - 0{\cdot}216x_n}$$

and the following values of y_{n+1} can be calculated

x_n	0·950	0·900	0·800	0·700	0·600	0·500	0·400	0·300
y_{n+1}	0·950	0·920	0·863	0·807	0·751	0·697	0·644	0·590

In the stripping section, $q = 1{\cdot}0$ and $g^{sp} = 0{\cdot}5(1{\cdot}226 + 1{\cdot}247) = 1{\cdot}237$.

From Equation (19) $\theta_f = 0$;
From Equation (20) $\theta_D = 2{\cdot}40$;
From Equation (18) $\theta_W = -1{\cdot}12$;
From Equation (21) $S = 0{\cdot}915$;
From Equation (17) $\theta^{sp} = -1{\cdot}104$;

From Equation (16) $$y_{m+1} = \frac{-2{\cdot}341x_m + 0{\cdot}01237}{-0{\cdot}237x_m - 1{\cdot}102}$$

Table 1. Data for solution of Example 1

	Water (B)	*Methanol* (A)
Molecular weight	18·02	32·04
Critical temperature (°K)	647·0	513·2
Boiling temperature (°K)	373·2	337·8
Latent heat at boiling temperature (cal/g-mole)	9,717	8,430
Ratio of latent heats at boiling temperature	1·152	
Distillate temperature (°K)	340	
Latent heat at distillate temperature (cal/g-mole)	10,120	8,410
Ratio of latent heats at distillate temperature	1·205	
Feed temperature (°K)	352	
Latent heat at feed temperature (cal/g-mole)	10,000	8,150
Ratio of latent heats at feed temperature	1·226	
Residue temperature (°K)	372	
Latent heat at residue temperature (cal/g-mole)	9,680	7,760
Ratio of latent heats at residue temperature	1·247	

and the following values of y_{m+1} can be calculated

x_m	0·300	0·200	0·100	0·010
y_{m+1}	0·588	0·396	0·197	0·010

All these values are plotted in Fig. 1, and the normal procedure of stepping off triangles is followed. The number of theoretical plates needed for the separation is found to be 10, which is identical to the result by the Ponchon-Savarit method. Both methods are illustrated in Fig. 1.

Open steam

The balances around the envelope in Fig. 2 are

Total material $V_{m+1} = L_m - W + S$ ..(27)

More volatile component A $V_{m+1}y_{m+1} = L_m x_m - W x_W$ ..(28)

Enthalpy $V_{m+1}H_{m+1} = L_m h_m - W h_W^{os}$ ..(29)

where $h_W^{os} = h_W - (SH_s)/W$

Eliminating V_{m+1}, L_m, W and rearranging gives

$$\frac{(1 - S/W)y_{m+1} - x_W}{y_{m+1} - x_m} = \frac{(1 - S/W)H_{m+1} - h_W^{os}}{H_{m+1} - h_m} \quad \ldots\ldots(30)$$

With the assumptions used above, this equation can be reduced to

$$y_{m+1} = \frac{[\theta_{os} - g(1 - S/W)]x_m + g x_W}{\theta_{os} + (g - 1)[x_W - (1 - S/W)x_m]} \quad \ldots\ldots\ldots(31)$$

where

$$\theta_{os} = \frac{2h_W^{os}}{\lambda_{A,F} + \lambda_{A,W}}$$

For $g = 1$, neglecting the variation in latent heat, Equation (31) reduces to

$$y = (W/S)(x_m - x_W) \quad \ldots\ldots\ldots(32)$$

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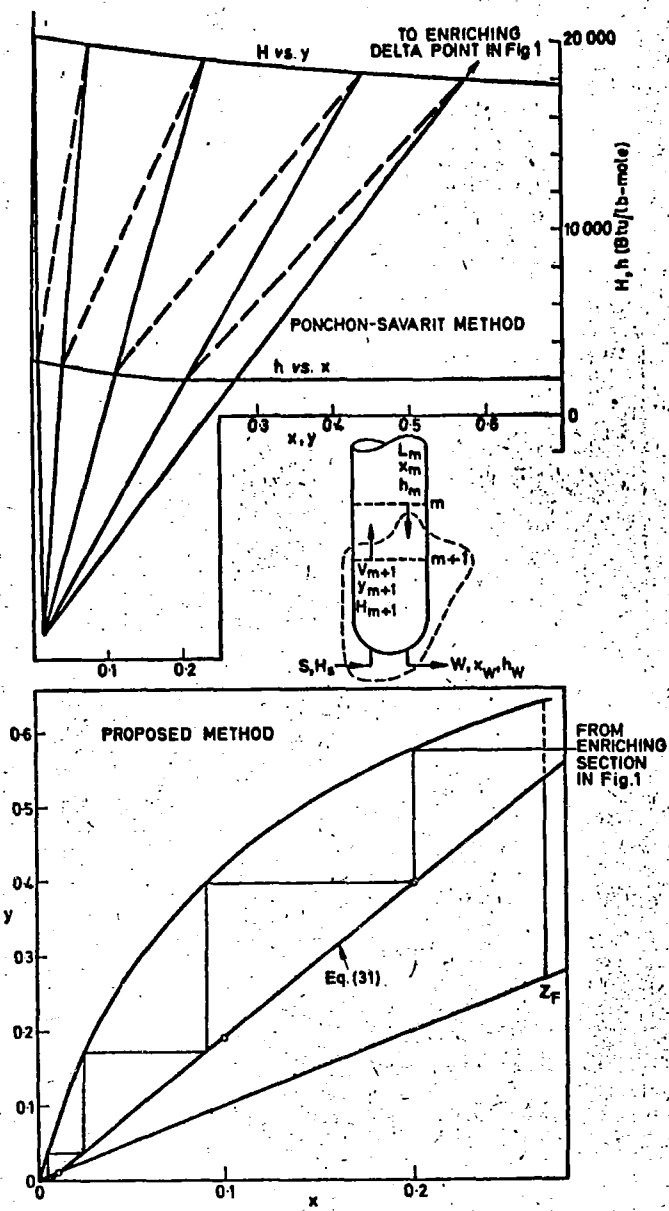

Fig. 2. Solution to Example 2, *where the reboiler in* Example 1 *is substituted by open steem*

Example 2

If open steam, initially saturated at 10 psig, is used to substitute the reboiler in *Example 1*, with the same distillate rate and composition and the same reflux ratio, what would be the steam rate, residue composition and the number of theoretical trays?

Solution:

The enthalpy of the steam is calculated from Treybal[19] as 20,280 Btu/lb-mole. Because the sensible heats of the feed, the distillate and the residue are assumed to be negligible, the total enthalpy of the steam supplied to the column should be equal to the heat removed in the condenser. Combining Equations (7) and (10) gives

$Q_c/D = 0{\cdot}50^{en}(\lambda_{A,F} + \lambda_{A,D}) = 20{,}200$ cal/gm-mole, where θ^{en} was calculated in *Example 1*. Hence

$$\begin{aligned} Q_c &= (20{,}200)(1{\cdot}8)(35) = 1{\cdot}272 \text{ million Btu/hr} \\ S &= 1{\cdot}272 \times 10^6/20{,}280 = 62{\cdot}7 \text{ lb-mole/hr} \\ W &= 110 + 62{\cdot}7 - 35 = 137{\cdot}7 \text{ lb-mole/hr} \\ x_W &= [110(0{\cdot}309) - 35(0{\cdot}95)]/137{\cdot}7 = 0{\cdot}00544 \\ h_W^{es} &= -62{\cdot}7(20{,}280)/137{\cdot}7 = -9{,}230 \\ \theta_W^{es} &= -2(9{,}230)/[1{\cdot}8(7{,}760 + 8{,}150)] = -0{\cdot}645 \end{aligned}$$

$$y_{m+1} = \frac{0{\cdot}00672 - 1{\cdot}319x_m}{-0{\cdot}6440 - 0{\cdot}129x_m}$$

from which the following values of y_{m+1} can be calculated

x_m	0·27	0·20	0·10	0·01	0·005
y_{m+1}	0·515	0·399	0·1905	0·0099	0·000

The enriching section is the same as in *Example 1*, and all of the calculated values are plotted in Fig. 2. The normal procedure of stepping off triangles is followed. The number of theoretical plates needed for the separation is found to be 10, which is identical to the result by the Ponchon-Savarit method. Both methods and the column are shown in Fig. 2.

Multiple feeds

The balances around the envelope in Fig. 3 are

Total material $V_{m+1} = L_m + D - F_1$ ..(33)

More volatile component A $V_{m+1}y_{m+1} = L_m x_m + Dx_D^{mf}$ ..(34)

where $x_D^{mf} = x_D - (F_1 Z_{F_1})/D$

Enthalpy $V_{m+1}H_{m+1} = L_m h_m + Dh_D^{mf}$ (35)

where $h_D^{mf} = h_D + (Q_c - F_1 H_{F_1})/D$

Eliminating V_{m+1}, L_m, D and rearranging gives

$$\frac{x_D^{mf} + (F_1/D - 1)y_{m+1}}{y_{m+1} - x_m} = \frac{h_D^{mf} + (F_1/D - 1)H_{m+1}}{H_{m+1} - h_m} \quad \ldots\ldots\ldots(36)$$

With the assumptions used above, this equation can be reduced to

$$y_{m+1} = \frac{[\theta_{mf} - g(1 - F_1/D)]x_m + gx_D^{mf}}{\theta_{mf} + (g-1)[x_D^{mf} - (1 - F_1/D)x_m]} \quad \ldots\ldots\ldots(37)$$

where

$$\theta_{mf} = 2h_D^{mf}/(\lambda_{A,F} + \lambda_{A,D})$$

and

$$g = g^{en}$$

When $g = 1$, and neglecting variation in latent heats of vaporisation, Equation (37) reduces to

$$y_{m+1} = \frac{L_m x_m + Dx_D - F_1 Z_{F_1}}{L_m + D - F_1} \quad \ldots\ldots\ldots(38)$$

Example 3

If the feed in *Example 1* is split into two streams to enter the column thus: (1) Feed 1: 10 lb-mole/hr of 70 mole% methanol; and (2) Feed 2: 100 lb-mole/hr of 27 mole% methanol, and the reflux ratio L_o/D is 0·735, how many theoretical trays are required?

Solution:

The temperatures, latent heats of vaporisation, and the ratios for the two feeds are shown in Table 2, and should be added to Table 1.

In the enriching section, $g = g^{en} = 0{\cdot}5(1{\cdot}205 + 1{\cdot}207) = 1{\cdot}206$.

From Equation (10) $\theta^{en} = 1{\cdot}762$, and from Equation (9)

$$y_{n+1} = \frac{0{\cdot}556x_n + 1{\cdot}146}{1{\cdot}9578 - 0{\cdot}206x_n}$$

from which the following values of y_{n+1} can be calculated:

x_n	0·95	0·90	0·80	0·70
y_{n+1}	0·95	0·93	0·887	0·847

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Table 2. Additional data for the solution of Example 3

	Water (B)	*Methanol* (A)
First feed temperature (°K) . .	343	
Latent heat at first feed temperature (cal/g-mole) . .	10,080	8 350
Ratio of latent heats at first feed temperature	1·207	
Second feed temperature (°K)	353	
Latent heat at second feed temperature (cal/g-mole) . .	9,990	8,160
Ratio of latent heats at second feed temperature	1·225	

In the multiple feeds section, $g = g^{en} = 0{\cdot}5(1{\cdot}205 + 1{\cdot}207) = 1{\cdot}206$, and $x_D^{mf} = 0{\cdot}95 - (10)(0{\cdot}7)/35 = 0{\cdot}75$. Because the enthalpies of the distillate and first feed are very small in comparison with the latent heats they can be neglected. Hence

$$h_D^{mf} = Q_c/D = (R+1)[x_D\lambda_{A,D} + (1-x_D)\lambda_{B,D}]$$
$$= 26{,}550 \text{ Btu/lb-mole}$$

and $\theta_{mf} = 1{\cdot}76$

From Equation (37) $y_{m+1} = [(0{\cdot}9x_m + 0{\cdot}904)/(1{\cdot}9145 - 0{\cdot}147x_m)]$ from which the following values of y_{m+1} can be calculated

x_m . .	0·7	0·6	0·5	0·4	0·3	0·27
y_{m+1} . .	0·846	0·79	0·735	0·68	0·628	0·612

In the stripping section, $q = 1{\cdot}0$ and $g^{sp} = 0{\cdot}5(1{\cdot}247 + 1{\cdot}225) = 1{\cdot}236$.
From Equation (19) $\theta_F = 0$
From Equation (20) $\theta_D = 1{\cdot}752$
From Equation (18) $\theta_W = -0{\cdot}817$
From Equation (21) $S = 0{\cdot}656$
From Equation (17) $\theta^{sp} = -0{\cdot}79$

From Equation (16) $y_{m+1} = \dfrac{-2{\cdot}026x_m + 0{\cdot}01236}{-0{\cdot}236x_m - 0{\cdot}792}$

from which the following values of y_{m+1} can be calculated

x_m	0·27	0·20	0·10	0·01
y_{m+1}	0·61	0·468	0·233	0·01

All these values are plotted in Fig. 3, on which the normal procedure of stepping off triangles is followed. The number of theoretical plates including reboiler is found to be 15, which is identical to the result by the Ponchon-Savarit method.

Side streams

The balances round the envelope in Fig. 4 are

Total material $V_{n+1} = L_n + D + T$ . . (39)

More volatile component A $V_{n+1}y_{n+1} = L_nx_n + Dx_D^y$ . . (40)

where $x_D^y = x_D + (Tx_T/D)$

Enthalpy $V_{n+1}H_{n+1} = L_nh_n + Dh_D^y$ . . (41)

where $h_D^y = h_D + (Th_T + Q_c)/D$

Eliminating V_{n+1}, L_n, D and rearranging gives

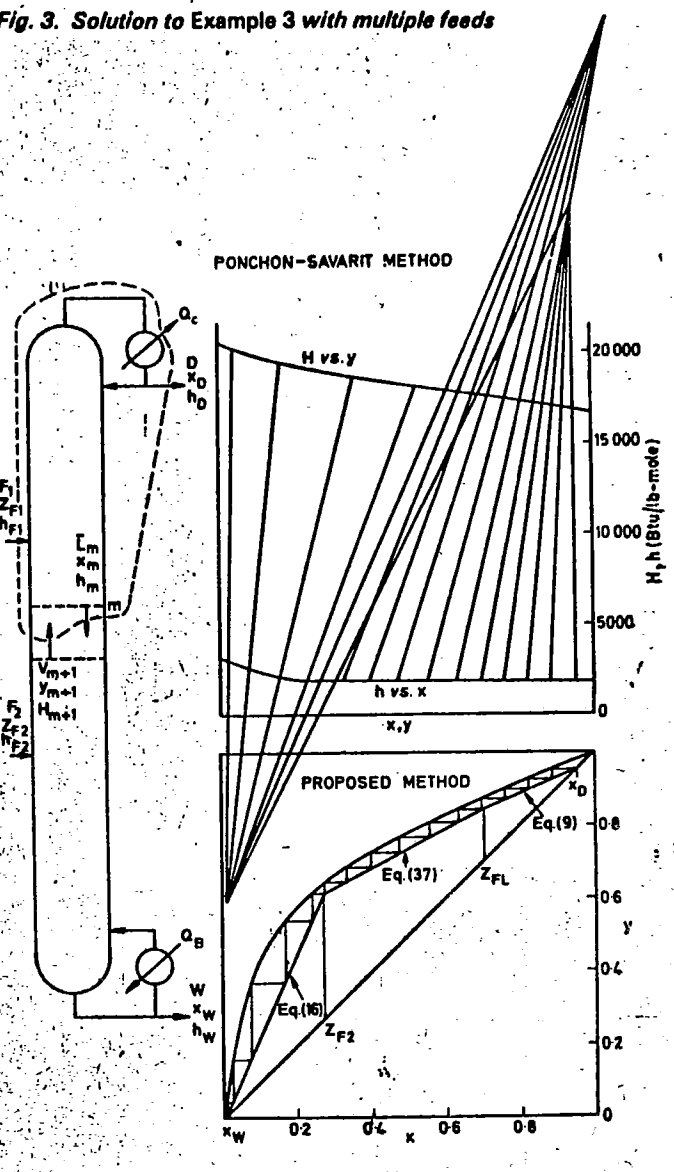

Fig. 3. Solution to Example 3 *with multiple feeds*

$$\frac{x_D^y - (1 + T/D)y_{n+1}}{y_{n+1} - x_n} = \frac{h_D^y - (1 + T/D)H_{n+1}}{H_{n+1} - h_n} \quad (42)$$

With the assumptions used above, this equation can be reduced to

$$y_{n+1} = \frac{[\theta_{ss} - g^{en}(1 + T/D)]x_n + g^{en}x_D^y}{\theta_{ss} + (g^{en} - 1)[x_D^y - (1 + T/D)x_n]} \quad \ldots\ldots\ldots (43)$$

where

$$\theta_{ss} = 2h_D^y/(\lambda_{A,F} + \lambda_{A,D})$$

If $g = 1$ and neglecting variation in the latent heats, Equation (43) reduces to

$$y_{n+1} = \frac{L_nx_n + Dx_D + Tx_T}{L_n + D + T} \quad \ldots\ldots\ldots (44$$

Example 4

If the feed in *Example 1* is replaced by a feed of 100 lb-mole/(27 mole% methanol) and a side stream is withdrawn at rate of 8·5 lb-mole/hr (70 mole% methanol), what is the numl of theoretical plates required for the separation with a reflu ratio $L_o/D = 1{\cdot}53$ and same distillate and residue composition as in *Example 1?*

Solution:

Because the streams have the same compositions as those in the previous examples, the temperatures, and latent heats

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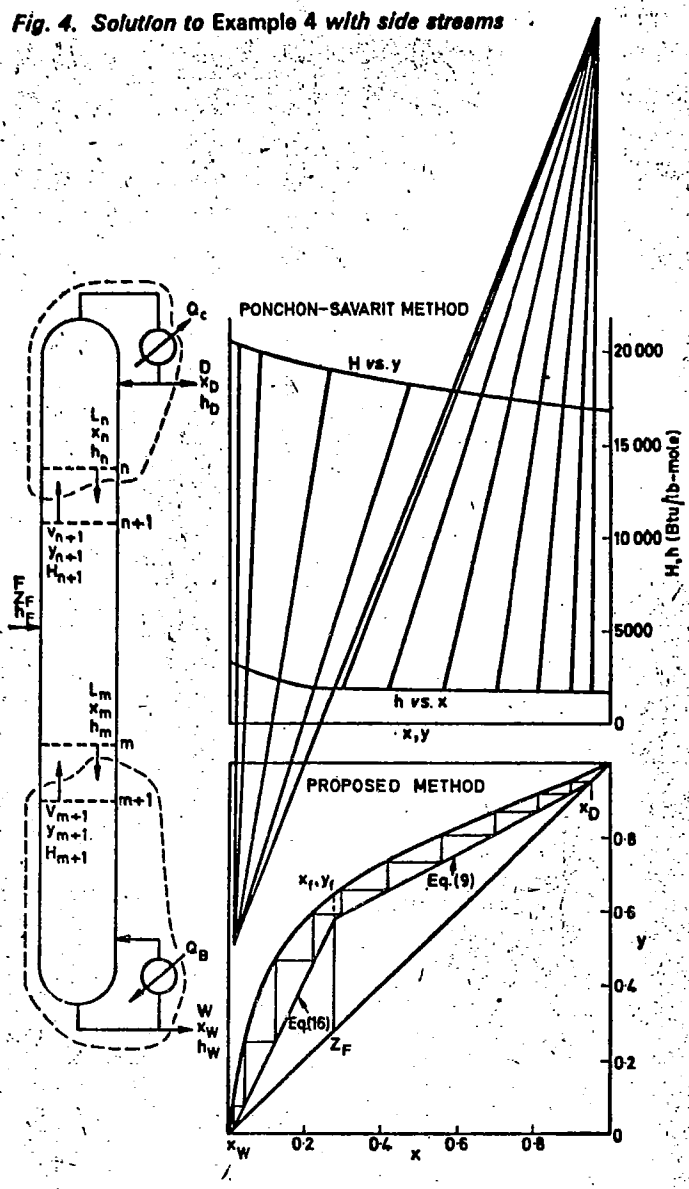
Fig. 4. Solution to Example 4 *with side streams*



have already been calculated. The operating curves can be estimated as follows. In the enriching section, $g^{en} = 1{\cdot}206$. From Equation (10), $\theta^{en} = 2{\cdot}54$, and a material balance gives $D = 21{\cdot}4$ lb-mole/hr, $W = 70{\cdot}1$ lb-mole/hr. From Equation (9)

$$y_{n+1} = \frac{1{\cdot}334x_n + 1{\cdot}146}{2{\cdot}7358 - 0{\cdot}206x_n}$$

from which the following values of y_{n+1} can be calculated

x_n	0·95	0·90	0·80	0·70
y_{n+1}	0·95	0·918	0·861	0·80

In the side stream and feed section
$x_D^{sf} = 1{\cdot}228$
$h_D^{sf} = Q_C/D = 38{,}700$
and $\theta_{ss} = 2{\cdot}55$
From Equation (43)

$$y_{n+1} = \frac{0{\cdot}865x_n + 1{\cdot}48}{-0{\cdot}288x_n + 2{\cdot}803}$$

from which the following values of y_{n+1} can be calculated

x_n ..	0·700	0·600	0·500	0·400	0·300	0·270
y_{n+1} ..	0·800	0·759	0·719	0·680	0·640	0·628

In the stripping section, $q = 1{\cdot}0$ and $g^{sp} = 0{\cdot}5(1{\cdot}247 + 1{\cdot}225) = 1{\cdot}236$
From Equation (19) $\theta_F = 0$
From Equation (20) $\theta_D = 2{\cdot}552$
From Equation (18) $\theta_W = -0{\cdot}778$
From Equation (21) $S = 0{\cdot}625$
From Equation (17) $\theta^{sp} = -0{\cdot}751$

From Equation (16) $y_{m+1} = \dfrac{-1{\cdot}987x_m + 0{\cdot}01236}{-0{\cdot}236x_m - 0{\cdot}753}$

from which the following values of y_{m+1} can be calculated

x_m	0·27	0·2	0·1	0·01
y_{m+1}	0·626	0·481	0·239	0·01

The values of x and y in the enriching, side stream and feed, and stripping sections are plotted in Fig. 4, on which the normal procedure of stepping off triangles is followed. The number of theoretical plates including reboiler is found to be 12, which is identical to the result by the Ponchon-Savarit method.

Conclusion

The examples illustrate a convenient and accurate method for calculating the number of theoretical plates needed for the rectification of a binary mixture with unequal molal latent heats. The result is more accurate than when using the McCabe-Thiele method, and the procedure is simpler than that of the Ponchon-Savarit method. The application of the method is not so limited as the Ponchon-Savarit method because the latent heat of vaporisation data required are more easily calculated or obtained than is the enthalpy-concentration diagram necessary for the Ponchon-Savarit method.

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new Dutch contracting office

Stone & Webster have decided to expand operations in the Netherlands and have formed a company—Stone & Webster Engineering (Holland) NV—which will be developed, at the earliest possible date, into a substantial integrated engineering, design, procurement and construction organisation. Managing director of the new company will be J. P. Collinge, who has been with Stone & Webster for 20 years.

The development of an integrated organisation in the Netherlands will make the group's services more readily available to certain markets, providing shorter lines of communication and a better knowledge of codes, practices, equipment fabricators, etc., in the most rapidly-growing industrial areas. To accelerate development of this new venture the wide experience of Stone & Webster's total resources will be available to the new office.

The new company will begin operations in May 1971, at 370 Sir Winston Curchilllaan, Rijswijk, The Netherlands.

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