AUTOMATIC CALCULATION OF
DISTILLATION TOWER DESIGN

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AUTOMATIC CALCULATION OF DISTILLATION TOWER DESIGN

By

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I. INTRODUCTION

Because the calculations required in the design of distillation columns for multicomponent mixtures are tedious and time consuming, it would be to the advantage of the chemical engineer to have available a system for automatically performing these calculations. The development of such a system was undertaken, and the results are herewith presented.

It was desired to use a computational method that could be carried out without the exercise of engineering judgment after a preliminary table of data had been prepared.

There were two alternative methods of approach to this problem: the first was to adapt one of the calculation methods presented by other authors to automatic calculating machines; the second was to develop, if possible, a calculation method particularly suited to automatic calculation.

Of the former, probably the most widely used is the Lewis and Matheson method (1). It was believed that if this method were used, considerable trouble would arise in attempting to perform automatically the matching of compositions above and below the feed tray, particularly if there were several distributed components.

Opler and Heitz (2) have made use of the IBM 602 Calculating Punch for performing the tray to tray calculations of the Lewis and Matheson method. They report the solution of four component systems with mole fractions calculated to four decimal places.

To avoid the troublesome matching of concentrations at the feed tray, it was decided to use the method of determining the separation that would be obtained from a given number of trays, feed composition and condition, feed tray location, and reflux ratio. This method might seem to be less flexible than the determination of the number of trays required to effect a given separation with a given reflux. This objection is not valid, however, if this rigorous calculation is used in conjunction with a quick, approximate method for determining the relation between the number of plates and the reflux ratio. Such a correlation has been given in a recent article by Donnell and Cooper (3) in which they make use of Underwood's (4) method for obtaining minimum reflux.

By fixing the number of trays and the feed tray location, it is also possible to make a reliable determination of the best feed tray position by making a series of calculations with the feed entering on different trays.

Among the calculation methods based on a fixed number of plates, and a fixed reflux ratio are those that have been presented by Thiele and Geddes (5), Hummel (6), and Edmister (7).

Of these, the Hummel method employs a graphical presentation of K of a reference component plotted against the number of plates as a basis for computations. This would obviously be unsuitable for automatic calculation.

In the Thiele and Geddes method, tray by tray calculations are based on an assumed temperature for each tray. The results from the enriching and exhausting sections are meshed at the feed tray, and the composition is found for each tray. Using these compositions, the assumed temperatures are checked and reassumed if in error.

The method proposed by Edmister makes use of overall equations for both sections of a column. These equations are based on the use of absorption and stripping factors, L/KV and KV/L. After these equations are evaluated the results must be meshed at the feed tray.

The major drawbacks to the use of either the Thiele and Geddes method or the Edmister method are that both require feed tray meshing after the initial calculations, and that both fail to provide a simple, systematic procedure to follow for the solution of the problem.

It was decided to use a method by which automatic calculation could more easily be performed.

The assumptions of constant molal overflow and negligible heat loss to the surroundings are made.

The first part of the derivation which follows is similar to that given by Edmister in the reference cited, except that in this case a total condenser is used instead of a partial condenser. The outstanding feature of the derivation is equation (42) which relates the composition of the distillate to the quantity of distillate, the number of trays in the column, the equilibrium conditions on each tray in the column, the position of the feed tray, the feed composition and thermal condition, and the reflux ratio.

When the distillate composition has been obtained, tray by tray calculations are made down the tower to the still.

The calculating machine chosen for this work was the IBM Calculating Punch, Type 602-A. This machine was chosen because it is one of the machines, along with the Type 602 machine, commonly found in accounting departments. It has greater storage capacity than the 602 machine, and its programming is more flexible.

With the present wiring of the control panels, a problem having up to twelve components can be calculated, with mole fractions computed to five decimals. It is planned to alter the wiring to give mole fractions to seven or eight decimal places since this procedure requires an accurate value for the concentration of vanishing components in the distillate and bottoms product.

II. DERIVATION OF EQUATIONS

By a material balance for any component at the top of the tower

$$V_1 y_1 = L_r x_d + D x_d \tag{1}$$

Rearranging and introducing K_1

$$y_1 = \frac{L_r x_d}{V_1} + \frac{D x_d}{V_1} \tag{2}$$

$$x_1 = x_d \left(\frac{L_r + D}{V_1 K_1} \right) \tag{3}$$

By a material balance around the top of the tower and between the first and second trays

$$V_2 y_2 = L_1 x_1 + D x_d \tag{4}$$

Rearranging and introducing K_2

$$y_2 = \frac{L_1 x_1}{V_2} + \frac{D x_d}{V_2} \tag{5}$$

$$x_1 = \frac{V_2 K_2}{L_1} \left(x_2 - \frac{D x_d}{V_2 K_2} \right) \tag{6}$$

Combining equations (3) and (6)

$$\frac{V_2 K_2 x_2}{L_1} - \frac{D x_d}{L_1} = x_d \left(\frac{L_r + D}{V_1 K_1} \right) \tag{7}$$

$$x_2 = \frac{D x_d}{V_2 K_2} + x_d \left(\frac{L_r L_1}{V_1 K_1 V_2 K_2} + \frac{D L_1}{V_1 K_1 V_2 K_2} \right) \tag{8}$$

By a material balance around the top of the tower and between the second and third trays and introducing K_3

$$V_3 y_3 = L_2 x_2 + D x_d \tag{9}$$

$$x_2 = \frac{V_3K_3x_3}{L_2} - \frac{D\,x_d}{L_2} \tag{10}$$

Combining equations (8) and (10)

$$\frac{V_3K_3x_3}{L_2} = \frac{Dx_d}{L_2} + \frac{Dx_d}{V_2K_2} + x_d\,\frac{L_rL_1}{V_1K_1V_2K_2} + \frac{D\,L_1}{V_1K_1V_2K_2} \tag{11}$$

$$\frac{x_3}{x_d} = \frac{D}{V_3K_3} + \left(\frac{L_2}{V_2K_2}\right)\left(\frac{D}{V_3K_3}\right) + \left(\frac{L_1}{V_1K_1}\right)\left(\frac{L_2}{V_2K_2}\right)\left(\frac{L_r}{V_3K_3}\right) + \left(\frac{L_1}{V_1K_1}\right)\left(\frac{L_2}{V_2K_2}\right)\left(\frac{D}{V_3K_3}\right) \tag{12}$$

Rearranging and substituting A for L/KV and y for K_3x_3

$$y_3V_3 = x_d\left[D\,(A_1A_2 + A_2 + 1) + L_r\,A_1A_2\right] \tag{13}$$

Rewriting in general form

$$(Vy)_{n+1} = x_d\left[D(A_1A_2\cdot\,\cdot\,\cdot A_n + A_2A_3\cdot\,\cdot\,\cdot A_n + \cdots + A_n + 1) + L_r(A_1A_2\cdot\,\cdot\,\cdot\,A_n)\right] \tag{14}$$

For convenience, these two functions of A are designated as follows:

$$f_1(A) = A_1\,A_2\cdot\,\cdot\,\cdot A_n + A_2\,A_3\cdot\,\cdot\,\cdot A_n + \cdot\,\cdot\,\cdot + A_n + 1 \tag{15}$$

$$f_2(A) = A_1\,A_2\cdot\,\cdot\,\cdot\,A_n \tag{16}$$

Equation (14) is then written

$$(Vy)_{n+1} = x_d\left[D\,f_1(A) + L_r\,f_2(A)\right] \tag{17}$$

By a material balance for any component at the bottom of the tower

$$L_1\,x_1 = V_sy_s + B\,x_s \tag{18}$$

$$x_1 = \frac{V_sy_s}{L_1} + \frac{B\,x_s}{L_1} \tag{19}$$

By a material balance around the bottom of the column and between the first and second trays

$$V_1y_1 = L_2x_2 - Bx_s \tag{20}$$

Introducing K_1

$$x_1 = \frac{L_2x_2}{V_1K_1} - \frac{B\ x_s}{V_1K_1} \tag{21}$$

Combining equations (19) and (21)

$$\frac{L_2x_2}{V_1K_1} = \frac{B\ x_s}{V_1K_1} + \frac{V_sy_s}{L_1} + \frac{B\ x_s}{L_1} \tag{22}$$

$$x_2 = \frac{Bx_s}{L_2} + \frac{V_1K_1V_2y_s}{L_1\ L_2} + \frac{V_1K_1Bx_s}{L_1\ L_2} \tag{23}$$

By a material balance around the bottom of the column and between the second and third trays

$$L_3x_3 = V_2\ y_2 + B\ x_s \tag{24}$$

Rearranging and introducing K_2

$$x_2 = \frac{L_3x_3}{V_2K_2} - \frac{B\ x_s}{V_2K_2} \tag{25}$$

Combining equations (23) and (25)

$$\frac{L_3x_3}{V_2K_2} = \frac{B\ x_s}{V_2K_2} + \frac{B\ x_s}{L_2} + \frac{V_1K_1V_sy_s}{L_1L_2} + \frac{V_1K_1B\ x_s}{L_1L_2} \tag{26}$$

Multiplying by V_2K_2 and substituting K_sx_s for y_s

$$L_3x_3 = B\ x_s + \left(\frac{V_2K_2}{L_2}\right) B\ x_s + \left(\frac{V_1K_1}{L_1}\right)\left(\frac{V_2K_2}{L_2}\right) V_sK_sx_s + \left(\frac{V_1K_1}{L_1}\right)\left(\frac{V_2K_2}{L_2}\right) Bx_s \tag{27}$$

Rearranging and substituting S for VK/L

$$L_3x_3 = x_s\left[B\ (S_1S_2 + S_2 + 1) + V_sK_s(S_1S_2)\right] \tag{28}$$

Rewritten in general form

$$(Lx)_{m+1} = x_s\left[B(S_1S_2\cdot\ .\ .S_m + S_2S_3\cdot\ .\ .S_m + .\ .\ . + S_m + 1) + V_sK_s(S_1S_2\cdot\ .\ S_m)\right] \tag{29}$$

The two functions of S are designated as follows:

$$f_1(S) = S_1S_2. . .S_m + S_2S_3. . .S_m + . . . + S_m + 1 \tag{30}$$

$$f_2(S) = S_1S_2. . .S_m \tag{31}$$

Equation (29) can then be written

$$(Lx)_{m+1} = x_s\left[B\, f_1(S) + V_sK_s\, f_2(S)\right] \tag{32}$$

Since $Lx = Vy/S$, equation (32) can be rewritten

$$(Vy)_{m+1} = S_{m+1}\, x_s\left[B\, f_1(S) + V_s\, K_s\, f_2(S)\right] \tag{33}$$

If the nth tray is immediately above the feed tray, and the mth tray is immediately below the feed tray, the expressions n+1 and m+1 will both designate the feed tray, and equations (17) and (33) may be equated.

$$x_d\left[D\, f_1(A) + L_r\, f_2(A)\right] = S_fx_s\left[B\, f_1(S) + V_sK_s\, f_2(S)\right] \tag{34}$$

The number of variables in equation (34) can be reduced by use of the following identities:

$$L_n/V_n = R/R+1 \tag{35}$$

$$L_r = L_n = RD \tag{36}$$

$$V_n = D(R+1) \tag{37}$$

$$B = 1 - D \tag{38}$$

$$V_m = C\, V_n \tag{39}$$

Equation (34) may now be written

$$x_d\left[D\, f_1(A) + RD\, f_2(A)\right] = S_fx_s\left[(1-D)\, f_1(S) + CD(R+1)\, K_s\, f_2(S)\right] \tag{40}$$

Substituting for x_s by the use of the equation

$$x_s = \frac{Fx_F - Dx_d}{1 - D} \tag{41}$$

and solving for x_d, equation (40) becomes

$$x_d = \frac{Fx_F S_f f_1(S) + Fx_F \left[(R+1)CK_s S_f f_2(S) - S_f f_1(S)\right] D}{\left[f_1(A) + Rf_2(A) + S_f f_1(S)\right] D + \left[(R+1)CK_s S_f f_2(S) - f_1(A) - Rf_2(A) - S_f f_1(S)\right] D^2} \tag{42}$$

To simplify equation (42) substitute the following terms:

$$a = f_1(A) \tag{43}$$

$$b = R\, f_2(A) \tag{44}$$

$$c = S_f\, f_1(S) \tag{45}$$

$$d = (R+1)CK_s\, S_f\, f_2(S) \tag{46}$$

For this calculation take as a basis $F = 1$.

Equation (42) becomes

$$x_d = \frac{x_f\, c + x_f\,(d - c)\, D}{(a+b+c)\, D + \left[d - (a+b+c)\right] D^2} \tag{47}$$

For further simplification make the following substitutions:

$$e = x_f\, c \tag{48}$$

$$f = x_f\,(d - c) \tag{49}$$

$$g = a + b + c \tag{50}$$

$$h = d - (a+b+c) \tag{51}$$

Equation (47) can now be written

$$x_d = \frac{e + fD}{gD + hD^2} \tag{52}$$

For the more volatile components the determination of x_s by equation (41) is not advisable due to the small difference between $F\, x_F$ and $D\, x_d$. For this reason an equation derived from equation (40) is used.

$$x_s = \frac{x_d\, D\, (a+b)}{e + D\,(d - c)} \tag{53}$$

The following series of equations obtained from material balances give the quantity of any component in the liquid stream leaving a plate in the upper section, the feed plate, and a plate in the lower section respectively.

Upper section:

$$(Lx)_1 = A_1\, D\, x_d\, (R+1) \tag{54}$$

$$(Lx)_2 = A_2 \left[(Lx)_1 + D\, x_d \right] \tag{55}$$

$$(Lx)_3 = A_3 \left[(Lx)_2 + D\, x_d \right] \tag{55a}$$

$$(Lx)_n = A_n \left[(Lx)_{n-1} + D\, x_d \right] \tag{55b}$$

Feed plate:

$$(Lx)_f = 1/S_f \left[(Lx)_n + D\, x_d \right] \tag{56}$$

where n is the plate above the feed plate.

Lower section:

$$(Lx)_m = 1/S_m \left[(Lx)_f - Bx_s \right] \tag{57}$$

$$(Lx)_2 = 1/S_2 \left[(Lx)_3 - Bx_s \right] \tag{57a}$$

$$(Lx)_1 = 1/S_1 \left[(Lx)_2 - Bx_s \right] \tag{57b}$$

The composition of the liquid leaving each plate can be readily obtained when the quantity of each component present has been obtained. For a component "a" on the nth tray

$$x_{a,n} = \frac{(Lx)_{a,n}}{\sum (Lx)_n} \tag{58}$$

Nomenclature

L = mols of liquid leaving a plate

V = mols of vapor leaving a plate

F = mols of feed

D = mols of distillate

B = mols of bottom product

x = mol fraction of any component in liquid phase

y = mol fraction of any component in vapor phase

R = Reflux ratio L/D

$K = y/x$

$A = L/KV$

$S = 1/A = KV/L$

$C = V_m/V_n$ C is defined by the thermal condition of the feed.

C = 1 when feed is a liquid at its boiling point.

Insert # 1

Subscripts:

r = reflux

d = distillate

s = still

n = tray number in enriching section numbered from condenser to feed tray

m = tray number in exhausting section numbered from still to feed tray

F = feed

f = feed tray

III. CALCULATION METHOD

Briefly, this calculation is based on a series of successive approximations of conditions in the tower, with the results of one calculation being used as the basis for the succeeding calculation. In any trial, if the assumed conditions are correct, they will be identical to the conditions calculated in that trial.

The first step is to make a preliminary estimate of the quantity and analysis of distillate and residue by assuming that nothing heavier than the heavy key (specified permissible percentage of high boiling compound allowed in distillate) will be contained in the distillate or nothing lighter than the light key will exist in the residue.

When an estimate of top and bottom compositions has been made, the approximate temperatures of the top and bottom of the column are obtained as the dew and boiling points. The first estimate of tray temperatures is then obtained by assuming an even temperature gradient from tray to tray.

Having previously set the reflux ratio, the ratio of liquid to vapor above the feed tray is given by equation (35); below the feed tray by the equation

$$L_m/V_m = \frac{1+(RC+C-1)\,D}{CD\,(R+1)} \tag{59}$$

From K data for the pressure of the tower, the values of K are found for each component, for the various tray temperatures. The absorption factors are then calculated for each component on each tray in the upper section of the tower, and the stripping factors are calculated for each component on each tray in the lower section. The functions of A and S are calculated for each component and the constants e, f, g, and h are determined for each component.

A value of D is found which, when substituted in equation (52) will give

$$\sum x_d = 1 \tag{60}$$

The composition of the residue is calculated by equation (53).

The quantity of each component in the liquid stream leaving each plate is calculated using equations (54) to (57b), and the composition of the liquid on each tray is obtained from equation (58).

Since the 1 iquid on each tray is at its boiling point, a new estimate of tray temperatures is obtained by determining the boiling points of mixtures of the calculated compositions. A new value for L_m/V_m is calculated using the new value for D in equation (59).

The entire calculation is repeated, using the new tray temperatures and the new value of L_m/V_m, until in any trial the tray temperatures and the value of D that are calculated are identical to those assumed.

IV. OPERATIONAL PRINCIPLES OF THE INTERNATIONAL BUSINESS MACHINES CALCULATING PUNCH, TYPE 602-A (8)

The IBM Calculating Punch, Type 602-A, performs the fundamental arithmetic computations, addition, subtraction, multiplication and division, either singly or in any combination selected by the operator. The factors are read into the machine from punched cards and the results are punched in the cards by the machine.

The standard machine has six storage units; the first will accommodate ten digits and the remaining five will each hold twelve. When a number is entered in a storage unit, any number already in the unit will automatically be cleared.

The machine also has six counters which also hold numbers. Counters differ from storage units in that a number which is read into a counter may be added to or subtracted from a number previously entered in the counter. Products and quotients from multiplications and divisions are also developed in the counters.

The operation of the machine is determined by a control panel which must be wired for each specific problem. Before the control panel is wired the problem is set up on a planning chart which shows in which storage unit each factor is to be entered, in which counters the results are obtained, and the sequence of the individual operations.

Each problem is performed by the machine in steps or programs, each program being represented by a line in the planning chart. The first step is always the read cycle, in which the factors are read from the cards into the machine. In each subsequent step a calculation is made, or numbers are transferred from one unit to another.

Electrical impulses are available at the program exit terminals, or hubs, as they are called, on each program cycle. These impulses control the operation of the units to which they are wired. If, for example, on program 3, it is desired to transfer a number from storage unit 6 to counter 1, wires from two of the program 3 exits would be run to read-out storage 6 and to plus counter 1. The numbers transfer from one unit to another as electrical impulses. Circuits between the units involved in such a transfer must be completed on the control panel. The major portion of the hubs on the right side of the panel are for this purpose.

The cards used in the IBM system contain eighty columns, each column having twelve positions in any of which a hole may be punched. Ten of the twelve positions correspond to zero and the nine digits and the other two positions are called X and Y. The X punch is used to actuate controls; the Y is not used in this problem. The numbers are read from the cards as they feed into the machine by a bank of reading brushes, one for each column, and are transmitted to the reading hubs on the control panel. The reading hubs are wired either through counter entry to a counter, or through storage entry to a storage unit, where the numbers will be available when needed.

The electrical impulses which control the operation of the machine may be wired through the pilot selector hubs in the upper left portion of the control panel. The pilot selectors are actually double throw relays.

When an impulse is wired to the common hub it is available at the normal hub when the pilot selector is in its normal position. The impulse is available at the transferred hub when the pilot selector has been "picked up."

If there are control impulses wired through pilot selectors the operations performed by the machine will be different for the cards which pick up the pilot selectors than for the remainder of the cards. The pilot selectors are picked up by an impulse to one of the following hubs: X or balance pick up, digit pick up, or immediate pick up. The last of these transfers the pilot selector only for the duration of the cycle in which it is picked up, while the first two cause the pilot selector to latch in the transferred position until it is dropped out by an impulse to the drop-out hub. If the drop-out hub is wired from punch drop-out impulse, the pilot selector will be dropped out after the card is punched. If drop-out is wired from read drop-out impulse, the pilot selector will be dropped out after the following card is read.

There are twenty control brushes in the machine located ahead of the eighty reading brushes. They are placed to read in any twenty of the eighty columns in the card. An X punched in one of these columns will be read by a control brush, and will be available at the corresponding control reading hub. If a pilot selector is to be used to control impulses from read cycles, it should be picked up from control reading brushes. If it is to be used to control impulses from program exits, the pilot selector is picked up from the reading brushes.

If, in performing a series of calculations, one of the factors remains constant for each calculation, that factor may be entered from the first card only, into one of the storage units. The number will remain in the storage unit and can be read out repeatedly until the storage unit is cleared by an impulse from read cycles to the storage read in hub. To prevent the impulse from reaching storage read in for all cards in a series except the first one, a wire is run from read cycles to the common hub of a pilot selector, and from the transferred hub of the same pilot selector to the read in hub of the storage unit. The pilot selector is picked up by an X read from the card by one of the control reading brushes. The first card in the series is therefore punched with an X which will pick up the pilot selector, and cause the group factor to be read into the storage unit. Since X's are not punched in subsequent cards in the series the group factor will remain in the storage unit until the first card in the next series is read in. In this type of calculation the first card is called the X card and the remainder are called NX cards.

Co-selectors are similar to the pilot selectors and may be used in conjunction with them or independently. They are picked up by an impulse to the co-selector pick up. If this impulse comes from a pilot selector couple exit, the co-selector will be transferred for the same length of time as the pilot selector. If the impulse comes from a program exit the co-selector will be transferred only through that program.

The circuits through which the numbers pass in moving from one unit to another in a certain program may introduce back circuits in another program. If this occurs the circuits are wired through the transferred side of a co-selector which is picked up for that program only.

The details of wiring a control panel for a specific calculation will be explained by the use of an example - control panel number 2 for this problem.

Using this board the machine will perform any of the following calculations:

$$(A+B)\ C = A'$$

$$(A+B)/C = A'$$

$$(A-B)\ C = A'$$

$$(A-B)/C = A'$$

The result obtained in each of these calculations may, if desired, be left in the machine and used as the term A of the following calculation. The selection of addition or subtraction, and multiplication or division is made by control punches in the card. This will be explained in detail later.

The description of this control panel will be with reference to the planning chart and the wiring diagram. The explanation will take the program steps in the order they appear on the chart and explain the wiring associated with each. The encircled numbers on the wiring diagram indicate the programs in which numbers are transmitted through the designated wires.

X Card

Read cycle. A is read from columns 31 - 39 of the X card into storage unit 6.

The first control reading hub is wired to the X or balance pick up for pilot selector 1, which is picked up by an X punched in the X card in the first control reading position.

APPLICATION ______ PROBLEM $(A \pm B) \overset{\times}{\div} C$

IBM CALCULATING PUNCH TYPE 602 A PLANNING CHART

PROGRAM SUPPRESS	PROGRAM STEP	OPERATION	STORAGE UNIT 1L	STORAGE UNIT DIVR.–MULT. 1R	COUNTER DIVIDEND 1	DIVIDEND 2	DIVIDEND 3	4	5	6	STORAGE UNITS 2L	2R	3L	3R	4L	4R	PUNCH UNITS 6L	6R*	7L	7R*	PROGRAM STEP
		X CARD READ CYCLE N X CARD		C								B						A			
	1								+A									RO			1
	2								±B			RO									2
	3								RO RE					A ± B							3
DIVIDE	4	MULT.				(A± B) C								RO							4
ON	5					RO RE											(A± B) C				5
SKIP	6	IMPULSE READ															PUNCH				6
	7					(A ± B)								Ro							7
	8	DIVIDE		RO	–	–	–		$\frac{A \pm B}{C}$												8
	9				RE	RE	RE		RO RE								$\frac{A \pm B}{C}$				9
	10																				10
	11	IMPULSE READ															PUNCH				11
	12																				12

*UNITS POSITION MUST BE WIRED TO PUNCH

FORM 22-9323-1

FIGURE 1

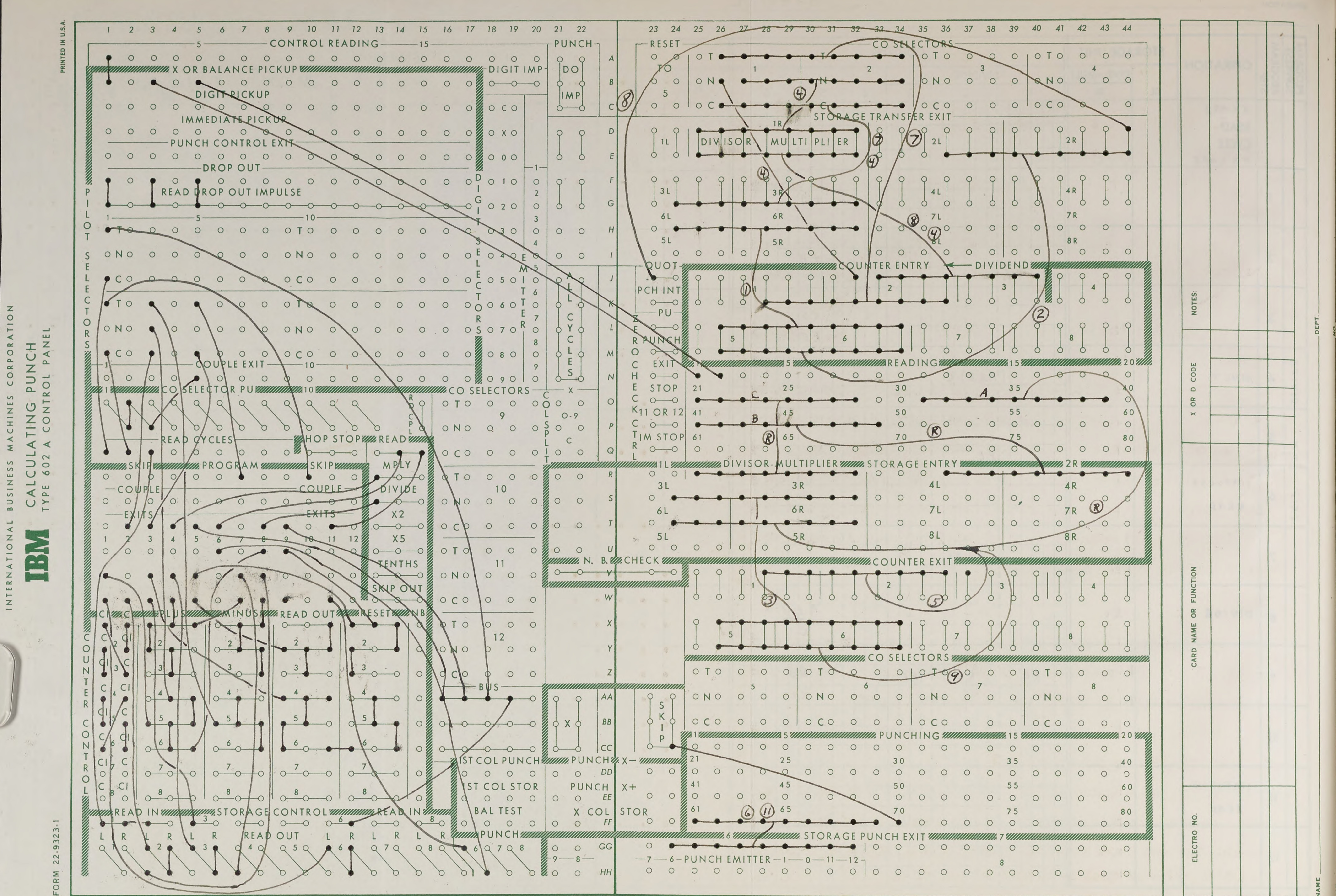
INTERNATIONAL BUSINESS MACHINES CORPORATION
IBM CALCULATING PUNCH
TYPE 602 A CONTROL PANEL
PRINTED IN U.S.A.
FORM 22-9323-1
CONTROL READING
PUNCH
RESET
CO SELECTORS
X OR BALANCE PICKUP
DIGIT IMP
DIGIT PICKUP
IMMEDIATE PICKUP
PUNCH CONTROL EXIT
DROP OUT
READ DROP OUT IMPULSE
STORAGE TRANSFER EXIT
DIVISOR-MULTIPLIER
PILOT SELECTORS
DIGIT SELECTORS
EMITTER
ALL CYCLES
ZERO CHECK CTRL
QUOT
PCH INT
PU
PUNCH
EXIT
STOP
11 OR 12
IM STOP
COUNTER ENTRY
DIVIDEND
READING
COUPLE EXIT
CO SELECTOR PU
COL SPLIT
READ CYCLES
HOP STOP
READ
SKIP
PROGRAM
MPLY
DIVIDE
X2
X5
TENTHS
SKIP OUT
COUPLE
EXITS
STORAGE ENTRY
N. B. CHECK
COUNTER EXIT
PLUS
MINUS
READ OUT
RESET
NB
COUNTER CONTROL
BUS
1ST COL PUNCH
1ST COL STOR
BAL TEST
PUNCH
X COL
STOR
PUNCHING
READ IN
STORAGE CONTROL
STORAGE PUNCH EXIT
PUNCH EMITTER
NOTES:
X OR D CODE
CARD NAME OR FUNCTION
ELECTRO NO.
DEPT.
NAME

FIGURE 2

The first read cycles hub is wired through the transferred side of pilot selector 1 to storage control read in.

On the right side of the board reading hubs 31 to 39 are wired to storage entry 6.

The balance of the programs are skipped by wiring from the second read cycles hub through the transferred side of pilot selector 1 to program skip 10.

Program 11. Program 10 is the next one taken, but since none of the program 10 exits are wired nothing will happen until the next program. Program 11 exits are wired to punch 6, and to read. An impulse to one of the punch hubs causes the figures in the corresponding storage unit to be punched in the card. Storage punch exit 6 is wired to punching hubs 61 - 69, the columns that will be punched in the card. The extreme right-hand position of a punch unit must be wired when punching from that unit.

Skip is always wired to the punch hub immediately following the last hub wired from storage punch exit.

NX Card

Read cycle. B is read from columns 41 - 49 and C from columns 21 - 28 of the NX card into storage units 2 and 1 respectively. The third read cycles hub is wired to storage control read in 1 and 2.

Reading hubs 41 - 49 are wired to storage entry 2, and reading hubs 21 - 28 are wired to storage entry 1.

Program 1. A is transferred from storage unit 6 to counters 4, 5, and 6 which are coupled together. Program 1 exits are wired to storage control read-out 6 and to counter control plus 4, 5, and 6. Storage transfer exit 6 is wired to counter entry 5 and 6.

Program 2. B is either added to or subtracted from A, depending upon the control punching in the card. If subtraction is desired, an X is punched in the first column of the card; for addition it is not punched. The first reading position is wired to X or balance pick up for pilot selector 3, which is, therefore, normal for addition and picked up for subtraction.

The performance of addition and subtraction are similar: with the first number in a counter, the second is entered in the same counter. If the counter control plus is wired from the exit for that program, the numbers will be added. If the counter control minus is wired, the second number will be subtracted from the first.

Program 2 exits are wired to storage control read-out 2, and through the normal side of pilot selector 3 to counter control plus 4, 5, and 6, or through the transferred side of pilot selector 3 to counter control minus 4, 5, and 6.

Storage transfer exit 2 is wired to counter entry 5 and 6.

Program 3. If the problem calls for division, an X is punched in the second column of the card. The second reading hub is wired to X or balance pick up for pilot selector 5, which is picked up for division.

The programs associated with multiplication are 4, 5, and 6. If multiplication is being performed, program 6 is the last one taken. Programs 7 through 11 are associated with division, and when division is being performed programs 4 through 6 are skipped.

In this program the quantity A±B is transferred from counters 5 and 6 to storage unit 3. Program 3 exits are wired to counter control read out and reset 4, 5, and 6, storage control read in 3, and through the transferred side of pilot selector 5 to program skip 7. The impulse from the program exit will not reach the skip hub unless division is to be performed and pilot selector 5 has been picked up.

Counter exits 5 and 6 are wired to storage entry 3.

Program 4. A ± B is read into counters 1, 2, and 3 where the product (A ± B) C is developed.

If there is a number in the storage unit 1R and another number is read into one of the counters in any program, the product of the two numbers will be developed in the counter, providing one of the multiply hubs is wired from an exit hub of the same program. The position of the decimal in the product will be the sum of the decimal places in the multiplier and the multiplicand.

Program 4 exits are wired to storage control read out 3, counter control plus 1, 2, and, and to multiply.

Storage transfer exit 3 is wired through the normal side of co-selectors 1 and 2 to one set of hubs of storage transfer exit 1. Since storage transfer exit 1 is wired to counter entries 2 and 3 for a later program, the circuit is completed between the normal hubs of the co-selectors and counter entries 2 and 3.

When a multiplicand is entered into a counter, its position is to the extreme right in the counter.

Program 5. The product (A ± B) C is read out of counters 1 and 2 and into storage unit 6. Each of the factors has four decimal places. The product will therefore have eight places, but since only four are desired, the first four places to the right are not wired from counter exit.

Program 5 exits are wired to counter control read out and reset 1, 2, and 3, and to storage control read in 6.

Counter exits 1 and 2 are wired to storage entry 6.

Program 6. (A ± B) C is punched from storage unit 6 into the card. Since the calculation is completed the next card is fed to the machine by an impulse to read.

Program 6 exits are wired to punch 6 and to read.

Storage punch exit 6 is wired to punching hubs 61 - 69, as previously stated.

Program 7. As previously explained, program 7 will be taken next after program 3 if division is to be performed.

A ± B is transferred from storage unit 3 to counters 1, 2, and 3. When division is being performed, the divisor is always entered in storage unit 1R, and the dividend in counters 1, 2, and 3. The dividend is entered in the counters so that the sum of the decimal places in the divisor and the decimal places desired in the quotient will equal the number of positions to the right of the decimal in the counters.

Program 7 exits are wired to storage control read out 3 and to counter control plus 1, 2, and 3.

Storage transfer exit 3 is wired through the transferred side of co-selectors 1 and 2 to counter entries 1 and 2. The co-selectors are picked up on division by a wire to the co-selector pick up hubs from the couple exit for pilot selector 5, which is picked up for division.

Program 8. The division of A ± B by C is performed in this program. Program 8 exits are wired to divide, to storage control read out 1R, and to counter controls minus 1, 2, and 3, and plus 4, 5, and 6.

Storage transfer exit 1 is wired to counter entries 2 and 3. One of the quotient hubs is wired to the extreme right position of counter entry 6 through the common hubs of the storage transfer exit 2 position that was previously wired to that counter entry position. The quotient is entered into the counter through this single wire.

Program 9. Counters 1, 2, and 3 are reset and the quotient is transferred from counters 5 and 6 to storage unit 6.

Program 9 exits are wired to counter controls reset 1, 2, and 3, read-out and reset 4, 5, and 6, and to storage control read in 6.

Counter exits 5 and 6 are wired to storage entry 6.

Program 10. None of the program 10 exits are wired. On X cards, however, when programs 1 through 9 are skipped, the skip hub of program 10 is wired from read cycles.

Program 11. The quotient in storage unit 6 is punched in the card as previously described for program 11 in the X Card explanation.

V. ADAPTATION OF THE CALCULATIONS TO THE CALCULATING MACHINE

A series of control panels for the IBM 602-A Calculating Punch were wired to enable the machine to perform the calculations as outlined in Calaulation Method. Some of the equations were rearranged to make them more easily adapted to machine computation.

In addition to being punched with a value of K, each card in the permanent file of K data was also punched with the reciprocal of that K. The determination of A and S are then similar and can be carried out with the same board.

$$A = (L/V)\ (1/K)$$

$$S = (V/L)\ (K)$$

The functions of A and S are also obtained with this board using the rearranged form of equations (15) and (30)

$$f_1(A) = \left\{\left[(A_1+1)\ A_2+1\right]\ .\ .\ .\ A_n+1\right\}$$

$$f_1(S) = \left\{\left[(S_I+1)\ S_{II}+1\right]\ .\ .\ .\ S_n+1\right\}$$

If the constants f and h are always taken as positive, equation (52) becomes

$$x_d = \frac{e \pm f\ D}{gD \pm hD^2}$$

and the cards are punched with x's to control the machine to add or subtract.

Equation (53) is altered in form with d − c always taken as positive.

$$x_s = \frac{x_d\ (a+b)}{c/D \pm (d-c)}$$

Control punching is again used to differentiate between plus and minus.

Table I lists the equations that are solved and the control panel used in each step of the calculation. The steps referred to are the same as used later in the detailed procedure.

TABLE I

CONTROL PANELS USED IN PERFORMING DIFFERENT CALCULATIONS

Step No.	Panel No.	Equation Solved
1		Preliminary details
2	1	$A = (L/V)\ (1/K)$
		$f_1(A) = \left\{\left[(A_1+1)\ A_2+1\right] \ldots A_n+1\right\}$
		$f_2(A) = A_1\ A_2 \ldots A_n$
		$S = (V/L)\ (K)$
		$f_1(S) = \left\{\left[(S_1+1)\ S_2+1\right] \ldots S_m+1\right\}$
		$f_2(S) = S_1\ S_2 \ldots S_m$
3	2	$b = R\ f_2(A)$
		$c = S_f\ f_1(S)$
		$d = (R+1)\ CK_s\ S_f\ f_2(S)$
4	3	$g = a + b + c$
		$h = d - (a + b + c)$
		$d - c$
5	1	$e = x_f\ c$
		$f = x_f\ (d - c)$
6	4	$x_d = \dfrac{e \pm fD}{gD \pm hD^2}$
		$\Sigma\ x_d = 1$
7	5	$x_s = \dfrac{x_d\ (a + b)}{C/D \pm (d - c)}$
8	2	$(Lx)_1 = A_1(R+1)\ Dx_d$
		$(Lx)_2 = A_2\ \left[(Lx)_1 + Dx_d\right]$

TABLE I continued

Step No.	Panel No.	Equation Solved
8 (con't.)		. . . . $(Lx)_f = \frac{(Lx)_n + D\,x_d}{S_f}$ . . . . $(Lx)_{II} = \frac{(Lx)_{III} - Bx_s}{S_{II}}$ $(Lx)_I = \frac{(Lx)_{II} - Bx_s}{S_I}$
9	6	$x_{a,n} = \frac{(Lx)_{a,n}}{\Sigma (Lx)_n}$
10	7	$\Sigma Kx = 1$ (for tray temperatures)

VI. DETAILED PROCEDURE FOR PERFORMING THE CALCULATION

Step 1; Preliminary Details

Supply the information required in Table II. This is the only portion of the problem that requires the judgment of a chemical engineer. Make the necessary calculations and fill in column 1 of Table III. After each complete calculation enter the data obtained in the next unused column.

Count out the decks of cards, and write the identifying symbol on the top card of each deck as specified in Table IV.

Select from the files the K cards for the specified pressure. Run the K cards through the sorter, removing the cards for components not present in the feed. The remaining cards constitute the working file of K cards for this problem.

Remove the K cards for the temperatures listed in Table III and divide them into two groups; one for the trays above the feed tray, and one for the feed tray and the trays below it. Set aside the K cards for the temperature of the reboiler for later use.

Arrange the first group with temperatures decreasing from top to bottom, and the second group with temperatures increasing from top to bottom.

Resort the two stacks, grouping the cards by components.

TABLE II

PRELIMINARY DATA

Pressure		
Reflux ratio (R)		
No. of trays above feed tray		
No. of trays below feed tray		
Feed composition	**Component**	**Mole Fraction**
Estimates		
Fraction of feed removed as distillate (D)		
Temperature of reboiler		
Temperature of top plate		

TABLE III

RESULTS OF CALCULATIONS

	Based on Table II	First Trial	Second Trial	Third Trial	Fourth Trial	Fifth Trial
D						
$V_m/L_m \left(= \frac{CD(R+1)}{1+(RC+C-1)D}\right)$						
Tray temperatures						
1 (top)						
2						
3						
feed						
III						
II						
I						
still						

TABLE III continued

	Based on Table II	First Trial	Second Trial	Third Trial	Fourth Trial	Fifth Trial
Compositions (last trial only)						
Distillate						
Bottom						

TABLE IV

DECKS OF CARDS REQUIRED FOR ONE COMPLETE CALCULATION

Identifying Symbol	Color of Cards	No. of Cards per Deck When Not Equal to Number of Components	No. of Decks
A_1, A_2, A_3. .	white		No. of trays above feed tray
f(A)	white	No. of components times No. of trays above feed tray	1
S_I, S_{II}, S_{III}. . .	white		No. of trays below feed tray plus one
f(S)	white	No. of components times No. of trays below feed tray	1
L/V	pink		1
V/L	pink		1
b 1	pink		1
c 1	pink		1
d 1	pink		1
b	white		1
c	white		1
d	white		1
d 2	pink		1
d 3	pink		1
d 4	pink		1
g	white		1
d - c	white		1

TABLE IV continued

Identifying Symbol	Color of Cards	No. of Cards per Deck When Not Equal to Number of Components	No. of Decks
e	white		1
e 1	pink		1
x_d	white		19
x_s	white		1
B 1	pink		1
B	white		1
D 1	pink		1
D	white		1
D 2	pink		1
Lx_1, Lx_2, . .	white		No. of trays above feed tray
L	white		1
Lx_f	white		1
Lx_I, Lx_{II}, . .	white		No. of trays below feed tray
x_1, x_2, . . .	white		No. of trays above feed tray
x_f	white		1
x_I, x_{II} . . .	white		No. of trays below feed tray
T	white	No. of trays plus one	1

Step 2

Control panel number 1, skip bar insert at column 52.

Reproduce the data from column 12 and columns 29 - 33 of the first stack of K cards, in column 12 and columns 46 - 50 of the A decks in numerical order.

Reproduce the data from column 12 and columns 19 - 23 of the second stack of K cards, in column 12 and columns 46 - 50 of the S decks in numerical order, followed by S_f deck. Remove the cards for the temperature of the feed tray from the stack of K cards, and reproduce the same data in deck f(S).

X punch column 3 in all cards in decks A and S.

Take one card from deck L/V and punch as follows:

X in first control reading position

1 in column 25

1 in column 35

L_n/V_n in columns 41 - 44

Using this as a master card, duplicate the punching in each of the other cards. Stack the A decks together, place one of the L/V cards on top, and run them through the machine. Remove the pink card and put the remainder aside for a later calculation.

Sort the deck f(A) by components and place one of the pink cards on top of the first card for each component. Run this deck through the machine. Discard all the cards except the last card for each component, i.e., the card on top of each pink card plus the bottom one. Write f(A) on the top card of the ones retained.

Take one card from deck V/L and punch as follows:

X in first control reading position

1 in column 25

1 in column 35

V_m/L_m in columns 41 - 44

Using this as a master card as before, duplicate the punching in the other cards. Stack the S decks together and place one of the V/L cards on top and run them through the machine. Remove the pink card and put the remainder aside for a later calculation.

Sort the deck f(S) by components and place one of the pink cards on top of the first card for each component. Run this deck through the machine. Discard all the cards except the last card for each component. Write f(S) on the top card of the ones retained.

Step 3

Control panel number 2, skip bar insert at column 61.

Punch an X in the first control reading position of each card in the bl, cl, and dl decks. Reproduce the results punched in the f(A) and f(S) decks in these three decks as follows:

Deck and columns from which data are taken	Deck and columns in which data are reproduced
f(S) 52 - 60	cl 31 - 39
f(S) 61 - 69	dl 31 - 39
f(A) 61 - 69	bl 31 - 39

The information entered in decks b, c, d, d2, d3, and d4 is punched in columns 21 - 28, with the decimal between columns 24 and 25. R is punched in each card in deck b, R + 1 is punched in each card in deck d2, and C is punched in each card in deck d4. If C is equal to one, this deck is omitted. The information in columns 61 - 69 of the first card for each component in the S deck is reproduced in decks c and d. The information in columns 19 - 23 of the K cards for the temperature of the reboiler is reproduced in deck d3.

Place the first b card under the first bl card, the second b card under the second bl card, and so on through both decks.

Repeat this procedure for the c and cl decks.

Place in the following order the first card from each of the decks involved: dl, d2, d3, d4, and d. These are followed by the second card from each deck, in the same order, and so on until the cards are in one stack. The three stacks of cards are run through the machine, after which the pink cards are discarded.

Step 4

Control panel number 3, skip bar insert at column 61.

Punch decks g and d - c as follows:

Deck and columns from which data are taken		Columns in which data are reproduced
f(A)	52 - 60	21 - 29
b	61 - 69	31 - 39
c	61 - 69	41 - 49
d	61 - 69	51 - 59

X punch the first column of each card in the d - c deck. Run both decks through the machine.

Step 5

Control panel number 1, skip bar insert at column 52.

Punch an X in the first column of a blank card and run it through the machine.

Reproduce the punching from the columns 61 - 69 and 70 - 78 of the d - e deck in columns 21 - 29 and 31 - 39 respectively of the el deck. Also punch an X in each of these cards in the first control reading position.

Enter the feed composition in deck e, in columns 47 - 50. Punch the mole fraction of the first component in the first card, the mole fraction of the second component in the second card, and so on. Place the first e card under the first el card, the second e card under the second el card, and so on until both decks are merged. Run the deck through the machine and discard the pink cards.

Punch an X in the second column of a blank card and run it through the machine.

Step 6

Control panel number 4, skip bar insert at column 70.

Reproduce the results punched in decks e and g in one of the x_d decks as follows:

Deck and columns from which data are taken	Columns in which data are reproduced
e 52 - 60	31 - 39
e 61 - 69	41 - 49
g 61 - 69	51 - 59
g 70 - 78	61 - 69

Examine each card in the d - e and g decks. If there is an X punched in column 79 of a card in the d - e deck, punch an X in column 1 of the corresponding card in x_d deck. If there is an X punched in column 79 of a card in the g deck, punch an X in column 2 of the corresponding card in x_d deck.

Reproduce eighteen duplicates of the x_d deck. A value of D is to be obtained, which will, when used in this calculation, give an answer equal to 1. A series of calculations is made using different values of D until the one is found that will give the result nearest to unity. Each value of D tried is punched in columns 26 - 28 of each card in one of the x_d decks. The selection of the values of D to use is best explained by an illustration. If D was estimated to be equal to .56, six decks of cards are punched with D equal to .45, .50, .55, .60, .65, and .70. The cards are run through the machine, and columns 75 - 80 of the last card in each deck (the white card) are inspected. These columns represent a six digit number, with the decimal after the first position.

If the answer obtained with D equal to .55 is greater than one, and the answer obtained with D equal to .60 is less than one, the next four decks are punched with D equal to .56, .57, .58, and .59. Again the results are examined and the range within which the correct value of D lies is determined. If .58 was too high and .57 was too low, the remaining nine decks are punched with D equal to .571, .572, .573, .574, .575, .576, .577, .578, and .579. These are run through the machine, and the one which gives the answer closest to unity is taken as the correct value of D. Discard all the x_d decks except the one in which the correct value of D is punched.

Step 7

Control panel number 5, skip bar insert at column 76.

Punch deck x_s as follows:

Deck and columns from which data are taken		Columns in which data are reproduced
d – c	21 – 29	21 – 29
d – c	31 – 39	31 – 39
d – c	41 – 49	41 – 49
d – c	70 – 78	51 – 59
x_d	70 – 74	61 – 65
x_d	26 – 28	66 – 68

Punch an X in column 1 of each card whose corresponding card in the d – c deck has an X punched in column 79.

Run the x_s deck through the machine.

Step 8

Control panel number 2, skip bar insert at column 61.

X punch the first control reading position of each card in B1 deck. Reproduce the information in columns 76 – 79 of x_s deck in columns 36 – 39.

Subtract D (obtained in step 6) from one, and punch the remainder in columns 25 – 27 of each card in B deck. Insert each B card under the corresponding B1 card and run the combined deck through the machine. Discard the pink cards.

X punch the first control reading position of each card in D1 deck. Reproduce the information in columns 70 – 73 of x_d deck in columns 36 – 39.

Punch D (obtained in step 6) in columns 25 – 27 in each card in D deck.

Punch R + 1 in each card in D2 deck in columns 21 - 28, with the decimal between columns 24 and 25.

Reproduce the information from column 12 and columns 62 - 69 of A_1 deck, in column 12 and columns 21 - 28 of Lx_1 deck. Place in the following order the first card from each of the decks involved: D1, D, D2, and Lx_1. These are followed by the second card from each deck, and so on until all the cards are in one stack. Run the stack through the machine and discard the pink cards. Separate the remaining cards into their two original decks, D and Lx_1.

Reproduce the following information as specified:

Deck and columns from which data are taken		Deck and columns in which data are reproduced	
Lx_1	61 - 69	L	31 - 39
A_2	12	Lx_2	12
A_2	62 - 69	Lx_2	21 - 28
D	61 - 69	Lx_2	41 - 49
A_3	12	Lx_3	12
A_3	62 - 69	Lx_3	21 - 28
D	61 - 69	Lx_3	41 - 49

(A deck similar to the above is punched for each tray above the feed tray.)

S_f	12	Lx_f	12
S_f	62 - 69	Lx_f	21 - 28
D	61 - 69	Lx_f	41 - 49

(A deck similar to the following is punched for each tray below the feed tray.)

S_{II}	12	Lx_{II}	12
S_{II}	62 - 69	Lx_{II}	21 - 28
B	61 - 69	Lx_{II}	41 - 49
S_I	12	Lx_I	12
S_I	62 - 69	Lx_I	21 - 28
B	61 - 69	Lx_I	41 - 49

Punch an X in the first control reading position of each card in the L deck. Punch an X in the second column of each card in the Lx_r deck. Punch an X in the first and second columns of each card in the Lx decks with the Roman subscripts.

Stack the decks in the following order from top to bottom: L, Lx_2, Lx_3, . . . Lx_r, . . . Lx_{II}, Lx_I.

In columns 9 and 10, punch each card with the number of the position of its deck in the stack. Sort the cards into groups of common components, and run them through the machine.

Resort the cards into the original decks.

Step 9

Control panel number 6, skip bar insert at columns 41 and 50.

Reproduce the information from columns 65 - 69 of decks Lx_1, Lx_2, Lx_3, . . . Lx_r, . . . Lx_{II}, and Lx_I, in columns 21 - 25 of decks x_1, x_2, x_3, . . . x_r, . . . x_{II}, and x_I respectively. Punch an X in the first control reading position in the last card of each deck. Run all the x decks through the machine. Punch an X in the first column of a blank card, and run it through the machine.

Take the last card in each deck and place it on the top of its own deck. Run the decks through the machine a second time. Punch an X in the second column of a blank card and run it through the machine.

Step 10

Control panel number 7, skip bar insert at column 76.

Punch X's in columns one and two, and in the first control reading position of each card in deck T. The information punched in columns 51 - 54 of all the cards in each of the x decks is transferred to each of the cards in the T deck. More specifically, the data in columns 51 - 54 of the first card in x_1 deck is punched in columns 25 - 28 of the first card in T deck. The data from the same columns in the second card in x_1 deck are punched in columns 29 - 32 of the same card, and so on until the data from all the cards in x_1 deck are punched in the first card in T deck. The same procedure is repeated for all the succeeding x decks. The data from columns 76 - 79 of the cards in the x_8 deck are similarly punched in the final card in T deck.

The object of step 10 is to determine the temperature of each tray in the column. A group of K cards for several adjacent temperatures are withdrawn from the K card file for the top tray temperature determination. The temperatures selected should range for several degrees on both sides of the estimated temperature for the tray. X punch in column 8 a blank card for each temperature represented in the group of K cards taken. Insert one of these cards below the last K card in each temperature group.

The machine will perform a series of calculations, one for each temperature, and will punch the results on the card following the K cards.

Place the first card from the T deck on top of the K cards and run them through the machine. When the correct temperature is passed, the machine will stop. Examine the last two results punched. The last one will be a number greater than one, and the proceeding one will be a number less than one. The temperature corresponding to the result nearest to one is the temperature of the tray.

Remove the cards from the feed hopper and stacker, discard all but the K cards, and replace them in the K file.

Repeat this procedure with each succeeding card in T deck, each time taking a new set of K cards.

Enter the results of this calculation in the second column of Table III. The entire calculation must be repeated until identical data are obtained for two consecutive trials.

APPENDIX: SAMPLE PROBLEM

A natural gasoline of composition given below is to be separated into an overhead product containing propane, isobutane, normal butane, and not over 3% isopentane, and a bottom product containing isopentane and heavier, and not over 5% normal butane. The column is to operate at 100 lbs./sq. in. absolute with a reflux ratio, L/D, of 3, and the feed is to enter in such a condition that no net vaporization or condensation occurs on the feed plate ($V_n = V_m$)

Feed composition (mole %)

Propane	15
Isobutane	15
Normal butane	25
Isopentane	10
Normal pentane	15
Heavier (hexanes)	20

Try a column having five plates, with the feed entering at the middle plate.

This problem illustrates this calculating method. It was worked on a desk calculator, however, not on an IBM machine.

TABLE II

PRELIMINARY DATA

Pressure	100 PSI	
Reflux ratio (R)	3	
No. of trays above feed tray	2	
No. of trays below feed trey	2	
Feed composition	Component	Mole fraction
	Propane	.15
	Iso Butane	.15
	N Butane	.25
	Iso Pentane	.10
	N Pentane	.15
	Hexanes	.20
Estimates		
Fraction of feed removed as distillate (D)	.5435	
Temperature of reboiler	242	
Temperature of top plate	133	

TABLE III

RESULTS OF CALCULATIONS

	Based on Table II	First Trial	Second Trial	Third Trial	Fourth Trial	Fifth Trial
D	.5435	.541	.538	.541	.541	
$V_m/L_m \left(= \frac{CD(R+1)}{1+(RC+C\ 1)D} \right)$	.826	.825	.823	.825	.825	
Tray temperatures						
1 (top)	133	137	137	137	137	
2	155	157	157	157	157	
3						
feed	177	177	177	177	177	
III						
II	198	198	197	197	197	
I	220	218	218	218	218	
still	242	238	238	238	238	

TABLE III continued

	Based on Table II	First Trial	Second Trial	Third Trial	Fourth Trial	Fifth Trial
Compositions (last trial only)						
Distillate						
C_3					.2769	
IC_4					.2640	
NC_4					.4087	
IC_5					.0322	
NC_5					.0169	
C_6					.0015	
Bottom						
C_3					.000383	
IC_4					.0156	
NC_4					.0628	
IC_5					.1801	
NC_5					.3058	
C_6					.4377	

Calculation Results for Third Trial

K

	Tray No. and Temperature °F.					
	1	2	f	II	I	still
Component	137	157	177	197	218	238
C_3	2.60	3.14	3.71	4.32	5.0	5.8
IC_4	1.07	1.34	1.64	1.96	2.33	2.75
NC_4	.83	1.07	1.34	1.64	1.99	2.37
IC_5	.37	.50	.65	.83	1.04	1.26
NC_5	.28	.37	.50	.66	.86	1.08
C_6	.14	.19	.26	.35	.45	.58

A or S

C_3	.288	.239	3.061	3.564	4.125	
IC_4	.701	.560	1.353	1.617	1.922	
NC_4	.904	.701	1.106	1.353	1.642	
IC_5	2.027	1.500	.536	.685	.858	
NC_5	2.679	2.027	.413	.545	.710	
C_6	5.357	3.947	.215	.289	.371	

	f_1 (A)	f_2 (A)	f_1 (S)	f_2 (S)
C_3	1.308	.0688	19.266	14.702
IC_4	1.953	.393	5.725	3.108
NC_4	2.335	.634	4.575	2.222
IC_5	5.541	3.041	2.273	.588
NC_5	8.457	5.430	1.932	.387
C_6	26.091	21.144	1.396	.107

	a	b	c	d
C_3	1.308	.2064	58.973	1044.065
IC_4	1.953	1.179	7.746	46.256
NC_4	2.335	1.902	5.060	23.297
IC_5	5.541	9.123	1.218	1.588
NC_5	8.457	16.290	.798	.690
C_6	26.091	63.432	.300	.0533

	e	f	g	h
C_3	8.850	147.764	60.487	983.578
IC_4	1.162	5.777	10.878	35.378
NC_4	1.265	4.559	9.297	14.000
IC_5	.1218	.0370	15.882	-14.294
NC_5	.1197	-.0162	25.545	-24.855
C_6	.0600	-.0494	89.823	-89.770

	x_d	Dx_d	x_s	Bx_s
C_3	.2769	.1498	.000383	.0001767
IC_4	.2640	.1428	.0156	.00716
NC_4	.4087	.2211	.0628	.0288
IC_5	.0322	.01742	.1801	.0826
NC_5	.0169	.009143	.3058	.1403
C_6	.0015	.0008115	.4377	.2009

Lx

	1	2	f	II	I	
C_3	.1725	.0770	.07409	.0207	.0049	
IC_4	.4004	.3042	.3303	.1998	.1002	
NC_4	.7994	.7154	.8467	.6045	.3506	
IC_5	.1412	.2379	.4763	.5747	.5735	
NC_5	.0977	.2168	.5469	.7460	.8640	
C_6	.01739	.0718	.3376	.4730	.7334	
total	1.6288	1.6231	2.6119	2.6197	2.6266	

X

	1	2	f	II	I	
C_3	.1059	.0474	.0283	.0079	.0018	
IC_4	.2458	.1874	.1264	.0762	.0381	
NC_4	.4907	.4407	.3241	.2308	.1334	
IC_5	.0866	.1465	.1823	.2194	.2183	
NC_5	.0601	.1335	.2093	.2848	.3289	
C_6	.01067	.0442	.1292	.1806	.2792	

Temperature Check

Tray No.	1	2	f	II	I	S
	137	157	177	197	218	238

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