The refrigerant flow to each condenser is maintained constant at all times unless the production unit is shut down, in which case the valve in the "Freon-11" supply line to the condenser on that unit is closed. The valve on the discharge line of the condenser is left open unless it is desired to disconnect the condenser from the system, in which case the valve is closed and the "Freon-11" drained into drums. A rupture disc was provided to give relief if both inlet and outlet valves on the condenser were accidentally closed.

The method by which the flow to each condenser is maintained constant is by inserting between the supply and return headers a by-pass with a diaphragm-operated valve set to maintain a constant pressure in the supply line. The pressure drops in the supply and return lines are negligible compared to those in the condensers so that holding the feed pressure constant automatically distributes the flow.

SCORE III. *Correctness of Solution.* Strangely, a considerable number of you believe the pressure drop through 12 condensers in parallel is 12 times that through one. It isn't. The power required for pumping is obtained by multiplying the volume handled in *your* system by the pressure drop across the pump required to circulate that volume through *your* system. It is not found by scaling up in proportion to your capacity the power required by J. C. Lawrence's pumps which may have worked against some head other than yours. These were the most frequent errors of method, although Bernoulli's theorem is still a mystery to some of you.

Credit was given for directness of solution as opposed to long cut-and-try methods, and for the exercise of judgment in the avoidance of elaborate methods when sufficiently good approximate methods were available.

Please do not feel from the above paragraphs that most of your solutions were poor. Many were very good indeed. The great majority arranged their solutions well, and gave proper reference to sources.

Problem Committee,

J. H. BOYD, JR.,
T. B. DREW,
R. P. GENEREAUX,
HOOD WORTHINGTON.

1940 ANNUAL STUDENT CONTEST PROBLEM

FOREWORD

Each year the Council of the American Institute of Chemical Engineers authorizes the Committee on Student Chapters, through a sub-committee to prepare a contest problem. All members of student chapters of the Institute are eligible to compete.

The sub-committee of the Committee on Student Chapters which prepared the problem and corrected the solutions submitted, consisted of the following: W. B. Rose, R. Voorhees, C. M. Cooper, I. L. Murray, and W. T. Nichols, Chairman. The sub-committee attempts at all times to make the problem one of a practical nature and typical of those which would be encountered in regular industrial work rather than simply to submit a problem of an academic nature.

The first prize, the A. McLaren White Award of $100.00 was given to Mr. Howard Campbell, McGill University, whose solution appears on the following pages. The other prize winners were as follows:

Wilmer L. Kranich, University of Pennsylvania, Second Prize—$50.00.
Leroy N. Chellis, Clarkson College of Technology, Third Prize—$25.00.
O. R. McIntire, University of Kansas, Honorable Mention and $10.00.

The Committee on Student Chapters and the Council of the American Institute of Chemical Engineers take this opportunity to express their appreciation to the sub-committee for the excellent manner in which the entire contest was handled.

CONTEST PROBLEM

1940

STUDENT CHAPTERS—AMERICAN INSTITUTE OF CHEMICAL ENGINEERS

Open Only to Undergraduates or Those Without a Degree in Chemical Engineering

DEADLINE FOR MAILING—Must be Postmarked not later than March 15, 1940 (See Rules)

Dear Contestant:

From now until you have turned in your solution to this problem, instead of being a student, you are a newly employed chemical engineer to whom we have turned for help in arriving at a decision important to the company for which we are all working. Your name is Mr. N. E. O'Phyte.

The problem is presented to you just as it might be under the conditions described above. It is a real problem, with a real solution. The solution could actually be used to determine the course of action of a company employing the operations described.

We wish you luck, and hope you really enjoy the problem. We're pulling for you just as we should if you were actually in our employ.

THE COMMITTEE.

RULES OF THE CONTEST

Solutions will be graded on (a) conclusions reached, (b) accuracy of computations, and (c) form of presentation.

It is to be assumed that the statement of the problem contains all the data available and your instructor is not to be consulted in regard to doubtful points. The problem is not to be discussed with any person whatever until after March 15, 1940. This is particularly important in cases where neighboring institutions may not begin the problem until after its completion by another chapter. The use of textbooks, handbooks, journal articles, and lecture notes is permitted. Submittal of a solution for the competition implies adherence to the above conditions.

A period of not more than 24 consecutive days is allowed for completion of the solution. This period may be selected at the discretion of the individual counsellor, but a solution must be postmarked not later than midnight March 15, 1940, in order to be eligible. Each solution should be accompanied by a letter of transmittal giving only the contestant's name, school address, home address, and student chapter, lightly attached to the report. This letter will be retained for identification by the Chairman of the Committee on Student Chapters. The solution itself must bear no reference to the student's name or institution by which it might be identified. Each counsellor should select the best solution, or solutions, from his chapter, not to exceed two in number, and send these registered mail to

PROFESSOR M. C. MOLSTAD,
ENGINEERING DEPT.,
UNIVERSITY OF PENNSYLVANIA,
PHILADELPHIA, PA.

INTEROFFICE MEMORANDUM
ENGINEERING DEPARTMENT

Sept. 9, 1939

To: MR. N. E. O'PHYTE

From: MR. I. L. MURRAY

Although you have been with us only a very short time and have had no industrial experience, I am going to ask you to do a very important job for us. The fact that I am leaving the plant immediately and shall be gone for about two weeks has prevented me from talking the matter over with you.

We have been instructed by our New York Office to double the production of our Acetic Acid Concentrating Department immediately. At present we feed weak acid into a continuous still where it is mixed with isopropyl acetate and essentially all the water is removed by azeotropic distillation. The strength of the acid leaving the base of the still is close to 100 per cent. This method has been satisfactory and the obvious procedure is to put in a second duplicate still. I am not convinced, however, that a second still need be as large in diameter as the present one, nor even that the process we now use is the most economical. Our Research Department recently suggested that we

consider as a substitute solvent extraction to remove most of the water, followed by distillation of the extract to remove the rest, and this process seems to me well worthy of investigation.

Before deciding on how to extend the plant, I would like to know approximately how much we would save (if anything) in investment and manufacturing cost by switching to solvent extraction. The savings would have to be considerable to outweigh our inexperience with this type of equipment.

I have already talked to Mr. Cooper, our factory manager, and have written Mr. Voorhees, asking that he give you whatever engineering data you may need. He will also supply you with details regarding our accounting practices and the approximate costs of various types of equipment and raw materials which may be involved.

I should like to advise you to devote a considerable amount of time to analyzing your problem before starting actual calculations. A practical analysis can be made only after you have assembled all the necessary facts, but if the analysis is made properly, it will probably save many hours of labor. You should try to visualize each step in the procedure of working out the problem before you start actual work on any particular step.

I have asked Mr. Voorhees to outline for you our reporting procedure. I wish to emphasize the fact that we are looking for an indication as to which way to proceed and your report will, therefore, not be a final estimate, and it will probably turn out that extreme accuracy in calculating will not be significant in determining which of the processes should be chosen.

cc. Mr. I. L. Murray

INTEROFFICE MEMORANDUM
OPERATING DEPARTMENT

Sept. 10, 1939

To: Mr. N. E. O'Phyte

From: Mr. C. M. Cooper

As requested by Mr. Murray, I give you herewith the details with regard to our acetic acid concentration system.

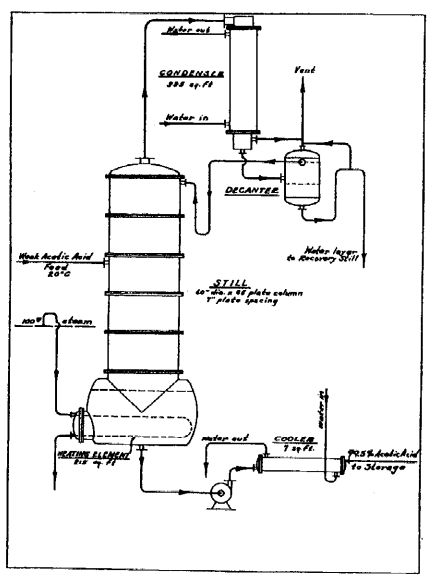
The system turns out 99.5 per cent acid by weight. Current figures for production and acid feed concentration for the past year

You may also need the data on our water temperature conditions.

Monthly Average Cooling Water Temperatures
(Four-Year Average)

Month	Temperature °C.
January	5.8
February	4.4
March	6.5
April	12.6
May	18.1
June	24.1
July	26.7
August	25.4
September	23.8
October	17.1
November	10.1
December	5.0

Note: Individual temperature readings may vary ±3.0° C. from a smooth curve drawn through the above points.



may be taken as representative of the operation of this system and are as follows:

Calendar Months	Acetic Acid Produced (expressed as 100% acid)	Wt.% Acid in Feed
September	123,000 lbs.	28.6
October	145,000	30.7
November	107,000	31.4
December	167,000	26.2
January	200,000	25.6
February	203,000	32.1
March	155,000	29.5
April	162,000	30.2
May	136,000	25.4
June	98,000	31.1
July	61,000	29.7
August	82,000	34.8
Total	1,639,000	

At present this acid is being concentrated in a 60″ diameter 35-plate atmospheric pressure continuous still by azeotropic distillation with isopropyl acetate. The entire top layer feeds back from the decanter to the column. 99.6 per cent of the weak acid is recovered as strong acid, the other 0.4 per cent being lost. The plate spacing is 7″, and the maximum pressure drop noted amounts to about 1.5″ water per plate. A flow sheet of this distillation system is attached. Equipment sizes are given on the flow sheet. The isopropyl acetate in the water layer leaving the decanter is recovered elsewhere in the plant and may be left out of the calculations. Other losses of isopropyl acetate are of negligible importance.

Please note that there is a seasonal fluctuation in production. This may be expected to continue as indicated. Also note that building height limitations will not allow the use of columns higher than that already in use, and this limitation applies also to any other equipment which you may figure on. I note that you are going to give consideration to substituting an extraction system. In this connection, I have available an extraction column, previously used in one of our operations, which could be used if its size is satisfactory. This column is in excellent condition and is at present in our salvage storage, its cost having already been written off. It is 18″ in diameter, of satisfactory design, is packed for 25′ with ½″ Raschig rings, and originally cost $2150.00. This column is about as high as could be accommodated in the building.

INTEROFFICE MEMORANDUM
RESEARCH DEPARTMENT

Sept. 10, 1939

To: Mr. N. E. O'Phyte

From: Mr. W. B. Rose

Mr. Murray has asked me to give you what data we have regarding extraction processes for concentrating acetic acid. I am afraid we haven't much. We were giving some consideration to this matter some months ago, but the work was discontinued in favor of more important matters before we had an opportunity to do much more than determine what are apparently the best extraction agents for acetic acid.

The best we were able to find were methyl isobutyl ketone and isopropyl ether. I am attaching all of the data we have at present, including some of the physical properties of isopropyl acetate and acetic acid, which you may need. I believe Mr. Voorhees, of your department, has made some calculations on these two systems and may be able to supply some useful data.

Vapor Pressures of Isopropyl Acetate, Isopropyl Ether, Methyl Isobutyl Ketone, and Acetic Acid Versus Temperature

	Temperature, °C.			
Vapor Pressure mm. Hg.	Isopropyl Acetate	Isopropyl Ether	Methyl Isobutyl Ketone	Acetic Acid
760	88.4	68.4	116.0	118.0
700	86.0	65.8	113.7	115.4
600	81.1	61.1	108.2	110.4
500	75.5	55.8	101.2	105.2
400	69.0	49.4	94.2	98.1
300	61.6	41.6	86.0	89.7
200	51.4	31.4	75.0	78.8
100	35.2	—	57.2	62.2
50	23.0	—	41.0	47.2

PHYSICAL PROPERTIES OF ISOPROPYL ACETATE, ISOPROPYL ETHER, METHYL ISOBUTYL KETONE, AND ACETIC ACID

	Specific Gravity at 20/20° C.	Change in Specific Gravity per °C.	Specific Heat Btu/Lb./°F.	Latent Heat of Vaporization Btu/Lb.
Isopropyl Acetate	0.8737	0.00115	0.45	149
Isopropyl Ether	0.7252	0.001033	0.60	132
Methyl Isobutyl Ketone	0.8024	0.000914	0.45	158
Acetic Acid	1.051	0.001122	0.55	174

Note: The above values for specific and latent heats may be considered constant over the temperature ranges involved in your design calculations.

COMPOSITION OF ISOPROPYL ACETATE-WATER, ISOPROPYL ETHER-WATER, AND METHYL ISOBUTYL KETONE-WATER CONSTANT BOILING MIXTURES

1. *Isopropyl Acetate-Water*

	Composition, % by Weight				
	Relative Volume of Layers	Isopropyl Acetate	Water	B.P. 760 mm. °C.	Sp.Gr. at 20/20 °C.
Heterogeneous					
Binary CBM	—	90.0	10.0	75.9	—
Top layer	91.4	98.2	1.8	—	0.875
Bottom layer	8.6	2.9	97.1	—	0.995

2. *Isopropyl Ether-Water*

	Composition, % by Weight				
	Relative Volume of Layers	Isopropyl Ether	Water	B.P. 760 mm. °C.	Sp.Gr. at 20/20 °C
Heterogeneous					
Binary CBM	—	95.9	4.1	62.2	—
Top layer	97.0	99.4	0.6	—	0.725
Bottom layer	3.0	1.2	98.8	—	0.997

3. *Methyl Isobutyl Ketone-Water*

	Composition, % by Weight				
	Relative Volume of Layers	Methyl Isobutyl Ketone	Water	B.P. 760 mm. °C.	Sp.Gr. at 20/20 °C.
Heterogeneous					
Binary CBM	—	75.1	24.9	87.9	—
Top layer	80.4	97.7	2.3	—	0.805
Bottom layer	19.6	2.0	98.0	—	0.996

EQUILIBRIUM AND MUTUAL SOLUBILITY DATA FOR THE SYSTEMS ACETIC ACID-WATER-ISOPROPYL ETHER AND ACETIC ACID-WATER-METHYL ISOBUTYL KETONE

1. *Acetic Acid-Water-Isopropyl Ether (at 20° C.)*

*Soly. of Water in Ether-Acid			*Soly. of Ether in Water-Acid		
Ether Wt. %	Acid Wt. %	Water	Water Wt. %	Acid Wt. %	Ether
100.0	.0	0.6%	100.0	.0	1.2%
84.9	15.1	4.8	62.4	37.6	4.1
67.5	32.5	9.9	53.8	46.2	7.8
56.6	43.4	16.3	49.1	50.9	11.8
38.4	61.6	29.2	42.9	57.1	19.4

†Equilibrium Data

Ether Layer		Water Layer	
Acetic Acid Wt. %	Density gm./cc.	Acetic Acid Wt. %	Density gm./cc.
0.18	0.725	0.69	0.998
0.37	0.726	1.41	0.999
0.79	0.728	2.89	1.001
1.93	0.732	6.42	1.006
4.82	0.744	13.30	1.015
11.40	0.770	25.50	1.032
21.60	—	36.70	—
31.10	—	44.30	—
36.20	—	46.40	—

2. *Acetic Acid-Water-Methyl Isobutyl Ketone (at 25° C.)*

*Soly. of Water in Ketone-Acid			*Soly. of Ketone in Water-Acid		
Ketone Wt. %	Acid Wt. %	Water	Water Wt. %	Acid Wt. %	Ketone
100.0	.0	2.16%	100.0	.0	1.58%
87.3	12.7	7.0	79.8	20.2	3.8
75.5	24.5	13.6	64.3	35.7	11.8
63.9	36.1	23.8	58.6	41.4	21.1
53.0	47.0	41.0	53.5	46.5	35.2

†Equilibrium Data

Ketone Layer		Water Layer	
Acetic Acid Wt. %	Density gm./cc.	Acetic Acid Wt. %	Density gm./cc.
1.87	0.798	2.85	0.995
8.9	0.804	11.7	0.996
17.3	0.807	20.5	0.998
24.6	0.809	26.2	0.999
30.8	0.811	32.8	1.000
33.6	0.812	34.6	1.001

It may be assumed that the above data are unaffected by temperature over the range involved in your design calculations.

* For example, when sufficient water is added to a mixture of ether and acid containing 56.6% ether to saturate it with respect to water, the resultant mixture of ether, acid, and water contains 16.3% water by wt.

† For example, when the concentration of acid in the ether layer is 4.82%, the corresponding acid concentration in the water layer is 13.30%.

INTEROFFICE MEMORANDUM
ENGINEERING DEPARTMENT

Sept. 11, 1939

To: MR. N. E. O'PHYTE

From: MR. R. VOORHEES

Following our brief conference this morning, I have given some consideration to the matter with which you are dealing. Mr. Cooper has given you the basic information regarding the currently operated distillation process. You also have the necessary data from Mr. Rose on the two possibilities for operation of an extraction system. I have done very little with these latter possibilities, as mentioned by Mr. Rose. I am attaching data resulting from some calculations of the height of transfer units and flooding velocities for columns used for extracting acetic acid with methyl isobutyl ketone and isopropyl ether, but have given no thought to the relative merits of these solvents and have no time to do so now. Mr. Murray had time to give you only the briefest instructions. I believe it may be helpful if I somewhat amplify the information contained in his memo.

Here is what you are expected to do:

We can double our production of concentrated acetic acid either by making additions to our present azeotropic distillation system if required, or by substituting for it a solvent extraction-distillation system. You should calculate the capital investment and operating costs involved in the two methods, and determine which will be the preferred direction to move. After having done so, you should report your findings in the form of a report to Mr. Murray in as brief, concise, and clear a manner as is consistent with giving a complete account of your work.

In connection with reporting, I advise the following segregation of subjects:

A. *Introduction*

B. *Summary of Results*

State which process you would recommend and give a tabulation of cost figures which will show the basis for your conclusion.

C. *Azeotropic Distillation*

Outline your procedure used to arrive at the design and cost calculations for this process.

D. *Solvent Extration Systems*

Do the same here.

E. *Calculations*

All of your calculating methods should be demonstrated. However, you need not include in your report every calculation in detail. For instance, if you make several calculations by the same formula, give the formula and a sample calculation, possibly tabulating the other resultant figures, along with the corresponding values used in deriving them.

F. *Flow Diagrams*

Include whatever flow diagrams you consider necessary.

The following discussion may be helpful.

If a solvent extraction process is used, it appears from preliminary laboratory work that the best extracting agents are either methyl isobutyl ketone or isopropyl ether, and that the solvent phase should be dispersed. The extraction process would consist of continuous countercurrent liquid-phase extraction of the acetic acid by the solvent, followed by atmospheric pressure distillation of the extract, during which water in the extract would be removed azeotropically along with excess solvent, if any excess were present. It may be assumed that the still should be operated under conditions such that the recovered solvent contains 0.001 per cent acid. The purity of the acid from the base of the still should be 99.5 per cent, as in the present process. Solvent in the raffinate from the extractor and in the water layer from the still decanter may be recovered elsewhere in the plant in existing equipment at so low a cost that it may be neglected. Other losses of solvent, as well as losses of acid other than that in the raffinate, may also be neglected.

In your cost calculations, the value of glacial acetic acid may be taken as $0.055 per pound, the cost of isopropyl acetate $0.051 per pound, the cost of isopropyl ether $0.060 per pound, and the cost of methyl isobutyl ketone $0.105 per pound. Steam (saturated, at 100 lbs./sq.in.ga.) is charged in the plant at $0.30 per thousand

pounds. The cost of cooling water and of electric power may be neglected. It may be assumed that labor and repair costs will be the same for either process. In this plant fixed charges on new investment are computed on the basis of 20 per cent per year.

Other assumptions which may be made and other data which are available include the following:

1. The plant operates 24 hours per day, and it is not necessary to consider down-time for repairs.
2. In the existing isopropyl acetate dehydration process, it may be assumed that the distillate is the true constant boiling mixture.
3. In the two extraction processes, it is specified that the recovered solvent is to contain 0.001 per cent acid. In determining the performance of the extractor, however, it will be permissible to assume that the solvent is acid-free.
4. In determining the operating conditions in the still handling the extract, the method of McCabe and Thiele may be employed. The fact that the feed and reflux are not at their respective boiling points may be ignored, and constant molal overflow may be assumed. In constructing the liquid-vapor equilibrium diagram, the presence of water may be neglected, and it may be assumed that mixtures of solvent and acid obey Raoult's law. In calculating the composition of the feed and product, however, the presence of the water should be taken into account, by assuming the water to be equivalent to an equal number of mols of solvent.
5. Heat transfer coefficients in all condensers may be taken as 150 Btu/hr./sq.ft./°F. for the condensing load and 50 Btu/hr./sq.ft./°F. for the condensate cooling load. Heat transfer coefficients in heating elements in still kettles and in coolers may be taken as 150 Btu/hr./sq.ft./°F.
6. Material leaving condensers and coolers should be at 35° C. For design purposes it may be assumed that the cooling water temperature should rise 15° C. in passing through the apparatus.
7. The cost of still columns may be estimated on the basis of $15.00 per sq. ft. of plate surface. Still columns should be specified in diameters which are multiples of 6".

H.T.U. AND FLOODING VELOCITY DATA FOR COLUMNS PACKED WITH ½" RASCHIG RINGS

(Solvent Phase Dispersed)

	$(H.T.U.)_{ow}$ Ft.	Flooding Velocity Cu.Ft./Hr./Sq.Ft.
Acetic Acid-Water-Isopropyl Ether	1.5	180
Acetic Acid-Water-Methyl Isobutyl Ketone	1.0	135

Note: $(H.T.U.)_{ow}$ is defined as the height of a transfer unit based on the overall difference between the actual concentration of solute in the water phase and the concentration of solute in the water phase which is in equilibrium with the solvent phase. It may be assumed that the values of $(H.T.U.)_{ow}$ given above are independent of operating conditions over the range involved in the design.

The flooding velocities given refer to the sum of the volumes of the two phases, measured at the respective liquid inlets.

We have recently done some work on extraction, in connection with another process, and have found a new method of calculation developed by A. P. Colburn ["The Simplified Calculation of Diffusional Processes. General Consideration of Two-Film Resistances," by Allan P. Colburn, Transactions of the A.I.Ch.E., Vol. 35, No. 2, p. 211 (1939)] to be the least tedious method which gives reliable results. Please note that I have established, by means of correspondence with Dr. Colburn, that a typographical error exists in Equation 13 on page 215. The expression, $(y_1 - y_2)$, should read, (y_1/y_2). This method may be outlined as follows:

The basic equation for the number of transfer units is:

$$N = \frac{Z}{(H.T.U.)_{ow}} = \int_{y_2}^{y_1} \frac{(dy)\ (1-y)_f}{(y-y^*)\ (1-y)}$$

(See table of nomenclature below.)

By making certain simplifying assumptions, this may be integrated as follows:

$$N = \frac{2.3}{(1 - mG_M/L_M)} \log[(1 - mG_M/L_M)\ (y_1/y_2) + mG_M/L_M]$$

(There is a typographical error in this equation in the original article.)

A plot of this equation is given in Fig. 1, attached.

8. Extraction columns may be estimated on the basis of $50.00 per cu. ft. of packed height.
9. The following data are available for estimating the cost of heat exchange equipment:

Surface, Sq.Ft.	Cost, $/Sq.Ft.
Under 50	12.00
" 100	9.00
" 200	7.25
" 300	5.25
" 500	5.00
" 1000	3.50

The cost of exchangers smaller than 10 sq. ft. may be assumed to be constant at $200.00.

10. The total cost of whatever installation is made (including miscellaneous minor equipment, instruments, piping, foundations, engineering, overhead, etc.) may be taken as 250 per cent of the cost of the major equipment, which includes still columns, extractor, and heat exchange surface.
11. It should be noted that due to association, vapor of acetic acid has an apparent molecular weight of 102.
12. For still columns having a plate spacing of 7", the allowable vapor velocity at any point in the column may be calculated by the expression

$$u = 0.065 \sqrt{\frac{d_l - d_v}{d_v}}$$

where u = allowable superficial vapor velocity, ft/sec.

d_l = density of liquid on plate, lbs./cu.ft., measured at column conditions. (Where two phases are presented, d_l applies to lighter liquid.)

d_v = density of vapor, lbs./cu.ft., measured at column conditions.

For such columns, the plate efficiency may be taken to be 65 per cent.

13. The following table includes data which may be of use in the calculations.

From this plot the number of transfer units required to effect a given separation may be determined for any value of mG_M/L_M.

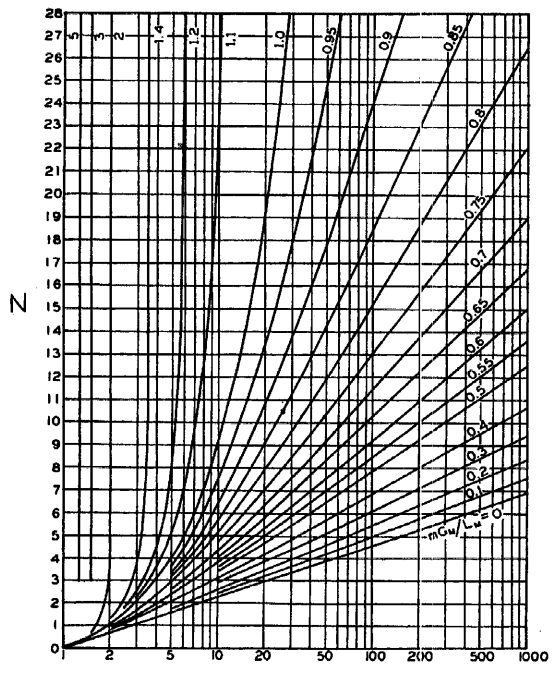


FIG. 1. Plot of Equation 13 taken from Transactions A.I.Ch.E., Vol. 35, No. 2, p. 216.

If the height of a transfer unit is known, the column height is then readily calculated.

TABLE OF NOMENCLATURE

d = differential operator.
G_M = molar velocity of water phase, lb.-mols/(hr.)(sq.ft.)
$(H.T.U.)_{OW}$ = height of a transfer unit, feet, based on the overall difference between the actual concentration of solute in the water phase and the concentration of solute in the water phase which is in equilibrium with the solvent phase.
L_M = molar velocity of solvent phase, lb.mols/(hr.)(sq.ft.)
m = slope of equilibrium line = dy^*/dx
N = number of overall transfer units, based on change in solute concentration in water phase.
x = mol fraction of solute in solvent phase.
y = mol fraction of solute in water phase.
y^* = equilibrium value of y corresponding to x.
$(1-y)_f$ = log mean of $(1-y)$ and $(1-y^*)$.
Z = column height, feet.

Subscripts:

1 = evaluated at rich end of apparatus.
2 = evaluated at lean end of apparatus.

There are two or three things you have to watch in using this method. First, y and G_M must refer to the water phase (Colburn, in his discussion of extraction, lets these terms refer to the solvent phase, which is permissible in general but which will not work if the attached graph is employed). Second, the term, mG_M/L_M, should be evaluated at the lean end of the apparatus, since most of the transfer units are required at that end. Third, be careful of what units you use. I would suggest that you stick strictly to those given in the table of nomenclature above.

Since the attached graph represents an equation which is accurate only if the assumptions made in its derivation are correct, its use in solving extraction problems will not give absolutely accurate results unless these assumptions hold. For the type of work you are doing, however, I believe the method will give results which are quite close enough.

Although the above outline should be sufficient for your purposes, Colburn's original article can, as you know, be found in our library.

Here are some additional specific pointers for you:

1. Remember that acid concentrations are in terms of weight percent.
2. I have been unable to locate the file covering the original design of our current azeotropic distillation unit. However, in order to save time, I believe you should consider that the existing accessories, such as condenser, heater, etc., are matched to the capacity of the column, and that if additional column capacity is required for the isopropyl acetate system, accessories can be used of sizes in direct proportion to the additional column capacity.
3. I do not recommend that you use any plate spacing other than 7". Building height limitations will therefore prevent the use of more than 35 plates in any column.
4. Note that the weak acid comes to either process at a temperature of 20° C., throughout the year.

ERRORS IN THE PROBLEM

The data for the constant boiling mixture, isopropyl acetate-water, contain a slight inconsistency. If the volumetric data for the top and bottom layers are employed in calculating the composition of the heterogeneous CBM, a composition of about 89 wt. % isopropyl acetate and 11 wt. % water is obtained. The above inconsistency was due to the presentation of experimentally determined values in all cases rather than the corresponding data calculated from only several of the basic experimentally determined values. This discrepancy has no effect on the solution of the problem, however. The data for the other CBM's contain similar inconsistencies. These data appear on page 600 of the Problem Statement.

The footnote describing the mutual solubility data for the systems acetic acid-water-isopropyl ether, and acetic acid-water-methyl isobutyl ketone, on page 601 of the problem statement, is incorrect as given. The footnote should read as follows:

" For example, the addition of 16.3 weight units of water is required for the saturation of 100 weight units of a mixture of acetic acid and water, containing 56.6% acid."*

This misstatement of the footnote, fortunately, has but a very minor effect on the correct solution of the problem.

A.I.Ch.E. Annual Student Competition

FIRST PRIZE WINNING SOLUTION

Contest Problem, 1940, Student Chapters, A.I.Ch.E.

REPORT ON THE ESTIMATED COSTS OF DOUBLING THE PRODUCTION OF THE ACETIC ACID CONCENTRATING DEPARTMENT *

BY HOWARD CAMPBELL, McGill University Student Chapter
McGill University, Montreal, Canada

ENGINEERING DEPARTMENT

March 6th, 1940

To: Mr. I. L. Murray.

Having investigated the possible methods of doubling the production of the Acetic Acid Concentrating Department with a view to capital investment required and costs of operation, I am now in a position to make some recommendations. For your convenience I have segregated the material of this report into the following sections:

I. Summary of Results and Proposed System.
II. Outlines of the Methods of Analysis of Each Possibility.
III. Calculations Involved.
IV. Summary of Sources of Data Used in the Calculations.

I would like to thank you for giving me the opportunity of tackling this problem, knowing the little experience that I have had. I hope, however, that I have justified your confidence.

Yours very truly,
N. E. O'PHYTE.

I. SUMMARY OF RESULTS AND RECOMMENDATIONS

At your suggestion I worked out the diameter of the still column necessary for azeotropic distillation with isopropyl acetate. My results show that the column now in use is as small as the production

* *Throughout the solution, statements in italics are comments by the Committee.*

will allow. Hence if this system is to be used the investment will be the installed cost of a duplicate plant.

In regard to the use of solvent extraction, I have devoted time only to the possibility of using just one of the solvents suggested by the research department. I consider that methyl isobutyl ketone would not be satisfactory for use in this plant. I have outlined my reasons for this under that heading.

Solvent extraction with isopropyl ether has definite possibilities. My calculations show that the production of the department can be doubled by merely installing an extractor into the present arrangement. Mr. C. M. Cooper has an extraction column in the salvage stores whose cost has been written off and which I find satisfactory to use. Thus the investment for this method is simply the cost of installing the column and that of the isopropyl ether needed.

I would recommend that this be the plan used. That the column in the salvage storage be installed with the present equipment and that the process used be continuous countercurrent extraction of the dilute solution with the solvent dispersed, using isopropyl ether, followed by separation of the acid from the solvent by distillation at atmospheric pressure. I have included flow diagrams of both processes.

In the flow sheet for the solvent extraction system, the contestant has used a pump for return of solvent from recovery still decanter to the extractor. By sufficient elevation of the condenser and decanter, a gravity return could be employed. The statement of the problem did not indicate this to be possible, and contestant was thus justified in using a pump.

The raffinate from the extractor would normally pass out through an overflow loop to maintain the desired liquid level.

In the following table, steam costs are based on 3,278,000 lbs. of glacial acetic acid per year, which is the desired production. Fixed charges are on a basis of 20 per cent of new investments.

TABULATION OF INVESTMENT AND COST OF OPERATION FOR POSSIBLE PROCESSES

	Capital Investment	Fixed Charges per Year	Steam Costs per Year
Azeotropic Distillation with Isopropyl Acetate (current process)	$34,000	$6,800	$9,850
Solvent Extraction using Isoproyl Ether	$3,725	$ 745	$3,880