STUDENT CONTEST PROBLEM FOR 1941

Foreword

At the request of the Council of the American Institute of Chemical Engineers, the Committee on Student Chapters appointed a subcommittee to prepare and handle the details of the 1941 student contest problem. The subcommittee consisted of: G. L. McCoy, J. A. Rice, H. W. Field and W. T. Dixon, Chairman. This committee merits the hearty appreciation of Council for their fine spirit of cooperation and the efficient manner in which they conducted the mechanics of this contest.

The first prize, the A. McLaren White Award of $100.00 was presented to Mr. E. Bruce Powell, Clarkson College of Technology, whose solution appears on the following pages. The other prize winners were as follows:

Weller R. Pierce, Clarkson College of Technology, Second Prize—$50.00.

Sidney M. Feldman, College of the City of New York, Third Prize—$25.00.

Robert Lee Powell, University of Missouri, Honorable Mention—$10.00.

Frank L. Wells, Oregon State Agricultural College, Honorable Mention—$10.00.

Craig Yacoe, University of Illinois, Honorable Mention—$10.00.

CONTEST PROBLEM

1941

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, 1941 (See Rules)

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, 1941. 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, 1941, 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. In this connection, graph paper bearing the name of the institution should be avoided.

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.

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PETROLAVA REFINING COMPANY

Atlanta, Texas

October 17, 1940

Development & Design Dept.

Office Memo.

To: C. H. E. FORTIWON

From: W. T. DIXON

Attached herewith are copies of all the correspondence and memoranda of our conferences on the preparation of isobutane charge for the projected Alkylation Plant in our refinery.

As discussed with you orally the other day, I am turning this whole matter over to you to see how well you make out. Of course, you appreciate that the subject is extremely important to this Company. For this reason a careful check of your answers will be made before submission to the Construction Department for preparation of detailed engineering drawings. However, do not let this fact dampen the enthusiasm and confidence which you expressed during our talk. I believe you have the stuff to do the job, so go to it.

In order to facilitate your work, I have attached an outline of what I expect you to prepare.

Good Luck!

WTD

Design Data Outline

The following should be included in the design data presented.

1. Sizes and description of major pieces of equipment. For example: Towers: Height, diameter, thickness, and number of trays. Heat Exchange Equipment: Heating surface.
2. A complete heat and material balance.
3. Tabulation of cost figures which determined the choice of equipment.
4. Sample calculations demonstrating all methods used giving particular attention to assumptions made.
5. Flow diagram showing major equipment with sufficient instrumentation for satisfactory control of operation.

It will not be necessary to calculate line sizes and pressure drops since our Engineering Department will handle this.

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PETROLAVA REFINING COMPANY

Atlanta, Texas

October 1, 1940

Manufacturing Dept.

MR. W. T. DIXON, Manager
Development & Design Dept.

Dear Sir:

This is to confirm the decision of which you were advised orally last week, namely, that the Management of Petrolava has decided to proceed at once with the design and construction of an Alkylation Plant for the production of iso-octane to increase the output and to improve the quality of our Petrolava Aviation Fuel. It was decided that the Alkylation Plant proper will be designed and constructed by the Wheelok-Loomis Company, and the design and construction of the unit for preparation of feed will be done by our own organization.

This letter is authority for you to proceed immediately with the preparation of design data for a unit to produce a stream of iso-butane

suitable for charging to the iso-octane (alkylation) plant to be constructed by the Wheelok-Loomis Company.

Mr. G. L. McCoy of the Wheelok-Loomis Company has been designated as liaison agent for that organization and all requirements as to quantity and quality of the feed should be obtained from him.

Mr. J. A. Rice has been appointed as the Manufacturing Department representative to furnish all data on manufacturing avails and requirements in this connection.

In view of the extreme importance of this project I would like to be kept advised of progress and would suggest that copies of all memoranda having to do with decisions on methods of procedure, etc., be forwarded to this office.

Very truly yours,
H. W. FIELD,
Manufacturing Dept.

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PETROLAVA REFINING COMPANY

Atlanta, Texas

October 4, 1940

Development & Design Dept.

MR. H. W. FIELD
Manufacturing Dept.

Dear Sir:

This is to advise receipt of your letter of October 1, 1940, in which you authorize the preparation of design data for a unit to prepare the iso-butane charge for an Alkylation Plant to be constructed by the Wheelok-Loomis Company.

Shortly after receiving your letter, a conference was held to lay out a plan of attack on this problem. This meeting was attended by Mr. G. L. McCoy of the Wheelok-Loomis Company, Mr. J. A. Rice of the Manufacturing Department, and Mr. C. H. E. Fortiwon and the writer, of this department.

The attached memorandum of this conference will show that a good deal has been accomplished and an arrangement has been made for a conference between our engineers and the Wheelok-Loomis technical staff in New York.

We have been given to understand by Mr. Rice that a fractionating tower now out of service at plant No. 18 is available, is in excellent mechanical condition and can be readily moved. The use of this tower together with the possible use of some of the auxiliaries such as condensers and coolers, may save a substantial part of the contemplated investment. This will be investigated carefully by Mr. Fortiwon.

To refresh your recollection and for your information, Mr. Fortiwon is a man who is new to our organization. We believe he has considerable possibilities as a Design Engineer and it is my intention to put the entire responsibility for this Alkylation charge development in his hands. I believe he will do an excellent job, but of course, since his experience with us is limited, his work will be checked carefully by Messrs. McCoy and Rice for "fit" with their construction and refining plans. I will have his engineering calculations reviewed by our design committee before submitting the result to the Construction Department.

We fully recognize the necessity for producing economically a precisely fractionated iso-butane stream in order to permit the Alkylation Plant to produce the maximum quantity of high octane Aviation Motor Fuel blending stock. You will be kept advised of progress in this matter.

Very truly yours,
W. T. DIXON,
Development & Design Dept.

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DEVELOPMENT AND DESIGN DEPARTMENT

October 4, 1940

MEMORANDUM

CONFERENCE ON UNIT TO PREPARE CHARGE FOR THE WHEELOK-LOOMIS ALKYLATION PLANT

On October 3, 1940, a conference was held to formulate plans for the preparation of design data for an iso-butane unit. This unit will produce iso-butane from the No. 16 Natural Gasoline Stabilization Plant reflux stream for charge to the Alkylation Plant to be constructed for Petrolava by the Wheelok-Loomis Company. The conference was attended by Mr. G. L. McCoy of Wheelok-Loomis,

Mr. J. A. Rice of the Manufacturing Dept. and Messrs. C. H. E. Fortiwon and W. T. Dixon of the Development and Design Dept.

The quality and quantity requirements for the charge stream to this plant were explained by Mr. McCoy. The Alkylation process will use concentrated sulfuric acid as a catalyst to react a stream containing butenes from the cracking area stabilization plant (No. 18) with the iso-butane from this projected unit to form an alkylate which is substantially iso-octane. Mr. McCoy emphasized that in the preparation of feed stock and in the design of the alkylation plant itself it was extremely important to maintain a high degree of purity of iso-butane (free of normal butane) in the non-olefinic portion of the feed. He suggested that the design be based on the preparation of a stream containing not more than 2 mol % propane nor 2 mol % normal butane. Furthermore he stated that the present plans call for 980 bbls. (42 gal.) of iso-butane of this purity per stream day maximum with the following anticipated variations throughout the year.

	42 gal. Bbls./Day
Dec., Jan., Feb.	500
Mar., April, May	690
June, July, Aug.	980
Sept., Oct., Nov.	770

The reason for this variation is to meet the avails of butenes from the cracking area.

After considerable discussion, agreement was reached on the following points:

1. Charge for the iso-butane unit.
   5000 bbls. (42 gal.) per day maximum charge, available as a liquid at 100° F. under its own vapor pressure.
   Analysis of Charge:

	Mol %		Mol %
C_1	0.3	i—C_4	20.0
C_2	2.5	n—C_4	65.0
C_3	12.2		

2. A two-tower system is essential since the desired material is a "heart cut."
3. In order to conserve iso-butane, the normal butane stream should not contain more than 2 mol % iso-butane and should leave the battery limits as a liquid at 100° F under tower pressure.

4. The iso-butane stream should likewise leave the battery limits on its way to the Alkylation Plant as a liquid at 100° F. under tower pressure.
5. The propane stream should leave as a vapor at 100° F. from the reflux drum.
6. The charge to the second tower should be in the form of a liquid at 100° F. under its own vapor pressure for ease of control.

Mr. Rice mentioned that a recent change in the operation of the stabilization unit at the cracking plant (No. 18) has put out of service a tower containing 21 bubble plates. He advised that this tower was good for 250# pressure and was in excellent condition. Further discussion disclosed that the plates in this tower were spaced 3 ft. apart due to a peculiarity of design felt necessary by its previous service but that in the proposed service this spacing could be changed at relatively small cost. It was decided that this tower together with its accessories would be investigated carefully since its use would reduce the investment in the new unit by a considerable amount if it could be used. Mr. Rice will transmit all the information which is available in connection with this tower.

Mr. Rice also agreed to review data in his office on cooling water temperatures and advise Mr. Fortiwon of his recommendation.

After some further discussion it was decided that Messrs. Fortiwon and Rice would go to New York for a discussion of this project with the design group of the Wheelok-Loomis Company. This move was deemed necessary due to the fact that the Development and Design people of Petrolava do not see "eye to eye" with the Wheelok-Loomis people on certain fundamentals of design.

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PETROLAVA REFINING COMPANY
Atlanta, Texas

October 4, 1940

Manufacturing Department

MR. W. T. DIXON
Development and Design Dept.

Attention: Mr. C. H. E. Fortiwon

Dear Sir:

In accordance with our discussion of yesterday on the subject of the iso-butane plant, I have tabulated below all the information available in this office on the idle tower at No. 18 stabilization plant. Data are also given on three heat exchange units which are not in operation at the present time and are available if you want to use them.

NO. 18 PLANT—IDLE TOWER

Material	carbon steel
Internal Diameter	2'6"
Shell Thickness	9/16"
No. of Trays	21
Tray Spacing	3'
Bottom Tray	12' from bottom head
Top Tray	12' from top head
Feed Nozzle	6" above 9th tray numbering trays from top down.
Other Nozzles	One above top tray. Two below bottom tray, of which one is connected to bottom tray downspout.

Auxiliary equipment includes the following heat exchange units having the following design specifications:

Unit A

Hot Side	55# gauge steam
Cold Side	35,000 #/hr. 58 MW liquid in @218° F. 8,000 #/hr. 58 MW liquid out @218° F. 27,000 #/hr. 58 MW vap. out @218° F. Duty = 3,000,000 *B. T. U./*hr. Press. 250 #/sq.in.g.

Unit B

Hot Side	18,000 #/hr. 44 MW vapor in @140° F. 13,000 #/hr. 44 MW liquid out @ 105° F. 5,000 #/hr. 44 MW vapor out @105° F. Press. 250 #/sq.in.g.
Cold Side	Water in @ 85° F. out @ 120° F. Duty = 1,900,000 *B.T.U./*hr.

Unit C

Hot Side	10,100 #/hr. 58 MW liq. in @ 160° F., out @ 100° F. Press. 250 #/sq.in.g.
Cold Side	Water in @ 85° F., out @ 120° F. Duty = 375,000 *B.T.U./*hr.

Concerning existing pumps and instruments, we have nothing to offer. When this tower was taken out of service use was found elsewhere for the pumps and instruments.

On the subject of cooling water temperature our experience dictates that 85° F. should be used for design in order to provide adequate cooling the year around in this climate.

Very truly yours,

J. A. RICE

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PETROLAVA REFINING COMPANY
Atlanta, Texas

October 14, 1940

Development & Design Dept.

MR. H. W. FIELD
Manufacturing Dept.

Dear Sir:

Pursuant to our last letter on the subject of the design of a plant for the production of iso-butane charge for the Alkylation Plant, this department has reached agreement on all points with the design group of the Wheelok-Loomis Company and is now proceeding with the preparation of design data.

The attached memorandum summarizes the results of the last discussion and tabulates the basic data agreed to by the Wheelok-Loomis people and our people. A carbon copy of a letter from Mr. G. L. McCoy on the subject of data to be used for estimating investment costs is attached for your information.

It was agreed that the Wheelok-Loomis information on this phase of the subject, since it is strictly up to date, should be used in determining optima for the plant.

So that our economic optimum calculations may be based on the best figures available, will you kindly furnish the latest basic manufacturing utilities costs?

Very truly yours,

W. T. DIXON

DEVELOPMENT AND DESIGN DEPT.

October 11, 1940

MEMORANDUM

CONFERENCE AT OFFICES OF THE WHEELOK-LOOMIS CO. ON DESIGN OF THE ISO-BUTANE PLANT

On October 9, 1940, Messrs. J. A. Rice and C. H. E. Fortiwon discussed various phases of the design work to be done for the iso-butane plant with representatives of the Wheelok-Loomis Company in their New York offices.

The first part of the discussion centered around the basic flow chart of the unit. The question here was whether: (1) the first fractionating tower would separate between propane overhead and iso-butane + normal butane as bottoms, with this bottom stream charging to the second tower for separation of the iso from the normal butane or (2) the first tower would take propane + iso-butane overhead with normal butane as a bottoms, the overhead stream after condensation being charged to the second tower for separation of the propane from the iso-butane.

A careful examination of the data and calculations available in the files of the Wheelok-Loomis design department disclosed that while there was little difference in the overall pictures between (1) and (2) the latter method had some advantages and hence was adopted for our design.

Furthermore it was agreed that heat exchange between feed and bottoms would have only minor advantage and hence would not be included.

The method to be used in calculating the number of plates needed for the separations was discussed at great length. The Wheelok-Loomis people have been using plate to plate calculations and were recommending that we do likewise. Our experience has been that the number of plates required and location of the feed can be estimated by assuming that the separation is being made on a mixture of the two "key" components only and applying the McCabe-Thiele method thereto. Our experience has shown that this simplification gives results sufficiently accurate for design work.

On the question of equilibrium constants for the various components it was agreed that "Absorption and Extraction" by Sherwood was the best general reference on the subject. Apparently their experience checks ours in this connection. A comparison of other data in use by the two groups (heat data, densities, critical temperatures,

etc.) showed substantial agreement. The data to be used are appended to this memorandum.

At the conclusion of the discussion, Mr. McCoy was requested to send us the latest data pertinent to calculations of investments for the purpose of determining economic optima. It was agreed that the operating costs for such calculations should be obtained from our own Manufacturing Department.

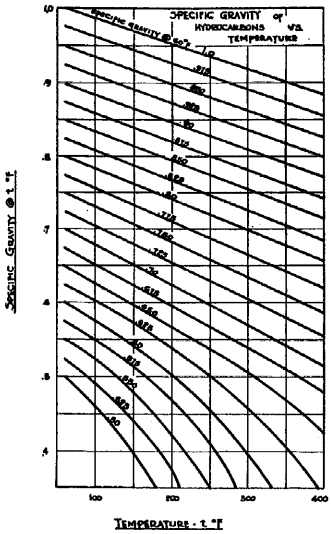

FIG. 1

PROPERTIES OF HYDROCARBONS

Compound	CH_4	C_2H_6	C_3H_8	n—C_4H_{10}	i—C_4H_{10}
Molecular Weight	16.03	30.05	44.06	58.08	58.08
Boiling Point, ° F.	—259	—127.2	—44.3	30.9	10
Critical Temp., ° F.	—116.5	90	204.3	307.4	273.2
Critical Press., lbs./sq.in. abs.	674	719	633	530	545
HHV, B.T.U./lb.	23,912	22,215	21,564	21,247	21,247
Sp.Gr. @ 60° F.	.247	.378	.511	.585	.565
Sp. Gr. @ Critical Conditions	.162	.212	.235	.219	.235

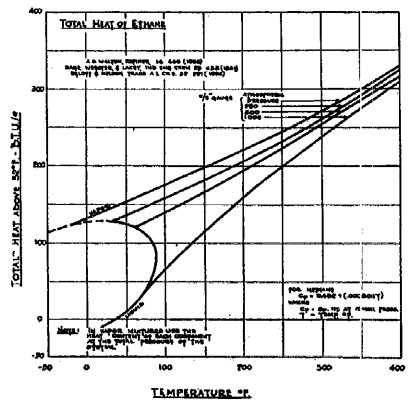

FIG. 2

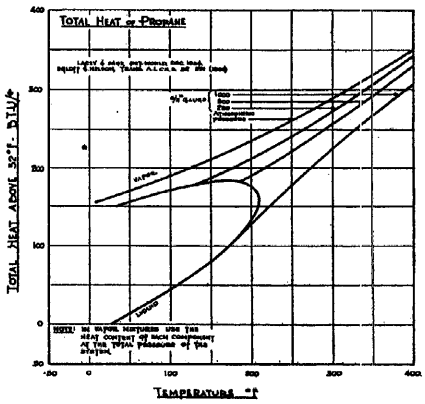

FIG. 3

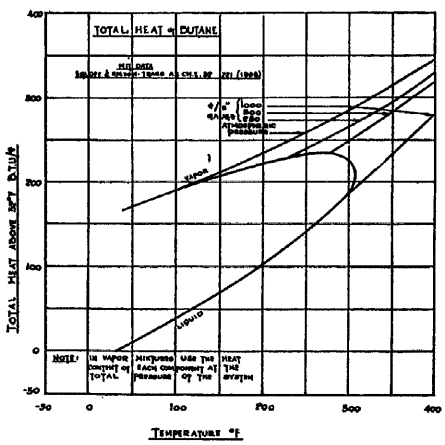

FIG. 4

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WHEELOK-LOOMIS COMPANY

New York, La.

October 11, 1940

MR. W. T. DIXON
Development & Design Dept.
Petrolava Refining Company
Atlanta, Texas.

Dear Sir:

On October 9, 1940, a conference was held in our offices on the subject of the iso-butane unit being designed by your staff.

Messrs. J. A. Rice and C. H. E. Fortiwon represented your company in this discussion and before leaving New York, they requested that we furnish you with the latest data which we have for calculating investment costs. This information is tabulated below.

Approximate Investment Costs

1. *Towers*

a. *Allowable vapor velocity* (2' tray spacing)

$$V = 4.3\sqrt{\frac{Td}{(MW)P}}$$

where:

V = allowable vapor velocity in ft./sec. based on total cross sectional area of shell
T = vapor temperature, degrees Rankine
d = sp. gravity @ operating conditions of liquid entrained by vapor
MW = molecular weight of vapor
P = operating pressure, lbs./sq.in. absolute.

b. *Shell thickness*

$$t = \frac{p \times D}{2SE}$$

where:

t = thickness in inches
p = maximum safety valve setting, lbs./sq.in. gauge (10% above maximum operating pressure)
D = diameter in inches
$2S = 27{,}500$
$E = 0.85$

Add 15% of Shell weight for clips, etc.
Allow a total of 15 ft. for space at top and bottom.

c. *Head Weight* (use shell thickness)

Thickness (ins.)	Diameter (ins.)	Weight (lbs.)
1	120	5875
1	114	5325
1	108	4850
⅞	108	4225
⅞	102	3775
⅞	96	3400
¾	96	2925
¾	90	2600
¾	84	2300
⅝	72	1450
½	54	750
⅜	36	275
¼	18	65

d. *Trays*

Taken at 75% efficiency
Weight = a ¼" steel plate of same diameter

e. *Cost*

Total = 15¢/lb. fabricated

2. *Structural Work and Foundations*

Height of Tower (ft.)	Ratio of Structural Work & Foundation Cost to Cost of Tower
50	0.4:1
100	1:1
150	2:1

3. *Heat Exchangers*

a. Minimum approach in water coolers = 15° F.
b. Water outlet temperature, maximum = 120° F.
c. Overall Heat Transfer coefficients

Boiling = 150
Condensing = 100 } B.t.u./Hr. × sq.ft. × ° F.
Cooling = 50

d. Cost of Surface

Sq. Ft.	$/Sq. Ft.
1000 & More	3.00
550	5.00
300	6.50
200	7.50
100	9.50

4. *Cost of Pumps* (low head)

42 Gallon bbls./day	Cost for Pump and Motor
150	$250
200	300
300	350
1,500	800
10,000	1,300
17,000	1,600
34,000	2,000

5. *Piping, Instruments and Misc.*

Add 100% to cost of items already listed.

We trust that the above data will serve your purpose but it should be emphasized that these figures are comparative rather than absolute and are to be used only for calculations for optimum equipment sizes.

Very truly yours,

G. L. McCoy.

4. *Power*

$/K.W.Hr. — Variable = $0.0080; Fixed = 0.0025; Total = 0.0105

5. *Repairs*—suggest 6% of total investment

6. *Depreciation and Obsolescence*—write off in 2½ years.

Very truly yours,

H. W. Field.

PETROLAVA REFINING COMPANY

Atlanta, Texas

October 16, 1940

Manufacturing Department

Mr. W. T. Dixon
Development & Design Dept.

Dear Sir:

Thank you for your letter of October 14, 1940, which presented the latest information on the progress of your design work for the iso-butane plant.

You requested the latest information on utilities costs for your optimum calculations. Our Cost and Yield section has handed me the following. In using these data may I suggest that you consider operation on a 24 hr. day, 350 day per year basis.

Operating Utilities Costs

1. *Labor*

#1 Operator	$1.12/hr.
#2 "	.91/hr.
#3 "	.79/hr.

2. *Steam*

Pressure (lbs./sq.in.ga.)	Var.	Cost/thousand lbs. Fixed	Total
20	20¢	10¢	30¢
60	25¢	10¢	35¢
140	28¢	10¢	38¢

3. *Water*

$/million gallons — Variable = $5.00; Fixed = 2.00; Total = 7.00

A.I.Ch.E. Annual Student Problem Contest

FIRST PRIZE WINNING SOLUTION

Contest Problem, 1941, Student Chapters, A. I.Ch.E.

By E. BRUCE POWELL, Clarkson College of Technology Student Chapter
Potsdam, New York

This project contains design data for a unit to produce a stream of iso-butane suitable for charging to an iso-octane (alkylation) plant.

PETROLAVA REFINING COMPANY

Atlanta, Texas

Development & Design Department — Feb. 20, 1941

Attention: Mr. W. T. Dixon:

Subject

Preparation of design data for a unit to produce a stream of iso-butane suitable for charging to the iso-octane (alkylation) plant to be constructed by the Wheelok-Loomis Company.

Specifications Given

1. 5,000 bbls. (42 gal.) per day maximum charge for the iso-butane unit, available as a liquid at 100° F. under its own vapor pressure.

Analysis of Charge

	Mol %		Mol %
C_1	0.3	i-C_4	20.0
C_2	2.5	n-C_4	65.0
C_3	12.2		