1970

STUDENT CONTEST PROBLEM

Each year the Student Chapters Committee of AIChE publishes a practical design problem to which
the members of AIChE Student Chapters are invited to provide solutions. The first prize, the
A. McClaren White Award, is $300, the A. E. Marshall Award carries with it $200, the third prize is
$100, and there were usually three papers receiving honorable mention. Winners of the first, second, and third prizes in 1970 were Fred D. Groos, Devens University,
Bruce A. Whipple, University of Colorado; and Larry W. Simonett, Oklahoma State University. Steven
A. Amid, Michigan State University; Loren B. Schreiber, University of Illinois; and Darley B. Wolfe,
R. A. Novak, received honorable mention. The awards will be made during the President's
Ohio State University, at which the recipients will be guests. Luncheon at the Annual Meeting in Chicago on November 30, 1970, on which the recipient of the
judged the solutions. Members of the committee were W. A. Gallup, chairman, and E. M. Norin,
T. Y. Novak, and C. G. Vinton, Jr.

Judges’ Comments

This year’s Student Contest Problem was selected as a typical industrial process design problem to
offer challenge and yet to be simple enough to be completed within the allotted time. A good
solution required a working knowledge of chemical engineering principles, an exercise of judgment,
and a degree of creativity. Detailed information was provided for plant design and manufacturing
and returns for optimization. The committee was encouraged to find evidence that many contestants dug into the literature to
review references and related articles. It was evident that many hours of effort went into
the design, and the conclusions drawn. (3) the assumptions made, (3) the approaches taken
or rejected in the solution, (4) a presentation of the final design with qualitative and quantitative flow
sheets, (5) a detailed list of equipment specifications, (6) a tabulation of process economics,
and (7) sample calculations including graphs and computer calculations if used.

The design required an optimization of the reactor, pulpification, and recycle sections of the
process. The forward reaction rate had to be calculated by a manipulation of expressions for the
process. The equilibrium constant and the reverse reaction rate derived from the data given. The forward rate
constant increased with increasing temperature, and the equilibrium constant decreased. Hence, the
reactor with a downward temperature gradient from feed to discharge end would be suggested. It was
discounting that only one contestant tackled the difficult integration of a nonisothermal plug-flow
reactor. Most of the contestants had their thinking locked in on a single isothermal stirred-tank
reactor.

Separation of normally gaseous reactants from the 65°C, melt point product was a formidable
problem, and several examples of good judgment were demonstrated in the varied solutions. These
were the calculation of the solubility of butadiene sulfone at its melting point, the minimization
of the concentration of product in the recycle stream, and the awareness of the process implications
of the melting point and the decomposition rate of the product.

It was a rewarding experience to review this year’s contest problem solutions; in fact, the judges
learned some things about chemical engineering practice from them. The contestants are to be
grateful for the demonstration of analytical ability, imagination, and diligence. The profession
should be thankful for a number of well-qualified graduates.

1970 Student Contest Committee
Problem

TO THE CONTESTANT:
This year’s student contest problem simulates a make-or-buy study by a chemical manufacturing company. You, as a chemical engineer, are assigned to make this study. You are to design a plant and to develop the associated economics so that a make-or-buy decision may be made.

The information required for this study will be presented in a conference. Extensive data are included with the problem to save you the task of finding it. If you need other data, be sure to reference it. Remember that in case of conflicting data, you are to use the data given in this problem.

To be eligible for the national competition, the solution to the problem must be arrived at by individual effort. In working the problem you should allow yourself 40 to 60 hours to complete it.

The results of your study should be in the form of a design report. The judges will consider the problem from both its nontechnical and technical aspects. The nontechnical area includes the report appearance, English, and organization. Your understanding of engineering concepts, of technical methods, and of the problem will comprise the technical area.

Good luck!

CONFERENCE NOTES:
Present: Don Leader (Manager, Process Engineering) Frank Fells (You, Process Engineer) Bob Adams (Another Process Engineer)

D. Leader: Jim, our Research Department has developed a number of products which are derivatives of butadiene sulfone. As we will be operating our butadiene sulfone derivatives plant at full capacity by the end of 1971, we would like to know whether we should buy or make our own butadiene sulfone.

From our market projections, we have determined the butadiene sulfone demand to be 10 million pounds a year. The project life is expected to be 10 years, and we can get a long-term contract on butadiene sulfone at $25/lb. (delivered) to fit our projected demand.

Bob has done some preliminary work on the problem, but he has none use for a plant start-up. I would like you to force your own work temporarily and devote your time to this evaluation.

F. Fells: How far did Bob get in his work?
B. Adams: I’ve narrowed the butadiene sulfone processing down to a continuous process. The batch process would not be competitive enough.

F. Fells: Could you tell me about the derivatives plant?
B. Adams: The butadiene sulfone derivatives plant is a continuous process and should have a 90% on-stream factor (300 days/year operation). The derivatives plant is designed to accept molten butadiene sulfone with the following specifications:

Butadiene = 0.5 %
Sulfur dioxide = 0.3 %

F. Fells: Do we have enough information to design a butadiene sulfone plant?

B. Adams: Yes, I believe I have all the information you will need for the butadiene sulfone plant design. The physical properties and the data for butadiene and butadiene sulfone are presented in Table 1. The data on sulfur dioxide can be found in Perry’s. Even though we know that the butadiene-sulfur dioxide-butiladiene sulfone system does not form an ideal solution, variation from ideality is probably small. In the absence of activity coefficient data, assume the mixture to be ideal. Figures 1 and 2 contain the equilibrium and rate data for the reaction:

\[
\text{H}_2\text{C} = \text{CH} = \text{CH} \rightarrow \text{SO}_2 + \frac{1}{2} \text{H}_2\text{O}
\]

F. Fells: What is the reaction mechanism?
B. Adams: The reaction mechanism is given by the stoichiometric equation. There are, however, some side reactions which can occur; for example,

\[
m \text{H}_2\text{C} = \text{CH} = \text{CH} \rightarrow \text{CH}_2\text{CH}_2\text{SO}_2
\]

The polymeric butadiene sulfone is amorphous and undesirable as it will build up on the walls of equipment.

F. Fells: How can its formation be minimized?
B. Adams: For all practical purposes the side reactions do not occur if the following conditions are met. Air should be excluded from the process system. The sulfur dioxide-to-butadiene mole ratio should be kept at one or greater than one. Finally,

<table>
<thead>
<tr>
<th>Butadiene Sulfone Properties (g)</th>
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<tbody>
<tr>
<td>Heat Capacity, Cp (g) 25 cal./mole °C at 25°C</td>
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<tr>
<td>Heat Capacity, Cp (g) 25 cal./mole °C at 25°C</td>
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<tr>
<td>Density, (g) 1.24 gm/cc at 72°C</td>
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<tr>
<td>Viscosity, (g) 0.4 centipoise at 80°C</td>
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<tr>
<td>Melt point, (°C) 65°C</td>
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<tr>
<td>Heat of fusion, (kJ/mol) 2.5 Kcal./mole at 25°C</td>
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<tr>
<td>Heat of vaporization, (kJ/mol) 12.3 Kcal./mole at 133°C</td>
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<tr>
<td>Normal boiling point, (°C) 151°C</td>
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<tr>
<td>Butadiene Properties (g)</td>
</tr>
<tr>
<td>Heat Capacity, Cp (g) 1.08 cal./g/mole °C at 40°C</td>
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<tr>
<td>Heat Capacity, Cp (g) 1.08 cal./g/mole °C at 130°C</td>
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<tr>
<td>Density, (g) 0.45 gm/cc at 130°C</td>
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<tr>
<td>Viscosity (g) 0.43 gm/cc at 130°C</td>
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<tr>
<td>Viscosity (g) 0.15 centipoise at 40°C</td>
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<tr>
<td>Viscosity (g) 0.05 centipoise at 130°C</td>
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<tr>
<td>Enthalpy of formation, (kJ/mol) (°C) 21.2 Kcal./mole at 35°C</td>
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</tbody>
</table>

55
tert-butyl catechol should be used at a level of 200 parts per million of butadiene in all process streams.

F. Finals: What information do you have on costs?
B. Adams: Raw material, utility, and overhead costs are given in Table 2. These cost estimations were recommended by our economic specialist. The butadiene sulfone plant, if built, will be located near Houston, Texas, on a developed site alongside our butadiene sulfone derivatives plant. Utilities will be available from the derivatives plant.

In my earlier work I used a recent article on cost estimating which uses the module technique (1). The bare module cost includes the purchase cost of the particular piece of equipment and all other costs associated with installing the piece of equipment with its necessary piping, instrumentation, insulation, etc. The sum of the bare module cost of each piece of major equipment represents the fixed capital investment for a battery limits plant. The cost-versus-capacity curves for various equipment appear in Figures 3 through 9.

F. Finals: By the way, John, you haven't mentioned anything about materials of construction. Are there any special corrosion problems?
B. Adams: No, there are not any unusual corrosion problems, and steel can be used throughout the process.

F. Finals: Well, thank you, John. I believe I have all the information I'll need.
B. Adams: O.K., and good luck to you.
Figure 3. Capital Cost of Heat Exchangers (1).
Figure 4A. Capital Cost of Pressure Vessels (1).
### Pressure Vessel Cost 3 - Sheet cast + Fx + Columns

#### Approximate Costs

<table>
<thead>
<tr>
<th>Material</th>
<th>Fx</th>
<th>Pressure Vessel</th>
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<tbody>
<tr>
<td>Steel</td>
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<tr>
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<td>Copper</td>
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#### Unit Costs

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#### Unit Costs for Fx

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#### Unit Costs for Pressure Vessel

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#### Table of Costs

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#### Figure 4B. Capital Cost of Pressure Vessels and Column Internals (I).
![Image of a page with a table and a diagram]
Figure 8. Capital Cost of Process Gas Compressors and Drivers (1).

Figure 7. Capital Cost of Horizontal Pressure Storage Vessels (1).
Figure 9. Capital Cost of Agitated, Jacketed Reactors ($).  

LITERATURE CITED


5. Company data.

