MTBE Production
Material Balance Project

You manage a chemical plant within a refinery complex that produces 60,000 tonne/y of methyl tertiary-butyl ether (MTBE). MTBE is a gasoline additive used to increase octane number that is produced from methanol and isobutylene. Methanol is purchased but the isobutylene is obtained from a refinery stream. The stream contains 23% isobutylene, 20% 1-butene and 57% 2-butenes and can be supplied at a maximum rate of 500 kmol/h. Only isobutylene reacts with methanol; 1-butene, cis-2-butene and trans-2-butene are inert for this reaction.

MTBE is produced by a liquid-phase reaction over a catalyst. The reaction is between isobutene and methanol as follows:

$$(CH_3)_2C{=}CH_2 \; + \; CH_3OH \; \rightarrow \; (CH_3)_3C\text{-}O\text{-}CH_3$$

In the temperature range of normal operations, there are no side reactions.

Process Description

A simplified process flow diagram for the MTBE plant is shown in Figure 1. The methanol and mixed butenes feed are pumped and heated to reaction conditions. The reactor operates at 30 bar to ensure that the reaction occurs in the liquid phase. The reaction is reversible but is operated at low temperatures to obtain favorable equilibrium behavior for MTBE production. The reactor effluent is distilled in Tower 901, with MTBE as the bottom product. Methanol is separated from the butenes with a methanol scrubber. Essentially all of the butenes pass through the scrubber while the methanol dissolves in the water phase. Methanol is separated from water by distillation in Tower 903 so that pure methanol reactant can be recycled.

Additional Process Information

Stream 1 – Assume that methanol is pure.
Stream 2 – Molar flow rate of mixed butenes is 500 kmol/h. Stream contains 23 mole% isobutylene and 77 mole% other butenes.
Stream 4 – Methanol-to-isobutylene molar ratio is 2.0.
R-901 – Fractional conversion is 0.960 with fresh catalyst but changes daily. See section on catalyst deactivation.
Stream 7 – All of the MTBE appears in T-901 bottoms. Stream composition is 95% MTBE and 5.0 % methanol.
T-902 – Process water sent to scrubber is controlled so that 5.0 kmol of water are used for every 1.0 kmol of methanol.
Stream 9 – All of the butenes appear in this stream. Assume that the stream has had water vapor removed so that mixed butenes are the only components.
Stream 11 – Stream contains pure methanol.
Stream 12 – Composition is 97 mole% water and 3.0 mole% methanol.

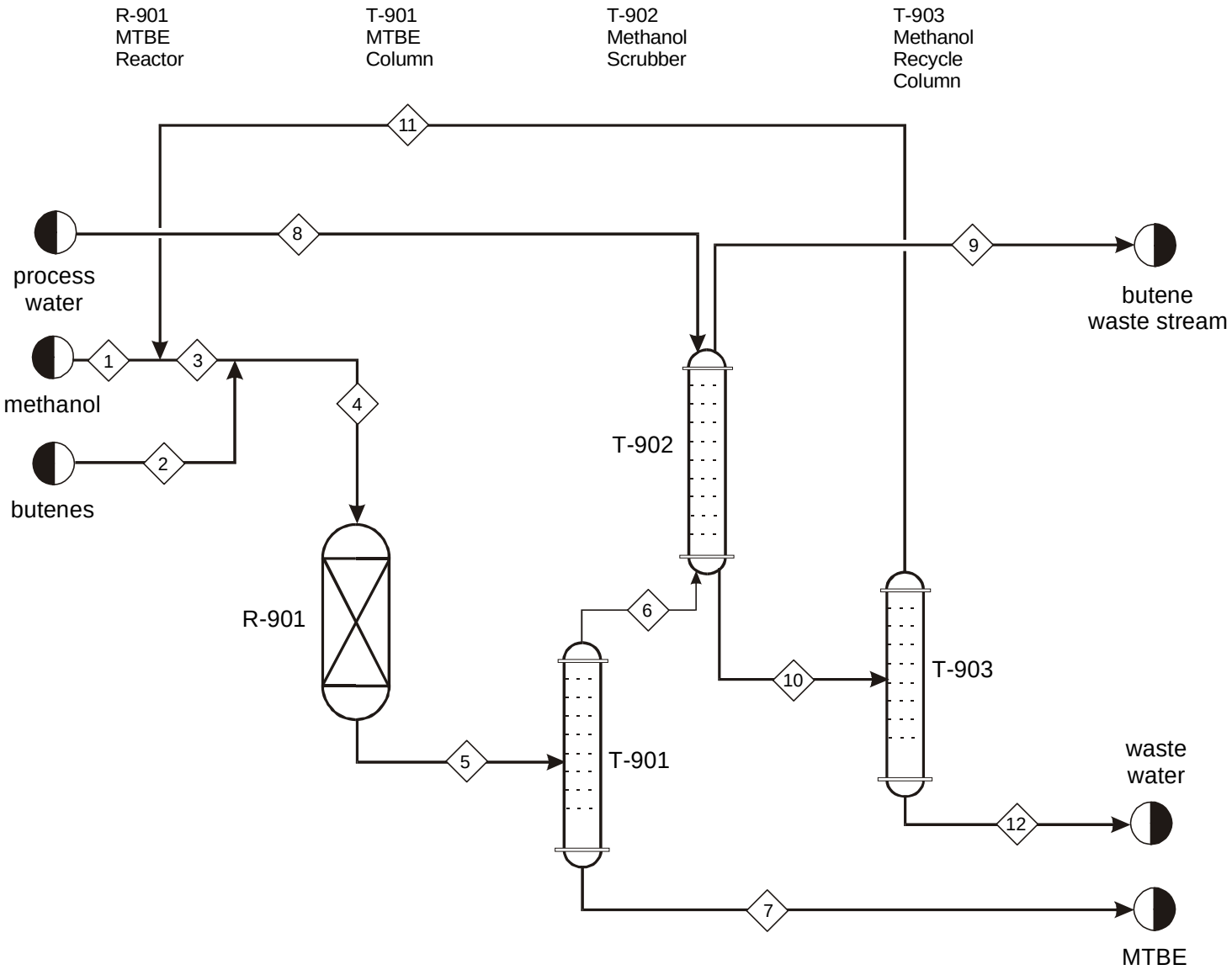

Figure 1: Process Flow Diagram for MTBE Production

Catalyst Deactivation

The process uses an acidic ion-exchange-resin catalyst. A fresh catalyst will provide 0.960 fractional conversion of isobutylene. Unfortunately, the catalyst deactivates with fractional conversion decreasing 0.002 per day. This might be written in equation form as

$$f = 0.962 - 0.002t$$

where t is the day-on-stream in the lifetime of the catalyst. Hence, with a new catalyst $t = 1$ and $f = 0.960$.

Operating Costs

Information on operating costs will be provided in a subsequent memo.

Problem

You, the engineering team, are to plan the operation of the MTBE process in order to produce 60,000 tonne/y (60,000,000 kg/y). Your goal is to minimize operating costs and maximize profit. You are constrained by the reactor feed rate (500 kmol/h), catalyst activity, and operating costs. You may replace the catalyst one or more times to meet annual production goals.

You may not use CAD software, but are encouraged to use spreadsheet calculations. You may write your own program if you prefer. Whether you use a spreadsheet or program, you must turn in hand calculations for one case to demonstrate that the program or spreadsheet is written correctly.

Group Formation

A student design group will consist of 3 or 4 group members. You are encouraged to choose a partner for this project to form a pair. When you have formed a pair, please write your names on the chart posted on Dr. Kugler's door. Dr. Kugler will combine pairs to form groups of four. Group assignments will be made on November 4.

Reports

Each group will be expected to prepare a written report recommending the best operating procedures for the MTBE process. This report is due at 3:00 PM, Wednesday, December 8. The report should follow the department's design-report guidelines. Data should be in the form of graphs and tables since this serves to both condense results and make them easily understandable. The appendix should include your spreadsheet or computer program and a hand calculation of a representative case. Hand calculations should be made using a pencil.

Report Authors

Although work on a group report can never be divided equally, only those members making substantial contributions to the final report should be listed as authors.

Additional Information

Feed and Product Prices

Mixed-butenes feed	$ 0.160 per lb
Methanol feed	$ 0.87 per US gallon
Process Water	$ 1.00 per ton
MTBE	$ 1.43 per US gallon
Butene waste stream	$ 0.155 per lb
Methanol in MTBE	$ 0.60 per US gallon

All feed and product prices are set by annual contracts with suppliers and customers. The plant buys the mixed-butenes feed from the refinery for $0.160 per pound. It sells the dry butenes in Stream 9 back to the refinery at a price of $0.155 per pound. The plant sells MTBE for blending with gasoline at $1.43 per U.S. gallon. The MTBE includes a methanol impurity which can also be added to gasoline in small quantities. The customer has agreed to pay $0.60 per U.S. gallon for the methanol that is mixed with the MTBE.

Other Costs

Plant operating expenses average $6400 per day. This amount should be charged whether or not plant is producing product.

The catalyst in the reactor costs $800,000. You will start operations with a fresh catalyst so that operations on day 1 will include an $800,000 charge. Fresh catalyst produces a fractional conversion of 0.960 on the first day of operation.

You may replace catalyst at any interval of your choosing. Catalyst replacement costs $800,000 and causes production to be shut down for 7 days. Daily operating expenses continue during the shutdown, but no feed is processed nor product produced.

Further Istructions

You should assume that a processing year consists of 330 days. This provides contingency days in every year for planned and unplanned shutdowns. You should plan to operate the MTBE plant for 330 consecutive days. Shutdowns for catalyst replacement count toward your 330 days.

You need to produce a minimum of 60,000 tonne/y of MTBE. Producing more is good, for it can be sold. If production goal is not met, MTBE must be purchased from competitors to make up

any deficiency. Assume than any MTBE purchased is pure and costs 20% more than your contract selling price.

Profits or loses should be stated in terms of millions of dollars, for example $1.22 million/y.