Material Balances Design Problem
Cumene Production

Background

Cumene (isopropyl benzene) is produced by reacting propylene and benzene over an acid catalyst. Cumene may be used to increase the octane in gasoline, but its primary use is as a feedstock for manufacturing phenol and acetone.

The plant where you are employed has been buying cumene to produce phenol. Management is considering manufacturing cumene rather than purchasing it to increase profits. Someone has made a preliminary sketch for such a process and has submitted to the engineering department for consideration. Your group is assigned the problem of evaluating the sketch and recommending improvements in the preliminary design.

Cumene Production Reactions

The reactions for cumene production from benzene and propylene are as follows:

C_3H_6	+	C_6H_6	$\rightarrow$	$C_6H_5\text{-}C_3H_7$
propylene		benzene		cumene

C_3H_6	+	$C_6H_5\text{-}C_3H_7$	$\rightarrow$	$C_3H_7\text{-}C_6H_4\text{-}C_3H_7$
propylene		cumene		diisopropyl benzene (DIPB)

The best technology for cumene production is a catalytic process that is optimized at 350°C and 25 atm. pressure. The benzene is kept in excess to limit the amount of DIPB product.

Process Description

The reactants are fed as liquids from their respective storage tanks. After being pumped up to the required pressure dictated by catalyst operating conditions, the reactants are mixed, vaporized and heated up to the reactor operating temperature. The catalyst converts the reactants to the desired and undesired products according to the reactions listed above. The molar feed ratio is 2:1 benzene to propylene; propylene conversion is 99%; the product molar selectivity ratio is 31:1 cumene to DIPB. The product gases are cooled to 40°C at 25 atm. pressure to condense essentially all of the cumene, DIPB, and unreacted benzene to a liquid. The unreacted propylene and a propane impurity are separated from the liquid and are used as fuel gas. The liquid stream is sent to two distillation towers. The first distillation tower separates benzene from cumene and DIPB. The benzene purity level is 98.1 mole%. We have no chemical market for this stream and plan to sell it as unleaded gasoline. The second distillation tower separates cumene from DIPB. The cumene is 99.9 mole% pure. The DIPB stream will be sold as fuel oil. A sketch of the process is attached. The reaction units and process streams are described in the tables.

Table 1. Description of Process Units

Symbol	Name	Comments
V-201	Vaporizer	Liquid feeds are vaporized and heated for reactor
R-201	Reactor	Vapors are reacted over catalyst; temperature 350°C; pressure 25 atm.; 99% propylene conversion per pass; 31/1 cumene/DIPB molar selectivity
S-201	Separator	Vapor is cooled to 40°C at 25 atm. pressure, separating essentially all of the benzene, cumene and DIPB as a liquid from propylene and propane gases
T-201	Distillation Tower No. 1	Overhead stream contains 98.1 mole% benzene, balance cumene; bottoms stream contains cumene and DIPB
T-202	Distillation Tower No. 2	Overhead stream contains 99.9 mole% cumene; bottoms stream contains pure DIPB

Table 2. Description of Process Streams

Stream Number	Comments
1	benzene>99.9 mole% pure; liquid feed
2	95 mole% propylene; 5 mole% propane; liquid feed
3	2/1 benzene/propylene molar feed ratio
4	99% propylene conversion; 31/1 cumene/DIPB molar selectivity
5	propylene + propane only
6	0 mole% propylene + propane
7	98.1 mole% benzene purity, balance cumene, sold as gasoline
8	0 mole% benzene
9	99.9 mole% cumene, balance DIPB; 100,000 tons/year production
10	100 mole% DIPB; sold as fuel oil

Problem

Your group needs to optimize the cumene manufacturing process to make maximum profit. Your plant currently purchases 100,000 tons of cumene per year to make phenol. Calculate material balances for the process in the sketch. Compute the value of the products and the cost for raw materials. Feedstock costs and product values are listed in Table 3. The difference between the product value and raw material costs is gross profit. We do not yet know how to calculate operating expenses for different process configurations so that operating expense will be ignored in these calculations.

Table 3. Prices for Feedstock's and Process Streams

Chemical or Fuel	Price
benzene feed, >99.9%	$0.90/gallon
propylene feed, 95 mole% propylene, 5 mole% propane	$0.095/lb
cumene, >99.8 mole%	$0.21/lb
fuel gas	$0.080/lb
gasoline	$0.60/gallon
fuel oil	$0.50/gallon

Your assignment is to propose process modifications that increase gross profit. You are constrained to operating the same catalyst with the same selectivity.

Design Groups

This is a group activity that will produce a group grade. You are to form your own 3 or 4 person group. Larger or smaller groups are not acceptable. Individuals who do not form groups will be assigned to one. Past experience suggests that students are happier in student-formed groups than in instructor-assigned groups.

Design Report

Design groups are to submit a single report signed by each participating member . Groups should follow department guidelines for design reports, which are distributed separately. Material balance calculations should be made by hand and be attached as an appendix to the typed report. Repetitive calculations made by computer (spreadsheet or programming) should be accompanied by one representative hand calculation.

Report Grading

Grading will be based on both content (2/3) and writing style (1/3). Everyone who signs the report as an author will receive the same grade. Individuals who do not contribute to the project should not be included as authors.

Date Due

Design reports are due at 3:00pm on December 6, 1995.

E.L. Kugler
November 12, 1995

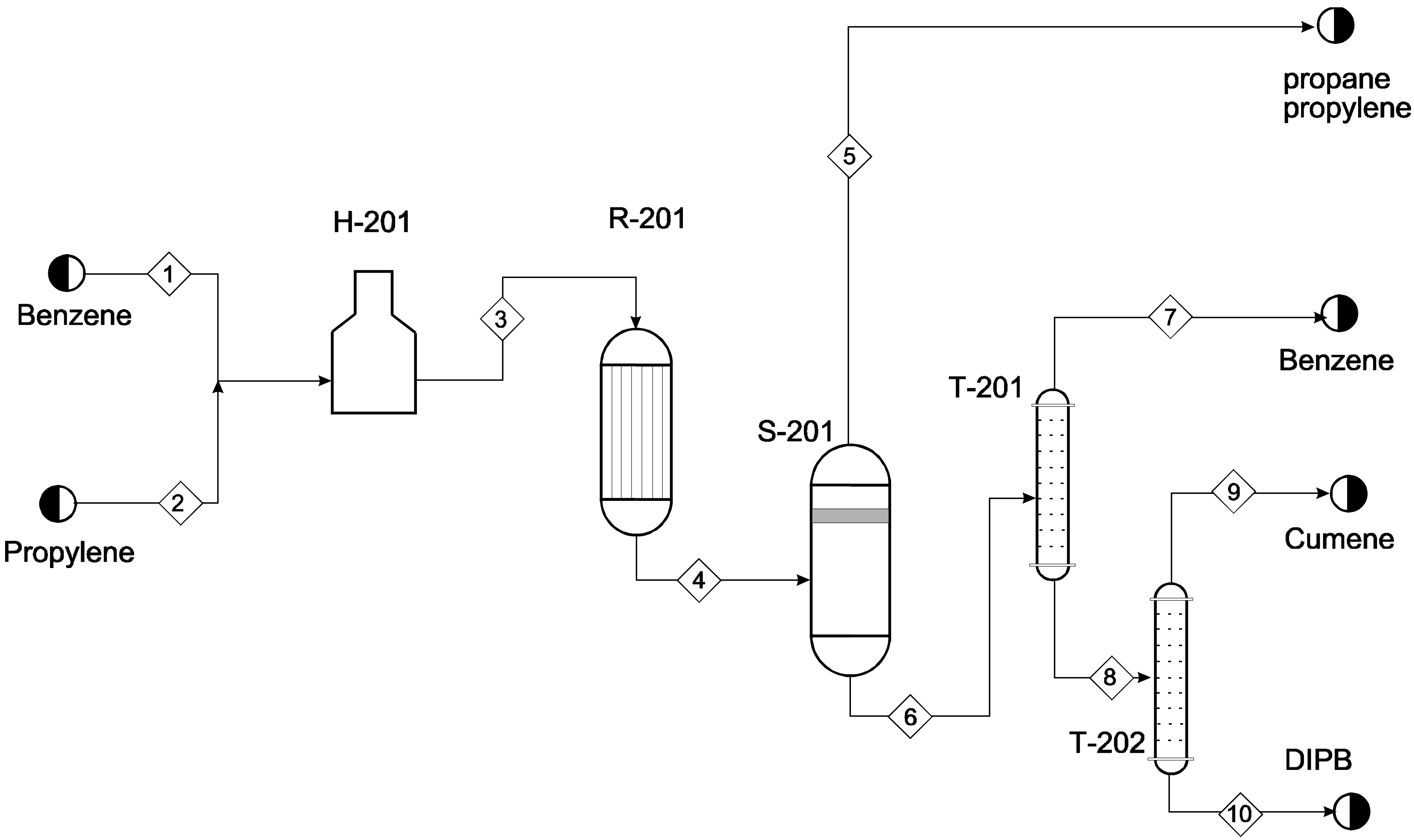

Figure 1: Preliminary Process Flow Diagram for Cumene Production