A Process Trouble-Shooting Problem

Joseph A. Shaeiwitz, Richard Turton
West Virginia University

Process trouble-shooting problems are another vehicle, complementary to design problems, to provide students with experience in solving open-ended problems. Since most graduates initial employment in the chemical industry involves existing plants, trouble-shooting problems also provide a valuable learning experience for students.

Problem Statement

The problem in question is based on the flowsheet for cumene production from benzene and propylene shown in Figure 1. The raw materials are assumed to be pure benzene and an inexpensive cut of propylene containing 5 wt% propane impurity. The reactions are as follows:

$$\underset{propylene}{C_3H_6} + \underset{benzene}{C_6H_6} \rightarrow \underset{cumene}{C_9H_{12}}$$

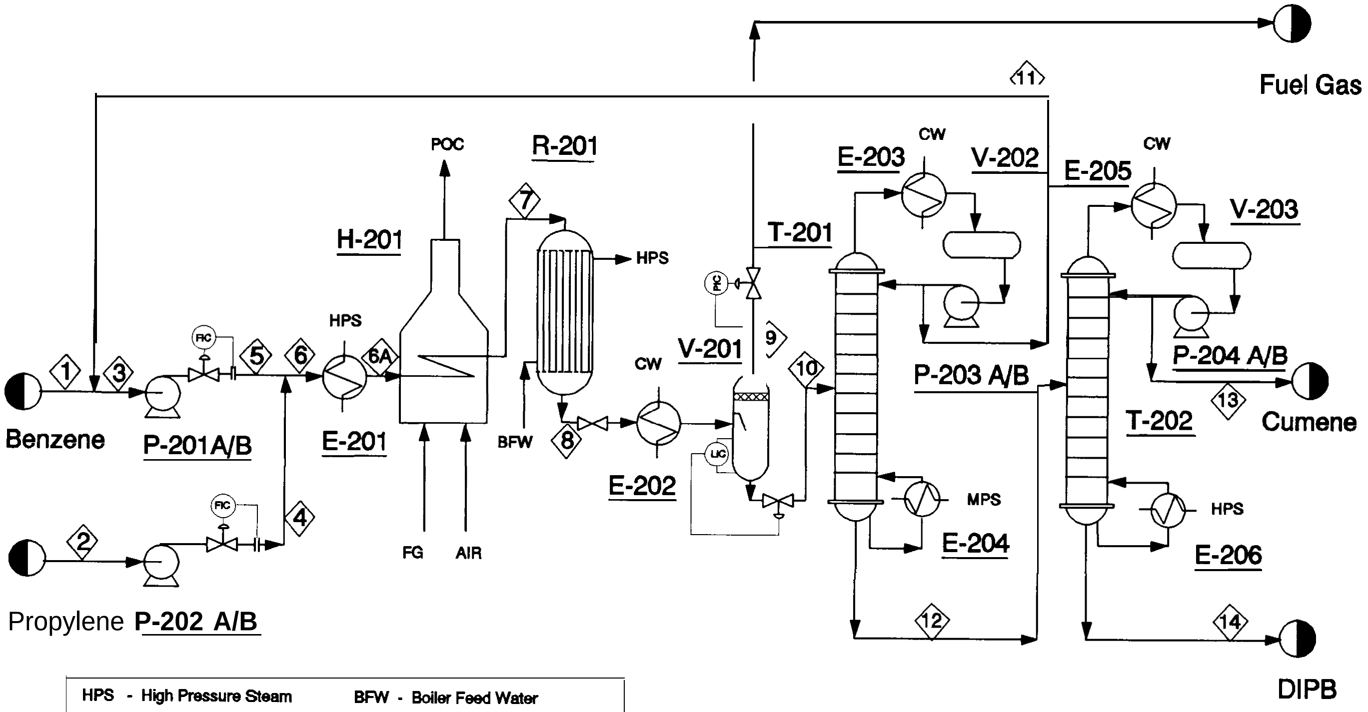
$$\underset{propylene}{C_3H_6} + \underset{cumene}{C_9H_{12}} \rightarrow \underset{p-diisopropyl\ benzene}{C_{12}H_{18}}$$

In the assignment, students are given the following information:

Lately, Unit 200 has not been operating within standard conditions. We have recently switched suppliers of propylene; however, our contract guarantees that the new propylene feed contain less than 5 wt% propane.

Upon examining present operating conditions, we have made the following observations:

1. *Production of cumene has dropped by about 6%, but flows of benzene (Stream I) and propylene (Stream 2) have remained the same. Pressure in the storage tanks (not shown on flowsheet) has not changed appreciably when measured at the same ambient temperature.*
2. *The amount offuel gas being produced has increased significantly and is estimated to be 65% greater than before. Additionally, it has been observed that the pressure control valve on the fuel gas line {Stream 9) leading from V-201 is now fully open, while previously it was controlling the flow.*



HPS - High Pressure Steam
MPS - Medium Pressure Steam
CW - Cooling Water
BFW - Boiler Feed Water
FG - Fuel Gas
POC - Products of Combustion

FIC - Flow Indicator Controller
PIC - Pressure Indicator Controller
NOTE : Column Controls not Shown on this PFD

Figure 1: Process Flow Diagram for Cumene Process (Unit 200)

3. *The benzene recycle Stream 11 has increased by about 8% and the temperature of Stream 3 into P-201 has increased by about 2°C.*

4. *Production of steam in the reactor has fallen by about 7%.*

5. *Catalyst in the reactor was changed 6 months ago; and, previous operating history (over last 10 years) indicates that no significant drop in catalyst activity should have occurred over this time period*

6. *p-diisopropyl benzene (p-DIPB) production, Stream 14, has dropped by nearly 20%.*

The assignment is to suggest possible causes for the observed problems and to suggest potential remedies. Students are provided with a complete simulation of the process as it should be operating, with stream tables, equipment specifications, and utility requirements.

Problem Solution

The observations given in items 1-6 above are obtained by simulating the process for propylene containing 10 wt% propane impurity, whale maintaining the same mass of propylene and propane fed in Stream 2. This would be the case if the impure feed were not detected. There is not enough information for students to be certain that this is the cause of the process disturbances. Other possibilities include, but are not limited to, poisoned or deactivated catalyst, slightly modified set-points for the temperature and pressure in the reactor (normal operation is at 3000 kPa and 350°C), failure of the flow controllers on Streams 1 and/or 2, or some combination of these.

Possible remedies include, but are not limited to, increasing the temperature or pressure in the reactor to compensate for the drop in conversion. Increasing the pressure can be accomplished by closing the valve after the reactor. Another possibility is to increase the flow of propylene feed. Increasing the propylene feed can only be accomplished by using the spare pump (P-202B) in series or in parallel with the operating pump (P-202A), due to limitations in pumping capacity shown on a pump and system curve plot, which is provided with the problem statement.

Increasing the reactor feed temperature can be accomplished by increasing the air and natural gas flows to the fired heater; but, the reactor operation is limited by heat transfer. The performance equation for the reactor

$$Q = UAAT$$

must be obeyed. Since the remedy involves maintaining the cumene production rate, the heat removal rate, Q, remains constant. Since overall flows on the process side are almost constant, and the process side is likely the limiting resistance, U remains constant. The heat transfer area, A, is also constant. Therefore, the temperature difference, AT, must also remain constant. Here, it is assumed that the temperature on the process side is constant at 350°C (which is not correct, but does simplify things), and that the boiler feed water vaporizes at 4237 kPa (254°C) to make high-pressure steam. The T-Q diagram for this situation is shown in Figure 2.

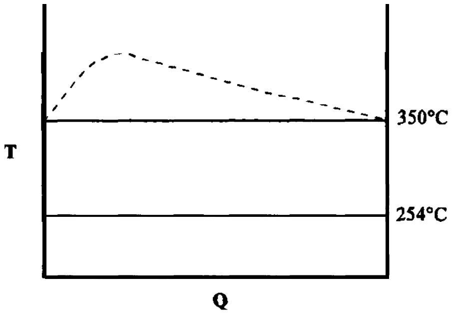


Figure 2: Assumed Temperature Profiles for the Reactor

Therefore, since the temperature difference must remain constant, the T-Q diagram indicates that increasing the reaction temperature must be accompanied by increasing the temperature of steam made. However, this requires an increased steam pressure. This can be accomplished by pumping the boiler feed water to a higher temperature; but, there might be equipment limitations should the temperature need to rise more than about 10”C.

In reality, the temperature profile in the reactor probably looks more like the dotted line in Figure 2. Although the analysis for this case would involve simultaneous material and energy balances along the reactor length, the same qualitative conclusions regarding the temperature and the boiler feed water will be found. Thus, the simple analysis presented is a powerful tool and gives correct qualitative results even if the quantitative results may be somewhat off.

Discussion

When this problem is discussed with students after the assignment, one point that is emphasized is that the cause for the observed disturbances most likely originates in the reactor. In an attempt to quantify why the cumene production dropped by 6°/0, while the p-DIPB production dropped by 20°/0, the concentration profiles in Figure 3 are introduced. If it is assumed that the reactor is operating at maximum cumene production, then the reactor length corresponds to the vertical dashed line. It is further assumed that the new conversion corresponds to the vertical dotted line. It can be seen from this qualitative plot that the percent drop in production of p-DIPB is larger than that for cumene because there is less p-DIPB formed. This same conclusion can be obtained by investigating the reaction network under the assumption that the cause is

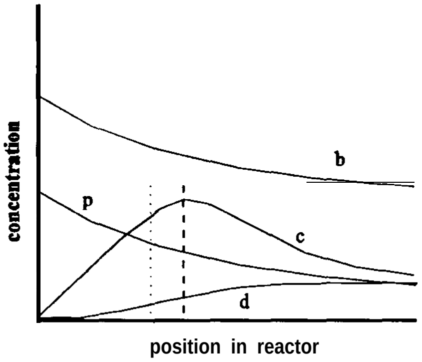


Figure 3: Concentration Profiles in Reactor
(Key: b=benzene, p=propylene, c=cumene, d=p-DIPB)

reduced propylene concentration. In the first reaction, a reduced propylene concentration results in reduced cumene production. Therefore, in the second reaction, both reactants have reduced concentrations, which results in a greater reduction in p-DIPB production.

Our experience with this problem is that students tend to focus on one possible cause and one potential remedy. This is a because they are still used to the single-answer problems used in traditional courses. Even with the vertical integration of design throughout our curriculum, single answers are still the mode.

The most popular single answer, in our experience, is catalyst deactivation or poisoning, which is certainly a reasonable possibility. The most popular single remedy is, therefore, plant shut-down to replace the catalyst. When we use problems like this, students must present their solutions and are subject to questions from faculty. Most can readily suggest an alternative cause and many can suggest an alternative remedy not requiring plant shut-down. However, it is unclear why they only report one possibility in the assignment.

A trouble-shooting problem such as this one has benefits beyond those of an open-ended problem. Creativity is also enhanced. Students are required to work backwards from what is observed to what could have caused the changes. They also learn that a cause and its effect can be located far from each other on a flowsheet. This type of problem gives them the same opportunity to synthesize their knowledge of chemical engineering principles as does an open-ended design problem. However, unlike comprehensive design problems, the trouble-shooting problem relies on intuitive understanding rather than repetitive, complex calculations. Therefore, it also gives students an opportunity to practice a skill that appears to have been lost in this era of high-speed computing, the “back of the envelope” calculation.

Conclusion

In summary, a process trouble-shooting problem, such as the one described here, provides students with an open-ended experience which is meant to enhance their problem-solving skills. Creativity is also enhanced. They learn that a cause and its effect can be located far from each other on a flowsheet. Unlike comprehensive design problems, the trouble-shooting problem relies on intuitive understanding rather than repetitive, complex calculations. Therefore, it also gives students an opportunity to develop an intuitive feel for chemical processes to complement their ability to do repetitive, detailed calculations.

Joseph A. Shaeiwitz received his B. S. degree from the University of Delaware and his M. S. and Ph.D. degrees from Carnegie Mellon University. His research interests are in design and design education. Of particular interest are the use of performance problems to complement design problems, the integration of design experiences throughout the curriculum, and assessment of learning outcomes.

Richard Turton received a B.Sc. from the University of Nottingham and an M. S. from Oregon State University. He then worked for 4 years in the engineering and construction industry prior to obtaining his Ph.D. from Oregon State University. His current research interests are focused in the area of fluidization and its application to the coating of pharmaceutical products and its use as an environmental clean-up technology.