

we should emphasize that our heat exchanger work has all been at steady state

In approaching the heat exchanger network, we took the point of view that early in design, we did only steady state calculations. Thus we used steady-state energy balances to describe normal operation in the network. We calculated the RGA and DC from a linear system approximation to these equations, and used it to make statements about controllability. There is not a contradiction here, merely a simplification: RGA and DC tell us the results of disturbances that moved the operation from one steady-state to another. To say any more about the time required to reach the new steady state, or the path followed, or the effects of continuing disturbances, we must make a dynamic analysis.

Seider et al (3) show how the RGA and DC may be extended to account for time-varying disturbances. In particular, they show that the severity of control loop interaction can vary with the frequency content (that is, the time-varying nature) of the input disturbance. These topics are beyond our scope, but you should return to them if you do this again for money.

but here's a transient problem that we wouldn't have caught with the RGA:

Kister (1) describes how trace components in a feed stream may accumulate to considerably higher concentrations in distillation towers. Imagine a chemical species with lower volatility than the overhead components, so that the rectifying section tends to wash it down, and higher volatility than the bottoms, so that the stripping section tends to push it up. Such volatility behavior is exacerbated by the nonlinear composition dependence of the activity coefficients. With no place to go, the component tends to accumulate in the tower, so that the tower undergoes a slow transient. The transient may be observed by a changing temperature profile as the composition profile varies in the tower.

Control loops, whose mission is to maintain the composition of the outlet streams, tend to prevent the component from leaving. For example, the rise in overhead temperature as the higher-boiling impurity approaches the top might trigger an increase in reflux flow, thus suppressing the impurity.

The accumulation has some limit. The component will either establish an exit flow to equal the inlet (a new steady state) or cause conditions to exceed some hydraulic limit, which subsequently forces its removal. In the first case, the interior concentration rises enough to deliver it to some outlet stream; if the control system does not object, it becomes a trace component of the product.

In the second case, the increased reflux or boilup (in an attempt to suppress the component) or a change in physical properties due to the presence of the component (in some cases generating a second liquid phase) exceed the capabilities of tray or packing to handle the internal tower flows. The column floods and delivers the accumulated component in an upset to an exit stream. Observers in the control room will see surges in pressure drop and temperature. Kister points out that these accumulation/upset cycles show periods of hours to days.

Our RGA would not have caught this problem during design. Instead, the design engineer would need to scrutinize the proposed feed stream for the possibility of trace components. Of course,

this is only one of many topics about which the designer should play “what if?”. The design engineer cannot become complacent.

life beyond design

A component-accumulation problem might arise in an operating plant long after the original design basis no longer applies. Control, interaction, and capacity limit problems might arise, as well. We have presented RGA and DC as screening tools in the context of process design. However, they may also be useful as diagnostic tools for engineers who are trying to improve existing processes.

Saletan (2) makes a useful division of engineering activity into three main areas: research, design, and operation. Rather than a linear progression from “lab bench to plant”, however, he arranges the three activities into a triangular structure. He views the interaction between research and operation to be particularly fruitful for successful process troubleshooting. Researchers, process designers, and plant engineers all require access to technical tools, and engineers in any of these areas benefit from knowing the responsibilities, capabilities, and constraints of the other areas.

It is most feasible in a university lecture course to arrange activities that resemble real design, and a laboratory course may indicate the flavor of engineering research. Students should not thereby underestimate the challenges and rewards of applying their skills to operation and troubleshooting during their professional careers.

the last message

Chemical processes are wonderfully complex nonlinear systems. Chemical engineers must be prepared to approach them at multiple levels, with a variety of tools, always looking to improve the analysis, but able to employ short-cut approximations when needed. Engineering judgment is developed by learning from your experiences, your colleagues, and your mistakes.

May your careers be long, rewarding, and worthwhile.

references

- (1) H. Kister, “Component Trapping in Distillation Towers: Causes, Symptoms and Cures”, Chem Engr Progress, August 2004.
- (2) D. Saletan, Creative Troubleshooting in the Chemical Process Industries, Chapman and Hall, 1994.
- (3) W. Seider, J. Seader, and D. Lewin, Product and Process Design Principles, 2nd ed, Wylie, 2004.