

to Luyben and Luyben (1997) and other chemical engineering textbooks on process control.

1.3 History

Control analysis and control system design for chemical and petroleum processes have traditionally followed the "unit operations approach" (Stephanopoulos, 1983). First, all of the control loops were established individually for each unit or piece of equipment in the plant. Then the pieces were combined together into an entire plant. This meant that any conflicts among the control loops somehow had to be reconciled. The implicit assumption of this approach was that the sum of the *individual* parts could effectively comprise the *whole* of the plant's control system. Over the last few decades, process control researchers and practitioners have developed effective control schemes for many of the traditional chemical unit operations. And for processes where these unit operations are arranged in series, each downstream unit simply sees disturbances from its upstream neighbor.

Most industrial processes contain a complex flowsheet with several recycle streams, energy integration, and many different unit operations. Essentially, the plantwide control problem is how to develop the control loops needed to operate an *entire* process and achieve its design objectives. Recycle streams and energy integration introduce a feedback of material and energy among units upstream and downstream. They also interconnect separate unit operations and create a path for disturbance propagation. The presence of recycle streams profoundly alters the dynamic behavior of the plant by introducing an integrating effect that is not localized to an isolated part of the process.

Despite this process complexity, the unit operations approach to control system design has worked reasonably well. In the past, plants with recycle streams contained many surge tanks to buffer disturbances, to minimize interaction, and to isolate units in the sequence of material flow. This allowed each unit to be controlled individually. Prior to the 1970s, low energy costs meant little economic incentive for energy integration. However, there is growing pressure to reduce capital investment, working capital, and operating cost and to respond to safety and environmental concerns. This has prompted design engineers to start eliminating many surge tanks, increasing recycle streams, and introducing heat integration for both existing and new plants. Often this is done without a complete understanding of their effects on plant operability.

So economic forces within the chemical industry are compelling improved capital productivity. Requirements for on-aim product quality control grow increasingly tighter. More energy integration occurs. Im-

What does not work