Active Constraint Regions for Economically Optimal Operation of Distillation Columns

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Control and operation of distillation columns has been widely studied, as illustrated by for example Skogestad (1993). Normally, it is assumed that the task is to control the product compositions at given setpoints ("two-point control"). However, in many cases it may be economically optimal to overpurify one of the products, and it is then no longer clear that two-point control is the best.

Somewhat surprisingly, the issue of optimal economic operation of distillation columns has been studied relatively little. The issue of active constraints for economically optimal operation was addressed about 40 years ago by (Maarleveld and Rijnsdorp, 1970), but they considered the extra degrees of freedom related to column pressure and preheating, and assumed two-point composition control. (Gordon, 1986) studied economical optimal operation and how it relates to product purity control. He introduced the avoid product giveaway rule, which states that it is optimal to maximize the flow of the more expensive product by keeping the amount of impurities in that stream at the maximum allowed (Gordon, 1986). The implication is that that one should always control the purity of the expensive product (active constraint rule). In this paper, we discuss this rule and point out its possible limitations.

When seeking to operate any plant in an economically optimal way, it is often critical to know which operational constraints are optimally active. The main focus of the paper is on showing how to identify active constraint regions as function of disturbances, through:

• Using knowledge of the optimization problem and of the behavior of distillation columns.

• Finding points in the disturbance space where individual constraint functions change between active and inactive, by finding where the sum of each constraint and its corresponding Lagrange multiplier is zero.

The second is used as an alternative to optimizing the model at a large number of points all over the disturbance space, thus decreasing the need for repeated optimizations.

We have identified how the active constraint set varies with the disturbances (feed flow rate and energy cost) for a single two-product column (with fixed product prices, case Ia) and with purity-dependent distillate price (case Ib)) and for two distillation columns in sequence (case II).

The results of this work serve to illustrate the following:

1. The complexity of the active constraint regions even for a relatively simple problem
2. How process knowledge can be used to reduce the need for (potentially time-consuming) optimization
3. Show when the avoid product giveaway rule is valid

For case Ia, we found that we had three distinct regions with different active sets. In case Ib we identified five regions, and in case II we identified eight. Only in case Ib did we find a region in which no constraints were active, which was in keeping with the avoid product giveaway rule. We showed that the borders between regions where only purity constraints are optimally active, are independent of feed flow rate.

We have also explained how the avoid product giveaway rule depends on two assumptions, of which one (one gets paid for the entire product stream, not just the desired component) is often valid and the second (overpurification costs energy) is always valid for realistic distillation cases.

References

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