Minimum Energy Requirements of the Distillation Process

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Abstract

Most of the machinery present in a generic chemical plant (e.g. an oil refinery, a pharmaceutical or polymer factory) aims at purifying materials. As a consequence, a large part of the energy use in many industrial sectors can be attributed to separation processes. These processes involve separating a mixture containing many chemical species into products of specified purity. For example, a petrochemical plant must separate a mixture composed of 50% propane and 50% propylene to sell propane and propylene products at 99% purity.

Distillation is a separation technology with high energy requirements. For instance, in the United States, around 18% of total energy consumption in the manufacturing sector can be attributed to distillation. Since many separation needs continue to be addressed with this technology, methods to determine the minimal energy used to accomplish a given distillation task have become important in both the scientific and the industrial communities. The recent rise in energy prices and demands further emphasizes the relevance of this problem.

The problem presented to this workshop consists of computing the minimal energy needed to operate a distillation column in order to carry out a specific separation task. This is the first step in the process design. Indeed, from the minimal energy consumption, an engineer can deduce the actual consumption of the distillation column to be built, its physical characteristics (for instance its height), and so on. The proposed problem can be formulated as a Mixed Integer Nonlinear Program (MINLP), where the discrete variables correspond to the column height (i.e., the number of elementary steps in the process) and the position of its feed stream; the continuous variables correspond to the flow rates, molar fractions, and temperatures of the many streams of matter involved.

Several difficulties arise when one tries to solve this problem directly. For instance, apart from a few exceptions associated with exotic mixtures, the

minimal energy consumption is achieved asymptotically as the column height goes to infinity. Thus the MINLP cannot be solved (strictly speaking). One can avoid this difficulty by replacing the objective function (representing the energy consumption) by a value reflecting the cost of building the column (i.e., its height) as well as its energy consumption. Such a value, however, depends upon the economic model used by the designer, the associated data, and the period considered. Therefore the computation of different scenarios (for separation tasks depending upon the demand and the economic situation) may be time-consuming.

Over the years, engineers have put forward many solution approaches for the minimal energy consumption problem. These approaches are based either on the geometry underlying the process or on notions from thermodynamics. The approach we plan to investigate is based on mathematical programming; more specifically, we will try to improve the problem formulation and to find new strategies for solving it.