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A Thermodynamic Analysis Contribution to Energy Optimization of Separation Processes

By

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The depletion of natural resources and environmental concerns have renewed interest for the conventional thermodynamic analysis of energy intensive processes. Encompassing both the first and second law of thermodynamics, entropy or exergy based analysis methods are efficient tools to pinpoint the various sources of irreversibility in a process but are of little help in finding how to minimize this irreversibility. Optimization is usually achieved through numerical solution of complex mathematical models. A simpler but challenging approach to global system optimization would consist in combining thermodynamic analysis and mathematical optimization techniques. This requires the development of suitable thermodynamic concepts based on the second law, to be used to formulate the problem and simplify the search procedure to achieve global optimization. In this presentation one of these concepts, namely the power of separation as well as its application to the problem of structural optimization of energy efficient hybrid distillation/membrane process is discussed.

First, the concept "power of separation" is introduced and a new interpretation of old thermodynamic concepts, such as exergy expenditure and exergy production rates is discussed in the context of separation processes. The exergy balance around a separation process is represented by exergy transfer equations through the process. The carriers of these transfers are the streams of matter or energy passing through the unit in constant quantity (flows of thermodynamic extensities). The intensive variables (thermodynamic intensities) put an exergy value on each carrier. The resulting model for exergy transfer is visualised on a simple diagram, presenting thermodynamic intensity vs. flows of thermodynamic extensities. The power of separation is illustrated on this diagram. This allows formulating the rational basis for a thermodynamic efficiency definition for separation processes. In a second part, a new short-cut method for energy optimization of hybrid separation processes is illustrated. It is based on the concept of power of separation for the retrofit problem of finding minimal energy requirement of an existing distillation column when coupling it in parallel with a membrane unit to separate a close-boiling mixture. The results are compared to those obtained with the GAMS-CONOPT solver for a superstructure problem formulation, which acts as a reference. The short-cut method results in a significant reduction in problem size and in the number of iterations for solving it.

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