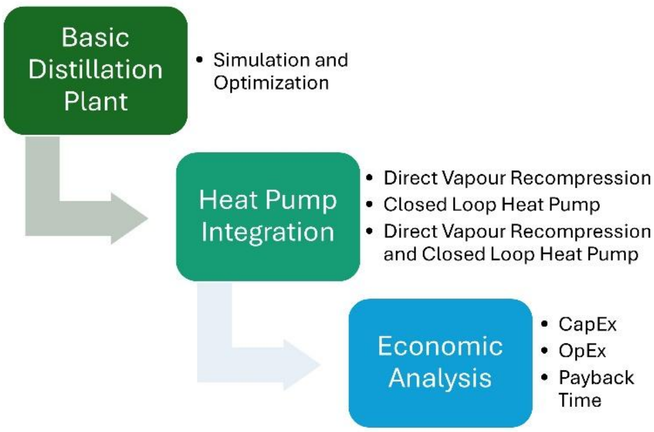
Improving Energy Efficiency in Ethanol Distillation: Simulation and Economic Assessment of Heat Pump Integration

Federico Cecchini [a], Iyan Melvin Nguetmi Nzepang [a], Valentina Innocenzi [a], Marina Prisciandaro [a]

[a] Department of Industrial Information and Engineering and of Economics, University of L'Aquila, Italy.

E-mail: federico.cecchini@graduate.univaq.it



Distillation is an important technique in the chemical industry for separating liquid mixtures based on the volatilities of their constituents. However, it is also one of the most energy-intensive processes, with the reboiler requiring large heat input. This strains a chemical plant's overall energy requirements, production costs, and product-related environmental impact. The literature presents multiple distillation plant optimisation case studies using energy recovery and efficiency technologies. However, it is often stated that optimization must be performed on an individual basis since the varying requirements of both the plant and the product to be distilled can influence the selection of energy efficiency and optimization systems. This study presents the findings from the energy optimization of an ethanol concentration plant with two distillation columns and various types of heat pumps. According to the European Pharmacopoeia recommendations for Ethanol 96%, the resulting ethanol should have a volume concentration ranging from 95.1% to 96.9%. The basic plant setup consists of a first stripping column running under vacuum conditions, followed by a second column operating at ambient conditions. This system is frequently used in food and pharmaceutical industries to avoid overheating of organic matter in the bottom reboiler of the first column. The material and energy balances of the various configurations under consideration, as well as their optimizations, were calculated using Aspen Plus simulation software. The UNIQUAC model was employed for water-ethanol mixture properties, whereas the REFPROP model was used for the properties of closed-loop pump refrigerant gasses. Four plant schemes were evaluated: Basic distillation plant, Basic plant with direct vapour recompression, Basic plant with closed-loop heat pump, and Basic plant with a combination of closed-loop heat pump and vapour recompression. The various scenarios were analysed from an energy perspective, examining energy budgets and attainable savings, as well as an economic standpoint, considering capital expenditures (CAPEX), operating costs (OPEX), and payback time. The simulations and economic analysis yield extensive comparisons of the performance of the various configurations. Although the use of heat pumps increases CAPEX, the large energy savings realized result in lower OPEX and a competitive payback period throughout the life of a distillation plant.

Keywords: *Distillation, Energy Optimization, Heat Pumps, Ethanol Distillation, Aspen Plus Simulation*