Design of ethanol dehydration process: heterogeneous azeotropic distillation vs. extractive distillation

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Ethanol dehydration process is important in producing high-purity ethanol from renewable biomass resources. In a diluted stream from fermentation after filtration or centrifuge to remove heavy phase materials, the ethanol content is typically less than 10 wt%. Taking a feed stream to the ethanol dehydration system with 6.4 wt% of ethanol as an example, this paper will investigate the optimal design flowsheet to produce high-purity ethanol via heterogeneous azeotropic distillation and to compare the result versus extractive distillation. A classical example of ethanol dehydration system is to use benzene as entrainer in a heterogeneous azeotropic distillation configuration to aid the separation. However, because benzene is a known carcinogen, this work will demonstrate the design concept using other possible alternative entrainer. As for the extractive distillation configuration, ethylene glycol will be used as extractive agent to aid the separation.

For the heterogeneous azeotropic distillation configuration, a column will be designed to act as both the pre-concentrator column and the recovery column in the process. The fresh feed together with the aqueous outlet stream from decanter is fed into this combined column with the bottom product of near pure water and the top product is fed into the heterogeneous azeotropic column. The bottom product of this heterogeneous azeotropic column is pure ethanol and the top vapor of this column will be close to the lowest boiling point of the ternary system (ternary azeotrope). This top vapor stream after condensation can naturally separated into two liquid phases with the organic phase containing entrainer which can be recycled back to this heterogeneous azeotropic column to aid the separation and the aqueous outlet stream is fed into the combined column as mentioned previously. The Total Annual Cost (TAC) will be used as the objective function to be minimized for the above two-column design. Possible alternative entrainers will be compared to obtain the optimized flowseet with the lowest TAC.

An alternative design is to use ethylene glycol as extractive agent in the ethanol dehydration system. The overall process with the extractive distillation configuration will contain three columns. The first column is the pre-concentrator column with the purpose of taking out most of the water in the fresh feed. The top product of this pre-concentrator column (near ethanol-water azeotrope) is fed into an extractive distillation column with the extractive agent also entering this column. The presence of the extractive agent alters the relative volatility between ethanol and water causing ethanol to move toward the top part and water to move toward the bottom part of this column together with the heavy extractive agent. The bottom product of the extractive distillation column is fed into the recovery column to produce pure water in the distillate and pure extractive agent in the column bottoms. This bottom stream is recycled back to the extractive distillation column for continue usage. The TAC of this optimized flowsheet via extractive distillation configuration will be compared to the optimized

flowsheet via heterogeneous azeotropic distillation configuration to find out which configuration will have the lowest TAC and the lowest operating energy consumption.

Keywords: Ethanol Dehydration, Heterogeneous Azeotropic Distillation, Extractive Distillation, Process Design.