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Review Paper

Techno-economic comparison of adsorption and azeotropic distillation processes for industrial ethanol dehydration

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1. ABSTRACT

This work compares two conventional methods of adsorption with zeolites and azeotropic distillation for dehydration of industrial ethanol (95%) to produce 99.8% ethanol. To this end, both processes were simulated by a similar feed flowrate of 136kg/h and the suitable alternative was selected using techno-economical study. The results revealed that the adsorption process is more economical than azeotropic distillation for ethanol dehydration, as it possesses lower total investment cost and total product price. The amount of production at break-even point and the investment-return period for the adsorption process were equal to 1,223,800 L and 12 months, respectively, and those for the azeotropic distillation were 2,004,905 L and 25 months, respectively. In addition, the net annual profit, net present value and internal rate-of-return for adsorption process were equal to 413456$, 1181279$ and 276%, respectively, which are much higher than those for the azeotropic distillation, equal to 263925$, 979370$ and 87%, respectively.

Keywords: Ethanol Dehydration; Simulation; Techno-Economic Assessment; Adsorption; Azeotropic Distillation

2. INTRODUCTION

Ethanol is widely used as an organic solvent in dye, cosmetics, perfumes, pharmaceutics and food manufactuings and is also regarded as a valuble and clean fuel source [1]. Anhydrous grade of ethanol with the minimum purity of 99.5 wt.% which is suitable for chemical industries and motor fuels should be produced from hydrous ethanol. However, the purification process is not easily possible since ethanol tend to form an azeotrope at the concentration of 96 wt.% with water [2, 3]. Among the available industrial techniques for ethanol dehydration, azeotropic distillation and adsorption via molecular sieves have attracted great attention. The former process is used for separating azeotropic mixtures with close boiling points and is the basis on the addition of a third component called the entrainer to change the relative volatility of the key components [3]. While in the later process, hydrophilic molecular sieves are employed to selectively adsorb water from water-ethanol mixture. Artificial aluminosilicate-based zeolites are generally used for ethanol dehydration [4].
The key factor for selecting an appropriate process to be performed in industrial scale is to be economically feasible and highly efficient. Techno-economical assessments allow for the evaluation of processes in terms of the total amount of investments, profits, investment rate-of-return and break-even point value, so that the best option with an ideal productivity and feasibility can be selected to be performed in full scale. Pointing to the priority of azeotropic distillation and adsorption for ethanol dehydration in the industry respect to other available technology, this study aims to conduct an economical evaluation of these two processes via a techno-economical assessment and choose the optimal option for a production plan of pure ethanol with a nominal capacity of 1,400,000 L/year.

3. METHODOLOGY

3.1. Process simulation

Two typical industrial plants of azeotropic distillation and adsorption to produce pure ethanol were designed via ASPEN Plus v.10. Hydrous ethanol (95 wt.% ethanol) at a flowrate of 136 kg/h was considered as the feedstock for both plants. The adsorption plant contains two fixed-bed columns that in each of which, 650kg of 3A zeolite is used for a period of 6

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months. Hot air at 200°C is also employed for the regeneration of adsorbents. In the azeotropic distillation plant, hydrous ethanol feedstock and benzene as entrainer are entered to a distillation column. Pure ethanol product is extracted from the bottom and the overhead stream containing water and benzene is directed to the second distillation column for benzene recovery. A 20 kg/h of fresh benzene is considered as the makeup stream.

3.2. Economical evaluation

The desired plan for both adsorption and azeotropic distillation plants is to produce 99.8 wt.% ethanol at a nominal capacity of 1,400,000 lit/year. Considering the stream factor equal to 0.9, the actual annual capacity will be 1,260,000 liter for 330 working days. The price of hydrous (95 wt.%) and pure (99.8 wt.%) ethanol is supposed equal to 0.56 $/L and 1.34 $/L, respectively. Hence, the feed annual cost and the product annual sale will be equal to 770,000 $ and 1,688,400 $, respectively. The annual cost for the desired amount of zeolite adsorbents in adsorption plant considering the unit price of 5 $/kg will be 13260 $ and that for the benzene used in the azeotropic distillation plant with the unit price of 1240 $/ton is equal to 147600 $. Fixed and annual costs of both plants were estimated according to the ref [5]. In addition, total product unit price, net annual profit, investment rate-of-return, net present value (NPV) and internal rate-of-return (IRR) were calculated for further evaluation of evonomical feasibility of the two suggested processes as follows:

$$\text{Total product unit price} = \frac{\text{Annual costs}}{\text{Annual procution amunt}} \quad (1)$$

$$\text{Net annual profit} = (\text{Total sale} - \text{Total production cost}) - 25\%\ \text{Tax} \quad (2)$$

$$\text{Investment rate-of-return (year)} = \frac{\text{Total investment (sum of fixed cost and working capital)}}{\text{Net annual profit}} \quad (3)$$

$$\text{NPV} = \sum_{t=1}^{n} \frac{R_t}{(1+i)^t} - \sum_{t=0}^{n} \frac{C_t}{(1+i)^t} + \sum_{t=1}^{n} \frac{SV_n}{(1+i)^n} \quad (4)$$

$$\text{NPV} = \sum_{t=1}^{n} \frac{R_t}{(1+IRR)^t} + \sum_{t=1}^{n} \frac{SV_n}{(1+IRR)^n} = 0 \quad (5)$$

In the last two abovemontioned relations, R_t, C_t, SV_n, i, and n are the project income at the year t, the project cost at the year t, salvage value at the year n, discount rate (considered as 22%), and project lifetime in year.

4. RESULTS AND DISCUSSION

Fig.1 illustrates the estimation results of the fixed and annual investments for adsorption and azeotropic distillation processes for pure ethanol production. As seen, adsorption process offers lower fixed (200,000$) and annual (1,043,200$) investments than azeotropic distillation (375,000$ and 1,224,800$). Working capital for both plants were predicted to be equal to 20% of the annual investments and also compared in Fig.1. It is inferred that the working capital for adsorption process (208,640$) is lower than azeotropic distillation (619,960$) as well. Considering the sum of fixed and working investments as the total investment for each plant, it is concluded that the ethanol purification using adsorption prosses requires less investment than azeotropic distillation.

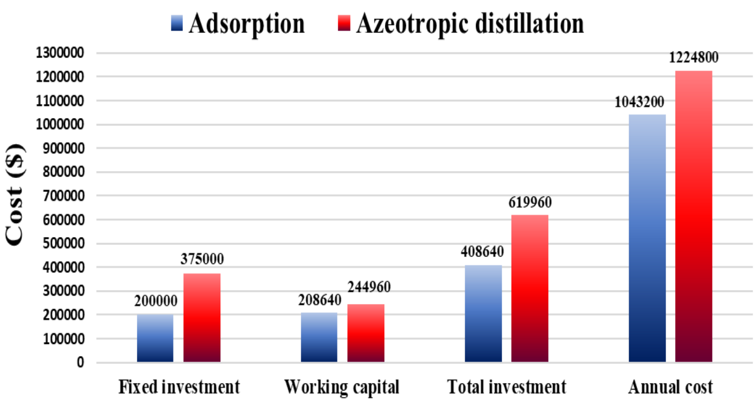

Figure 1. Comparison of the required investments for ethanol purification using adsorption and azeotropic distillation processes

The evaluation of profitability criterions for both adsorption and azeotropic distillation processes also approved the economical superiority of adsorption process. The total unit product price and net annual profit for adsorption process were found to be 0.827$/L and 413456$, respectively; whereas those for the azeotropic distillation were obtained equal to 0.972$/L and 263925$, respectively. This superiority can be attributed to the following reasons:

1. Lower utility (Water, electricity, and steam) consumption for adsorption process.
2. Requirement of more process equipments for azeotropic distillation that increases the maintenance and depreciation costs
3. Higher price for benzene entrainer in azeotropic distillation than 3A zeolites in adsorption process

The investment rate-of-return for adsorption process was estimated to be 12 months and that for the azeotropic distillation was found to be 25 months. Moreover, the amount of production at break-even point for adsorption and azeotropic distillation processes were equal to 2,004,905L and 1,223,800L, respectively. The obtained values for NPV and IRR for adsorption process were equal to 1,181,279$ and 276%, respectively that were much better than those for azeotropic distillation being equal to 979,370$ and 87%, respectively. The abovementioned results confirm that the pure ethanol production using adsorption process can provide more profits in a shorter period of time.

5. CONCLUSION

Techno-economical evaluation of two processes of azeotropic distillation and adsorption via 3A zeolites for the production of pure ethanol with a nominal capacity of 1,400,000L/year indicated that the adsorption process is a more economical option as it requires lower total investments and provides higher profits at a shorter time period.

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