A Review on Energy Efficient Hybrid Distillation/Pervaporation Process for Separation of Isopropyl Alcohol Azeotrope

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Abstract: Hybrid separation process which basically pairs two processes together plays an important role in separation of azeotropic or constant boiling mixtures. A hybrid system can be defined as a process system consisting of different unit operations that are interlinked and optimized to achieve a predefined task. Therefore, if distillation is the basic separation system, a hybrid distillation system consists of a distillation column that is interlinked with another unit operation to achieve a better (cheaper, easier, enhanced) separation. A Hybrid separation process basically deeds the advantages of pervaporation and distillation, while the negative aspects are minimized. This also minimizes energy expenses. This review focusing to minimize 50-60 % energy saving in chemical industry. This review focus on the energy savings in industry using hybrid system (distillation and Pervaporation combination) for separation of isopropyl alcohol and water azeotrope.

Index Terms: distillation, pervaporation, membrane separation process, hybrid separation process, energy efficient.

I. INTRODUCTION

Industrial membranes have recognized as important components of chemical processing industries since last few decades. Membrane-based technology is regarded as the new technology of the chemical engineering and has been widely used for applications as purification, concentration and fractionation of fluid mixtures. Pervaporation is a comparatively new membrane separation process that has some features in common with reverse osmosis and membrane gas separation.[1] In pervaporation, the liquid mixture to be alienated (feed) is placed in contact with one side of membrane and the permeated(permeate) is removed as a low-pressure vapor from the other side. The permeate vapour can be condensed and collected or released as anticipated. The chemical potential gradient a mixed the membrane is the driving force for the mass transport. The impetus can also be created by applying either a vacuum or an inert purge (normally air or steam) on the permeate side to sustain the permeate vapors pressure lower than the partial pressure of the feed liquid. Though pervaporation is one of the most prevalent areas of present membrane research, the conception of pervaporation separation is not novel. The phenomenon of pervaporation was first revealed by Kober(1917),who initiated the term in a publication reporting selective permeation of water from Aqueous solutions of albumin and toluene through collodion (cellulose nitrate) films.

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[2] Compared to other membrane separation processes, pervaporation is in a far not as much of progressive state. Pervaporation is a broadly used membrane separation process for the separation of liquid mixtures. Pervaporation is most suitable for the separation of close boiling or azeotropic mixtures. One of the most recurrent industrial application areas of pervaporation is desiccation of solvents that form an azeotrope with water e.g. ethanol, isopropanol, tetrahydro-furane. Due to it's high discernment and low operational cost, pervaporation can be a useful alternative to distillation. The understanding of the pervaporation separation is incomplete. It is thought at present by some researchers that the preferential sorption of a component in the membrane is the prerequisite to the preferential permeation of that component.[3] Based on this idea, several methods for the assortment of membrane materials have been planned. On the other hand, an ideal sorption of liquid in polymer is generally assumed to describe the mass transfer using the commonly accepted solution-diffusion model. This controversy affects the proper understanding of the pervaporation mechanism and appropriate selection of the membrane materials. For a membrane to be effective for a specific separation, it is always anticipated to have a membrane with good permeability and selectivity.[4] However, the hydrodynamic circumstances of the flow for the feed and sometimes for the permeate cannot be ignored. Distillation is the most widely used technique to separate liquid mixtures. However, the distillation separation of mixtures with an azeotropic compostion or with components with low relative volatility or close boiling mixtures is expensive in energy expense and auxillary substances are usually required.[5] A hybrid process appreciates the advantages of the pervaporation and distillation, while the negative features are minimized. Several processes have been offered in the literature and are functional in the industry such as for the dehydration of alcohols, aprotic solvents, and esters, as well as for the removal of VOC's (volatile organic compounds) from aqueous streams. The function and application of pervaporation in individual applications and in hybrid processes can be extended if the involved capital cost of the pervaporation unit is minimized. The steadiness of the Pervaporation membranes, the concentration and temperature polarization and the temperature drop that occurs in the liquid are the factors that escalate the required membrane area, the quantity of auxillary equipment and the relating capital and operating cost. That is why hybrid pervaporation-distillation process issued, which feats the advantages of pervaporation and distillation, while the negative aspects are reduced.[7] since some literature outcomes related to this as follows.

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Maulik Achary et al *(2016)* studied membrane separation techniques and Pervaporation process to purify the chemicals. Pervaporation, in its simplest form, is an energy efficient combination of membrane permeation and evaporation. Nowadays to separate alcohol water mixture by hybrid distillation, Pervaporation is gaining significant attention in industry. Normally conventional azeotropic distillation is used to remove the water from an azeotropic isopropyl alcohol (IPA) /water mixture. As per author study, using this new technique (distillation and Pervaporation) we can reduce operating cost and eliminate the use of chemical entrainer. This aspect leads to the development and adoption of new better technology over a conventional one. [1] Supaporn Jewprasat et al (2015) developed and used bacterial cellulose (BC) and poly (vinyl alcohol) (PVA) composite membrane for dehydration of ethanol by Pervaporation. BC film was modified by immersing BC in 10% (w/v) PVA solution followed by cross-linking with glutaraldehyde. The degree of swelling of the composite membrane in water was significantly higher than that in ethanol, which was due to the presence of the hydrophilic BC and PVA. The permeate flux and selectivity were studied as a function of temperature. When temperature was increased, the total permeation flux increased, while the selectivity decreased. [2] SohailRasool Lone et al (2015) reported the modeling and simulation of a hybrid process, based on the combination of distillation and Pervaporation, for the separation of azeotropic mixture of alcohol and ether. Simulation tasks were carried out with MATLAB and the results of alternative process configurations that result from the relative location of separation technologies have been compared on the basis of the required membrane area. [3] John H. Bermudez Jaimes et al (2014) studied ethanol separation by Pervaporation from ethanol-water mixtures. The Pervaporation was evaluated at 30 °C using a hydrophobic membrane of Polydimethylsiloxane (PDMS) for ethanol recovery, using ethanol concentrations characteristic of sugarcane fermentation. [4] Clément Servel et al (2014) reported an innovative simulation methodology that can be applied to determine the membrane performances that have to be achieved to replace conventional processes with a hybrid process while respecting constraints that are fixed by industrial specifications. This method is applied to the case of acetic acid dehydration. A hybrid process consisting of a pervaporation module equipped with a hydrophilic membrane coupled with a distillation column is proposed and studied. As a result, this work shows that commercially available membranes have a selectivity that is too low to induce significant economic savings for this application, although some materials that are not yet commercialized show very interesting separation results [5]. Nóra Valentíny (2013) studied and compared two pervaporation models, the solution-diffusion model of Rautenbach [A] and its developed form [B]. Models are compared and evaluated with computer simulation on the dehydration processes of isobutanol-water and ethanol-water mixtures. Simulations of a hybrid separation method containing pervaporation for the separation of these mixtures are performed. Model 2 shows better behavior than model 1[6] Nwe Nwe Win et al (2012) studied the permeation behavior of ethanol and water in pervaporation (PV) experiments using organic composite membrane; that is a polyvinyl alcohol (PVA) based active layer and a polyacrylo nitrile supported layer was studied by measuring permeation flux and separation factor. The effects of permeate pressure (20-50 mbar), feed water concentration (5-1 wt %), and feed temperature (65-75°C) were examined in their study. It was found that permeate pressure raised with reducing permeate flux and separation factor. Permeation flux enhanced and separation factor reduced with increasing feed water concentration and feed temperature. [7] Korbinian Kraemer et al (2011) suggested hybrid extraction–distillation downstream process with ABE extraction in an external column. By means of computer-aided molecular design (CAMD), mesitylene is identified as novel solvent with excellent properties for ABE extraction from the fermentation broth. An optimal flow sheet is developed by systematic process synthesis which combines shortcut and rigorous models with rigorous numerical optimization. Optimization of the flow sheet structure and the operating point, consideration of heat integration, and the evaluation of the minimum energy demands are covered. [8] A. K. Frolkova et al (2010) worked on survey of the present-day methods of dehydration of ethanol resulting from fermentation processes. The existing separation techniques for water–ethanol mixtures of various compositions are compared, and the conditions under which each particular technique is preferable are formulated. [9] V. Udeye, et al (2009) developed the process design of a continuous ethanol distillation unit based on the heterogeneous azeotropic approach using *n*-heptane as the entrainer. An ethanol distillation unit was designed using mainly stainless steel. Bubble caps were constructed for a column consisting of bubble caps 11 stages. The decanter design was used for organic reflux. A reboiler with an electric heater was used in the dehydrating column. The prototype design restricted the feed flow rates to 0.2 kgmol/h of ethanol 95.0 mol%, using the mixed reflux between *n*-heptane and ethanol during distillation process**.** Final product of an approximate 99.2mol% of absolute ethanol. [10] A hybrid column/pervaporation process is studied by William L. Luyben (2009). Process is designed to produce 99.77 wt % ethanol from a feed stream of ethanol/water mixture with composition near the azeotrope.. A simplified dynamic pervaporation model is developed that captures the essential features of the process using energy and component balances along with overall pervaporation performance relationships. Dynamic simulations are used to demonstrate the effectiveness of a control structure that uses a cascade composition/temperature structure. A simple process modification is shown to improve controllability.[11] Anett Lovasz et al (2009) studied on the modeling of pervaporation is applied. The modified Rautenbach model is selected again, as an integral part of our methodology. The applicability of the methodology is investigated in the case of ternary mixtures: the connections between the model parameters of the binary and ternary mixtures are studied. For the possibility of comparison the widely investigated water ethanol as binary and water ethanol 2-propanol as ternary mixture. PERVAP 2210 PVA/PAN composite membrane were chosen.

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[12] Atilla Evcin et al (2009) studied homogeneous PDMS membranes and mixed membranes were prepared by solution casting technique by introducing hydrophilic or hydrophobic zeolites into the polymer matrix. The prepared membranes were tested in a laboratory scale pervaporation experimental set-up. The effects of experimental parameters such as the type and composition of zeolites on permeation flux and separation factors were investigated. When tested on ethanol/water mixtures, the zeolite-filled membrane of hydrophobic origin was found to give much higher selectivity for ethanol compared to that of hydrophilic nature. [13] Shin-Ling Wee et al (2008) reviewed on the role of zeolite membrane and its progress in the pervaporation process. The fundamental aspects of pervaporation over different types of membranes are reviewed and compared. The focus of this review is on zeolite membrane covering: (a) synthesis of zeolite membranes; (b) membrane characterization; (c) pervaporation studies; (d) its applications in alcohol dehydration, organic/organic separations and acid separations. The transport mechanism during pervaporation is discussed and the issues related with pervaporation are addressed. Innovation and future development of zeolite membrane in pervaporation are also presented. [14] Carsten Buchaly et al (2007) reviewed on the modeling, simulation and process analysis for a hybrid separation process, the combination of reactive distillation with membrane separation, is presented. The application is illustrated by the heterogeneously catalyzed *n*-propyl propionate synthesis from 1-propanol and propionic acid. The membrane module is located in the distillate stream of the reactive distillation column in order to selectively remove the produced water without use of entrainers. Key aspects for the theoretical description of reactive distillation processes are discussed. For the stand-alone reactive separation process, the simulation results with excellent properties for ABE extraction from the fermentation broth. An optimal flow sheet is developed by systematic process synthesis which combines shortcut and rigorous models with rigorous numerical optimization. Optimization of the flowsheet structure and the operating point, consideration of heat integration, and the evaluation of the minimum energy demands are covered. It is shown that the total annualized costs of the novel process are considerably lower compared to the costs of alternative hybrid or pure distillation processes. [15] Mario Roza et al (2006) observed that application field for pervaporation has extended from the fine chemical and solvent recovery field into the solvent production area. A number of new and more efficient hybrid separation plant configurations in this area with distillation and pervaporation are shown. For these case studies a user added subroutine for the pervaporation has been used to simulate the plant. This subroutine has been developed by Sulzer Chemtech to run with the Pro/IIw and AspenPlusw simulation packages. The subroutine uses a finite element model. The mass balance over each element is calculated using measured flux coefficients and the difference in fugacities on either side of the membranes. As per Author's study, energy saving of more than 50% can be reached compared to traditional separation schemes. [16]

II. HYBRID SEPARATION PROCESS

It has been broadly documented that membrane separation processes can offer many advantages over conventional mass transfer processes. A large number of membrane separation processes are currently being employed in various sectors of industries. Despite the advantages, membrane processes often suffer from limitations when used individually. To overcome such limitations, membrane-based mixed processes have been developed to increase the productivity of the target separation processes. Membrane technologies have recently evolved as an additional category of separation processes to the inherent mass transport processes. Membrane separation technologies offer benefits over existing mass transfer processes like high selectivity, 50%-60% low energy consumption, moderate cost to performance ratio and compact and modular design. Although common separation processes are still demanding in literature, other efficient, though expensive, separation processes are increasingly being taken up as alternatives. There are several reasons for this newly ascending attention, the most significant being environmental concern and up gradation in efficiency of separation. During the past decade, mixed distillation/pervaporation processes have been developed for the separation of azeotropic mixtures as well as the dehydration of aqueous-organic mixtures using hydrophilic or organophilic membranes according to the separation task to be accomplished. When pervaporation modules are used alone, they are more expensive than pervaporation membranes combined with a conventional process, thus the interest in using them in the context of a mixed process. One of the applications is the separation of azeotropic mixtures, for which they are especially designed, because the separation does not depend on the equilibrium between components, but on the difference between the activities on the two sides of the membrane. The disadvantage for using membrane processes is that only low concentrations and low flow rates of feed streams can be treated to keep the prices reasonably low. Mixed processes provide an interesting alternative, because using a conventional separation step such as distillation for the initial separation task leaves the last difficult separation to the membrane, reducing the concentrations and flow rates to be treated, thus requiring a less expensive process. However, membrane processes have several inherent margins. For example, a membrane system designed to treat waste water may be limited by the water's osmotic pressure, viscosity, temperature, and high concentration of suspended solids. Therefore, the optimal separation process in many cases may be a "Membrane-based mixed process" that combines either a membrane process with a conventional process or a membrane process with other membrane process. A mixed process is apposite when it offers significant rewards (such as lower capital and production costs or reduced energy requirements) over the exclusive use of conventional processes. Moreover, membrane mixed processes may achieve separations that are otherwise unrealistic or altogether impossible to achieve with either conventional process.

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III. ADVANTAGES OF HYBRID SEPARATION PROCESS

Mixed processes like combination of distillation and pervaporation are very encouraging especially in cases where extraordinary product purities are required. To minimize costs, particularly energy costs, make possible a difficult separation, and/or improve the degree of separation, mixed systems, consisting of two or more separation operations of different types in series are used. Mixed systems of different types cut energy expense, make separations that are not otherwise possible and/or recover the degree of separation.

IV. DISCUSSIONS

The developments in hybrid separation systems have emerged in recent years. There are some developments have done by chemical engineers for reducing the energy requirement and for achieving higher efficiency of product. Through the review of literature there is a future scope in hybrid separation process (distillation+ Pervaporation) in chemical industry. This process involving a young membrane separation process in industry, minimizes energy requirement over traditional separation process. Also from literature review it has been observed that there is very little work is done in isopropyl alcohol azeotropes using hybrid separation. Membrane is very crucial part of this system and the work done so far is based on PERVAP 2210 commercial available membrane. We are focusing in development of this distillation+Pervaporation separation process using locally available membrane (poly ether sulfone-poly vinyl alcohol) cheaper than PERVAP 2210.

V. CONCLUSION

It is now extensively been accepted that the membrane separation processes can offer many compensations over conventional mass transfer processes. A large number of membrane separation processes are currently being adopted in various sectors of industries. Despite the advantages, membrane processes often suffer limitations when used individually. To overcome such limitations, membrane-based mixed processes have been developed to maximize the productivity of the target separation processes. A mixed process attempts to exploit the gains of both the processes, while minimizing the shortcomings. Pervaporation is a developing membrane separation process. More recently, the mixed processes integrating pervaporation with other variable liquid separating technologies are acquiring impetus. With these developments we have more reasons to believe that mixed processes will play even more important roles in future.

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