The latest technological development for ethanol dehydration is creating quite a buzz in the industry

Unlocking intrinsic value in existing ethanol facilities

When attending conferences and reading trade magazines you might have noticed the lack of discussion around ethanol drying processes. There are two main reasons for this. Firstly, improvements at the front end have stolen the headlines as advanced milling technologies are commercialised, higher yield grinding techniques are being deployed and next generation enzymes are introduced to the market. Secondly, few innovations have been seen at the back-end drying process and advances, while important, fall into the category of small incremental improvements as opposed to attention-grabbing game changers.

Plant operators continuously look to make modifications to operate at optimum efficiencies with many plants succeeding to operate beyond nameplate capacity. Current focus of many operators is on increasing feedstock diversity (where possible adding advanced feedstock), increasing output capacity and improving energy efficiency.

Investments in such technologies reach the tens of millions, but may often lead to bottlenecks downstream in the distillation and dehydration section of the plant. One might think that the only way of dealing with such bottlenecks is to add molecular sieve bottles to the drying section and, if necessary, undertake larger CAPEX projects to expand the rectifier and vaporiser throughput capacity. However, there is a solution gaining momentum amongst operators looking to increase capacity and efficiency without undertaking such large projects: membrane based drying.

Membranes separate water from ethanol continuously. There is no need to add chemicals to break the azeotrope or to regenerate the membranes

The development of a novel membrane-based solution to treat the molecular sieve regenerate stream is attracting attention in the biofuels sector. By installing a standalone membrane system in parallel to an existing molecular sieve, the distillation and dehydration capacity can be increased significantly. This is an elegant way of resolving drying limitations for producers working on front-end improvements. This bolt-on improvement can be done in a non-intrusive way and immediately unlock value.

Tried and tested

For more than 40 years membranes have been used in industrial processes to separate a variety of mixtures in liquid, vapour and gas phases. Process parameters, such as final product quality, temperature, pressure and impurities, dictate which membrane is best suited for the task at hand: ceramic or polymeric, organophilic or hydrophilic, plate & frame or capillary, and so on.

Most ethanol producers are used to membranes for water treatment. Water separation usually occurs at the 'end-of-the-pipe' where effluent streams are treated after the main production process. These systems need ample space due to the large membrane surface area required for the separation task.

Membrane-based solvent separation processes, such as ethanol drying, have a

Whitefox ICE technology

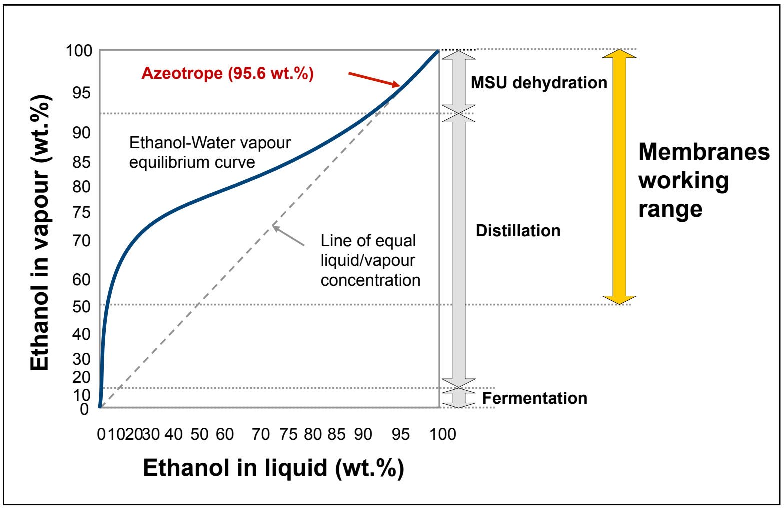

Figure 1: Equilibrium curve

much smaller footprint and, more importantly, can be applied 'in-situ' (during the production process) which has the potential to realise intrinsic value in existing ethanol facilities.

In ethanol dehydration, membranes separate water from ethanol continuously. There is no need to add chemicals to break the azeotrope or to regenerate the membranes as with ceramic beads in molecular sieves. The separation occurs when passing the ethanol/water feed from distillation over the membrane with some pressure and applying a vacuum to draw the water through the wall of the membrane. What is left is the in-spec ethanol product with virtually no water and a water rich side stream with very little ethanol to be recovered.

Discussing some of the key principles of integrating membranes in ethanol dehydration, Dr Stephen Blum of Whitefox, a provider of membrane technology for ethanol drying, says: 'Typically, in industrial applications dealing with aqueous-organic mixtures, the organic solvent is the valuable component. The first question to be addressed is whether the organic solvent is the majority component or the minority component. Membranes are designed to pass either water, called hydrophilic, or organics, called organophilic. Product from hydrophilic membranes is immediately in-spec which is one of the reasons Whitefox uses hydrophilic membranes.

'The second question is whether the membrane is exposed to liquid or vapour. Liquid membranes are more prone to fouling, scaling and chemical aggression which reduces production capacity and lifetime. In contrast, vapour phase membranes are exposed to clean vapour feed allowing stable operation, compact design and long lifetimes. With membranes operating in the vapour phase the separation characteristics of distillation, evaporation and adsorption can be combined to achieve optimum heat integration for minimum energy usage.'

The role of membranes

Ethanol plants are designed around the azeotrope principle. In the distillation tower, as the ethanol concentration increases on its way to the top of the column the ethanol water mixture at some point reaches the azeotrope, meaning liquid and vapour have the same concentration. At this point distillation cannot be used to obtain higher percentages of ethanol regardless of the amount of energy applied to the distillation process. Up to 75-80 wt% ethanol, distillation is very efficient. As the ethanol concentration in the vapour approaches the azeotropic point (Figure 1) many stages are needed which leads to tall columns and increasing energy consumption.

While molecular sieves work efficiently with water concentrations in the feed of around 7%, which necessitates a distillate purity close to azeotropic concentration, membranes can dehydrate from anywhere above 50%, with no reflux condensers and significantly shorter columns. This opens up numerous opportunities in the distillation and drying sections which could have a major impact on energy consumption.

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Membranes also have the ability to dehydrate other water-rich process streams which traditionally have to be recycled to the distillation section. One such stream is the regenerate stream or purge from the molecular sieve units (see 'Before' in Figure 2).

Molecular sieves need to recycle a portion of the anhydrous product back into the beds to remove the adsorbed water, thus producing a hydrous regenerate stream which is subsequently recycled back to the rectifier. Typically, the regenerate and recycle streams represent 10-25% of the total output.

Dehydrating the regenerate stream (see 'After' in Figure 2) eliminates the recycle, offering a number of benefits such as increased output capacity by 10-25% and reduced energy and water consumption.

Another advantage of

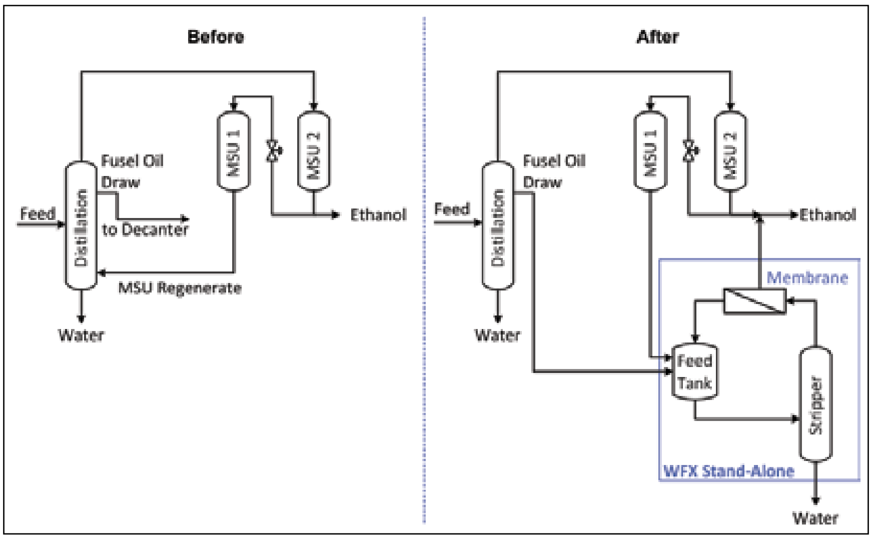

Figure 2: Side stream treatment


Whitefox's Stephan Blum (right) in discussion with a customer

membranes is their tolerance to fusel oils. Stephan Blum says: 'In many cases fusel oils are removed during the distillation phase to achieve stable operation of the reflux rectifier. Existing processes may use large amounts of water to separate fusels before they are added back into the product or sold off separately. This creates inherent inefficiencies. Knowing that membranes are fusel oil tolerant and can dehydrate fusel oil rich streams to final product, enables you to explore a number of possibilities for improving your existing process. The benefit of using membranes to treat side streams can be quite significant, both in terms of water and energy savings, but also capacity increase.'

Empowering plant engineers

As a consequence of the fundamentals discussed above, the combination of distillation and conventional drying with vapour-based membrane technology offers attractive process integration opportunities. Membranes offer a wide range of opportunities for ethanol producers, helping them avoid MSU regen recycle, reduce or eliminate reflux, limit distillation and dehydrate ethanol containing fusel oils.

Ethanol producers are opening their eyes to this opportunity as membrane drying is gaining momentum.

Membranes, therefore, could significantly alter the way plant operators think about plant designs and would allow engineers to create new opportunities for efficiency gain. We can see a number of interesting ways of combining this technology with the various innovations at the front end to unlock more value from an ethanol producer's existing assets. ●

For more information:
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The benefits of technology collaborations – a case study

Since its first industrial-scale ethanol drying installation in 2002, Whitefox has seen a growing understanding amongst operators of how membrane technology can add value at their plants. This is based in part on the close working relationship that Whitefox encourages with its clients, where free flow of information plays an important role in identifying bottlenecks. The company has found that, by sharing membrane drying know-how, its clients are often able to identify their own target areas for efficiency gains or capacity increase which are then discussed jointly by the client and Whitefox.

A recent example from a US producer demonstrates the benefits of this approach. The producer owns several plants, each one different, from capacity, to technology, to product quality. Plant strategies also differ depending on location, feedstock and market conditions. After several meetings between Whitefox and the producer the plant engineers understood the key operational characteristics of Whitefox's ICE technology and were able to determine technical and operational parameters. Whitefox provided its simulations and cost-benefit analysis and options were then prioritised.

One of the plants, currently operating at 60 million gallons per year, requires extra drying capacity as a consequence of improvements to the front-end. The rectifier is operating at its maximum limit so they planned to invest in new rectifier capacity. Simulations carried out by Whitefox showed a more practical solution involving a bolt-on membrane system installed alongside the current MSU system to dehydrate directly the regenerate stream from 70 wt% to 99 wt% (final product).

This solution frees up an annual 9 million gallon (15%) capacity in the rectifier column allowing the plant to increase its capacity with its current assets. The financial benefit assessment showed that this is a far more effective way of increasing the capacity and can be done with a payback of close to a year and 35-40% internal rate of return.

With the increased understanding from working together on the expansion project, the producer is now investigating membrane solutions at other plants including co-production of industrial and fuel grade ethanol to satisfy an increasing demand of high-grade ethanol from the US and Europe and drying of fusels (eliminating decantation) to control moisture in final product.

By providing membrane know-how, simulation capabilities and design parameters Whitefox encourages plant engineers to develop specific solutions for their plants. By working closely together, better solutions can be designed that take into account the CAPEX and OPEX drivers of the project.