
# Yield Increase and Energy Savings in Bioethanol and DDGS Manufacturing with Membralox® Technology

## Overview

At over 110 million cubic meters (29 billion US gallons) in 2019, global ethanol production from renewable plant-based origins is a substantial contributor to climate-friendly energy sourcing. As such, it fits in with various governmental renewables and climate policies. Of significant importance in bioethanol production is the most valuable by-product from the dry milling ethanol production process: a high-energy, high-protein and nutrient-rich animal feed ingredient known as distillers dried grain with solubles, or DDGS. At approximately 45 million metric tons of global annual production output and growing, the value of distillers grains is increasingly being recognized, not only as a favorable alternative to traditional feedstock but also for its economic impact on ethanol producers' revenue.

Other value streams from bioethanol production are in some cases distillers oil, and carbon dioxide from the ethanol fermentation, which is captured and re-used.

Ethanol is produced sustainably by yeast fermentation of sugars from biomass feedstock — mainly grains (corn, wheat, barley, rye, triticale) or sugar (cane, beet).

A corn or wheat biorefinery producing bioethanol and DDGS does so in roughly equal quantities. These biorefineries employ similar processes, varying only slightly depending on the type of feedstock used (Figure 1). The most important steps include:

- Extraction ("liquefaction") of sugars from feedstock carbohydrates (*e.g.* starch from grains)
- Fermentation to convert sugars into ethanol
- Distillation to recover ethanol from the fermentation broth
- Stillage processing, to produce DDGS animal feed or biogas

An excellent opportunity for maximizing production yield and reducing process cost is the treatment of the thin stillage (Figure 1).

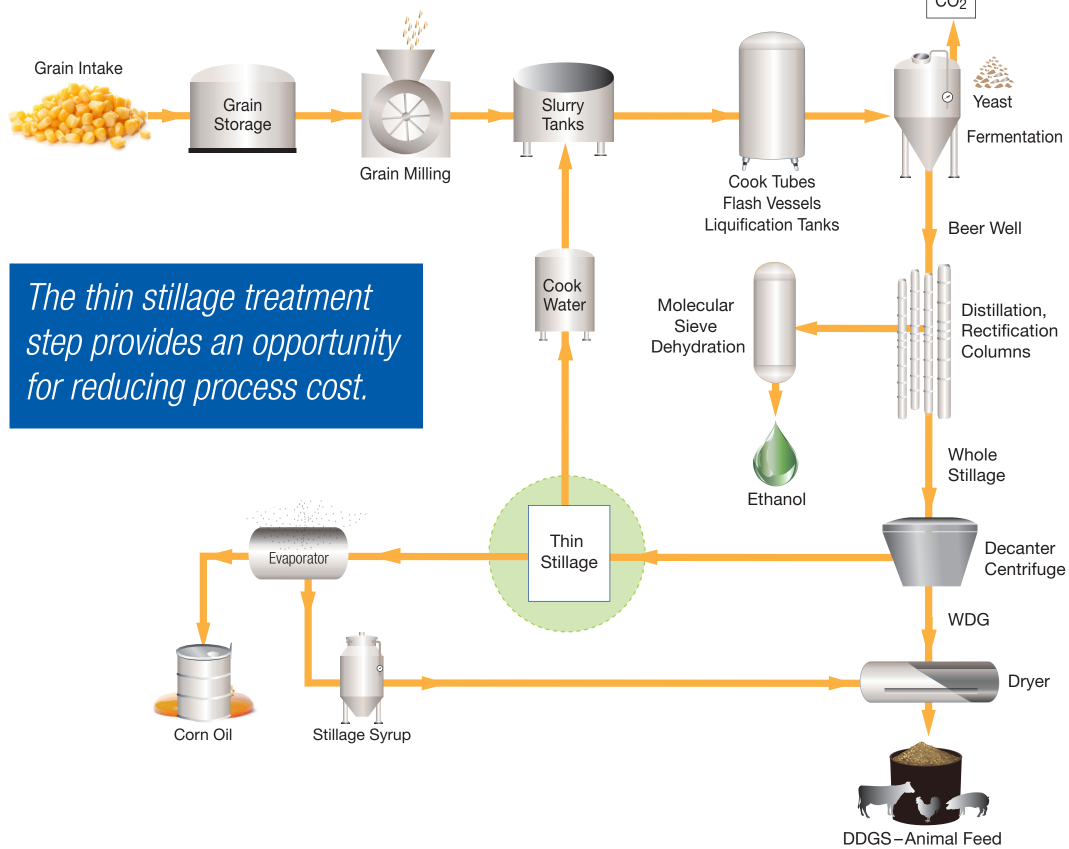
Membralox Ceramic Crossflow System

## The Challenge

A bioethanol producer using corn as the carbohydrate source needed to handle 250 m$^3$/hour (1100 US gal/min) of thin stillage on a continuous basis, while improving their cost of ownership when compared to a standard system for thin stillage processing.

Whole stillage consists of fermentation bottoms from the distillation process. It is typically clarified using decanting centrifuges, yielding two streams: a high solids slurry and an aqueous liquid known as thin stillage. The slurry, also called wet distillers grain (WDG), consists primarily of unfermented grain residues and yeast. It has a high protein content and is used as a valuable source of animal feed in different forms. The thin stillage contains up to 5-7% suspended solids, oil and over 90% water.

Figure 1: Typical process flow diagram for bioethanol production from animal feed corn. The focus of process improvement in this application is at the thin stillage stage.




*The thin stillage treatment step provides an opportunity for reducing process cost.*

A common practice is to recycle a portion of thin stillage back to the carbohydrate cook/slurry tanks as make-up water at the beginning of the process. Due to the remaining high suspended solids in this liquid, and the presence of oils and other miscellaneous components, the recycled thin stillage adds to the non-fermentable solids load in the fermenters, hence decreasing fermentation capacity and negatively affecting ethanol yield.

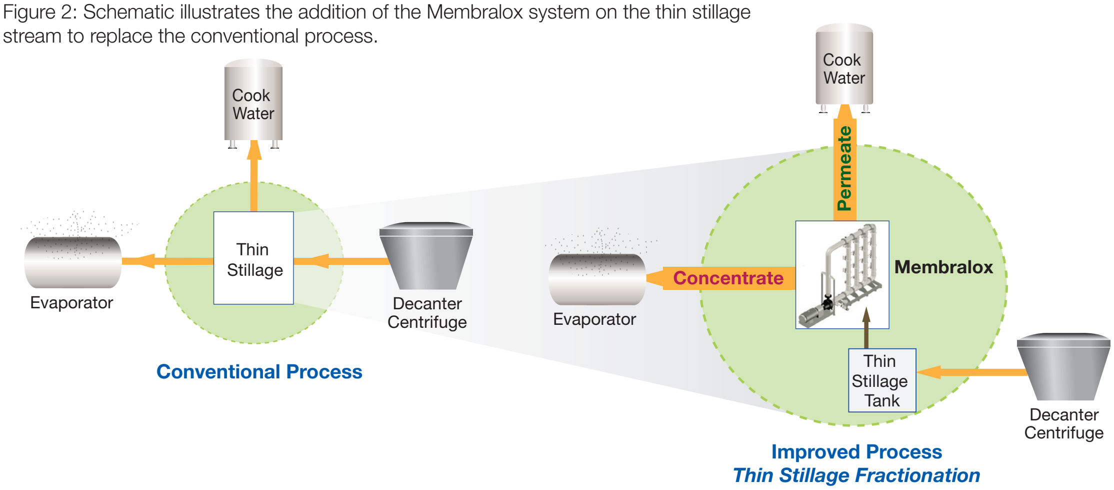
The liquid that is not routed back to the cook/slurry tanks is sent through a multiple-effect evaporation system where it is concentrated into syrup containing 25-50% solids. The syrup is high in protein and fat content, and it is combined with the wet distillers grain coming off the decanters and dried for animal feed known as dried distillers grain with solubles (DDGS). In some processes, oil may be extracted from the syrup as a separate value-added stream. Evaporation of the thin stillage results in high energy costs.

Thin stillage can also be fed into an anaerobic digester to produce biogas for energy, however it is not an easy substrate for this process.

## The Solution

Extensive large-scale pilot trials using Membralox ceramic crossflow technology installed on a thin stillage feed stream at 80 °C (176 °F) with 3-5% dry suspended solids provided the required cost savings and ROI for the bioethanol producer (Figure 2). The new technology demonstrated the feasibility and benefits of precise separation and concentration of this stream.

Figure 2: Schematic illustrates the addition of the Membralox system on the thin stillage stream to replace the conventional process.



## An Enclosed System Using Crossflow Filtration

The Membralox ceramic system is enclosed, limiting product exposure to the environment. This provides operator safety due to the high temperature processing, and limits oxidation, which would be detrimental to DDGS quality.

In crossflow filtration, feed fluid continually sweeps across the membrane surface parallel to the filtration membrane. Separation takes place as permeate (filtrate) passes through the membrane and retentate is recirculated and concentrated (Figure 3).

Figure 3: Crossflow filtration principle

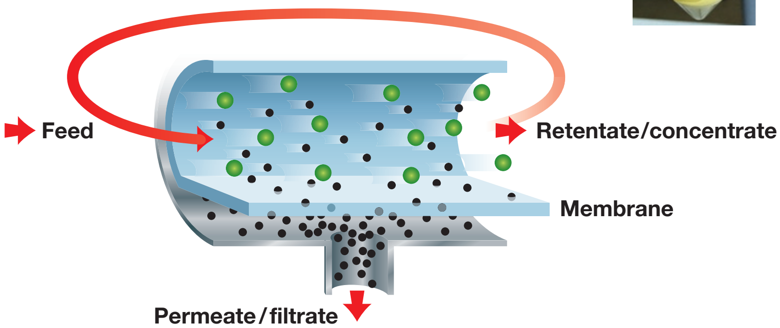



Figure 4: Exceptional fractionation of thin stillage results in crystal clear permeate *(right)* and high suspended solids retentate *(middle)*. The nutrition profile of the retentate stream (about 15% dry solids) includes crude proteins, fat, fibers and salts.

## Reproducible and Precise Separation

Thin stillage liquid is fractionated into exceptionally clear permeate (almost free from suspended solids, large proteins and oil) and retentate streams (high solids and oil). This is key to the success of this application.

Membrane separation provides a reproducible, consistent barrier that will always provide a precise separation, regardless of feed fluid properties or any system upsets resulting from the upstream centrifugation. Selection of the membrane cut-off to achieve this precise separation is tailored in part to the nature of the suspended solids in the feed stream. This application requires a tight cut-off, which ensures that suspended solids fragments coming off the decanting centrifuge are effectively captured in the retentate stream.

The crystal clear permeate (Figure 4) is fully recycled as make-up water to the beginning of the process. This permeate contains less than 0.1% suspended solids.

The clarity and lack of suspended solids and oils in this permeate, as compared to the quality of the untreated thin stillage has a significant positive impact on fermentation yield and is one of the determinants of success in this application. In addition, the high permeate quality may offer future value-add possibilities by capitalizing on its nutrient profile.

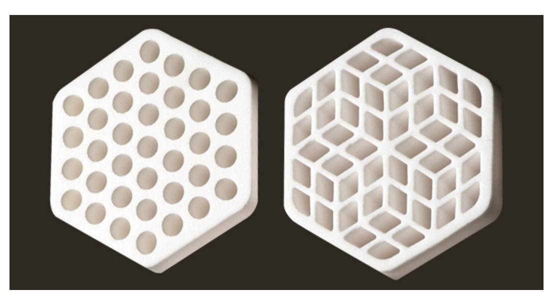
## High Suspended Solids Yield

In this application, the membranes achieve a concentrated retentate with over 15% dry solids. This concentrate stream (Figure 4) requires less energy for downstream evaporation, due to its lower moisture content than untreated thin stillage. The energy savings gained at this step of the process contribute significantly to the success of this project.

Finally, the more proteins and other nutrients that are retained in the retentate stream, the greater the final yield and nutritional value of the syrup added back to the animal feed end product.

The ability to achieve the required retentate concentration is impacted by the size and design of the membrane channels (Figure 5).

Figure 5: Cross sectional view of Membralox EP48-40IC membranes (48 channels, *right*), which pack 47% higher filtration area into the same geometry than traditional EP37-40 membranes (37 channels, *left*) with concentric ring design.



Their selection is based on product concentration, viscosity and suspended solids load in the feed fluid, and reflects an optimization of the desired benefits. When comparing like designs, the larger the channels, the greater the ability to achieve high retentate concentration and high permeate yield, yet the lower the filtration area. On the other hand, when comparing different designs of like channel diameter, namely traditional concentric ring versus 'intermingled channel' (IC) design, the IC design allows a much higher filtration area.

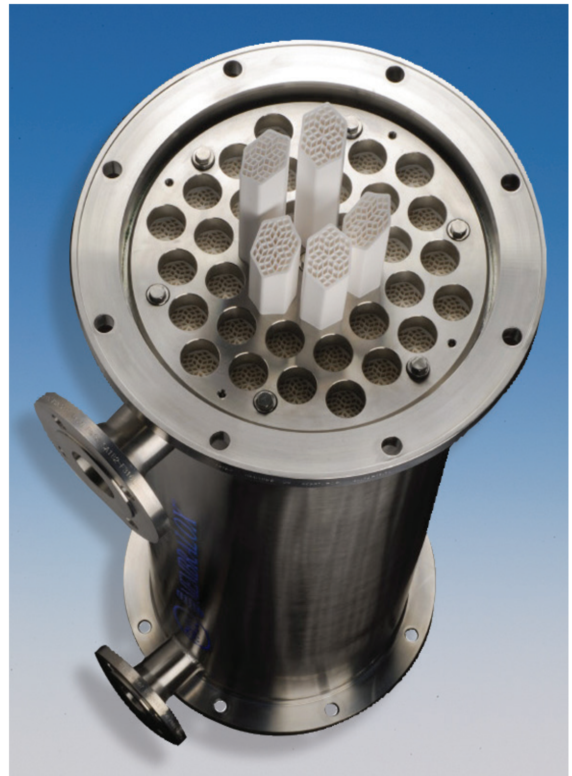
In this application, Membralox IC membranes with 4 mm membranes (EP48-40IC) were selected to provide the highest membrane area while achieving the highest possible concentration in the most compact footprint. Within the same module geometry, the IC membranes with their honeycomb design enable 39-47% higher filtration area than traditional ceramic membranes with concentric ring design (Figure 5). The result is highly compact modules (Figure 6), which has a significant impact on system configuration, footprint, and cost of ownership.

## Compact System Design for Continuous Production

The resulting full-scale solution developed by Pall to handle 250 $m^3$/hour (1100 US gal/min) of thin stillage on a continuous basis was an industrial size crossflow system based on Membralox HCB modules loaded with IC membranes. The total installed membrane area is close to 2000 $m^2$ (21,528 $ft^2$).

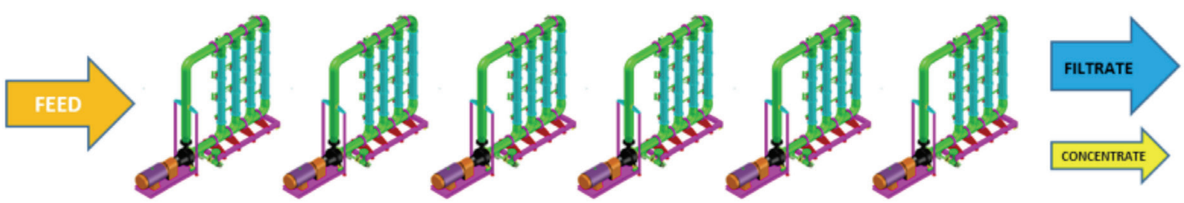
The system consists of multiple filtration loops to enable 24/7 operation at constant throughput. At any time, several filtration loops operate in serial in production mode, while at least 1 filtration loop is concurrently cleaned in place (CIP). CIP occurs sequentially, alternating from loop to loop. (Figure 7). Typically, each filtration loop operates in production for up to 48 hours, then it is automatically cleaned.

Figure 6: The Membralox 36P48-40HCB module consists of 36 EP48-40IC multi-channel membranes, mounted in a compact Membralox HCB housing.



Optional diafiltration maximizes the amount of permeate and the concentration of the retentate. Finally, the optimal combination of flux versus trans-membrane pressure (TMP) control during system operation provides yet another means of enhancing product recovery.

Figure 7: Schematic of Membralox crossflow ceramic system for thin stillage fractionation, with multiple filtration loops.




*Due to the vertical arrangement of the ceramic modules, each filtration loop results in a 9 $m^2$ (97 $ft^2$) system footprint.*

## The Benefits

Implementing Pall Membralox crossflow technology to fractionate thin stillage provided the strong impetus to improve the conventional process and achieve significantly better economics for this large greenfield project.

Cost savings were realized due to the following factors:

- Ethanol fermentation yield increase, due to effectively purifying the thin stillage into high quality permeate used as recycled make-up water, free from non-fermentable solids and other undesirable components
- Significant energy cost savings at the evaporator, by decreasing the water content and increasing the suspended solids load of the thin stillage sent to the evaporator by at least 3 times
- Animal feed yield increase, by increasing the suspended solids component in the syrup
- Potential to create other value-added streams especially from the permeate
- Process simplicity, reliability and safety due to system automation

## About Pall Corporation

Pall Corporation is a global filtration, separation and purification leader providing solutions to meet the critical fluid management needs of customers across the broad spectrum of life sciences and industry. We work with our customers to advance health, safety and environmentally responsible technologies.

Pall Food and Beverage provides products and services to ensure product quality and maintain process reliability in beverage and food production. Our solutions also assist in consumer protection, waste minimization and reduction of operating costs.

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FBABMEMSTILLAGEEN May 2020