



APPLICATION NOTE

# VSEP Filtration in Ethanol Production

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Stillage and Vinasse Treatment Solution

## Overview

The search for alternative fuels to gasoline has yielded a clear, viable candidate: ethanol. Ethanol production has been on the rise globally, a direct result of both governmental regulations as well as economic incentive. Both regulations and incentives are driven by environmental concern as well as a desire to reduce overall dependency on fossil fuel. Global ethanol production has increased from 4.3 billion gallons in the year 2000 up to 19.9 billion gallons in the year 2009.

The largest ethanol producers in the world are the United States and Brazil (Table 1). These countries combine for 86% of the world's ethanol production. The ethanol production in both countries has been motivated by government mandates to use ethanol-blended gasoline. These governments impose these mandates and regulations for the following reasons:

1. Environmental: Ethanol is a clean-burning fuel relative to other additives and options such as MTBE. Environmental and health-related concerns have been raised about the impact of MTBE, causing governments around the world to phase out its use as an additive in favor of ethanol.
2. Economical: Governments can stimulate many sectors of their domestic economy via ethanol production: agriculture, construction, and production job markets.
3. Political: Reducing dependency on foreign sources of fuel and energy can be politically advantageous for local governments.

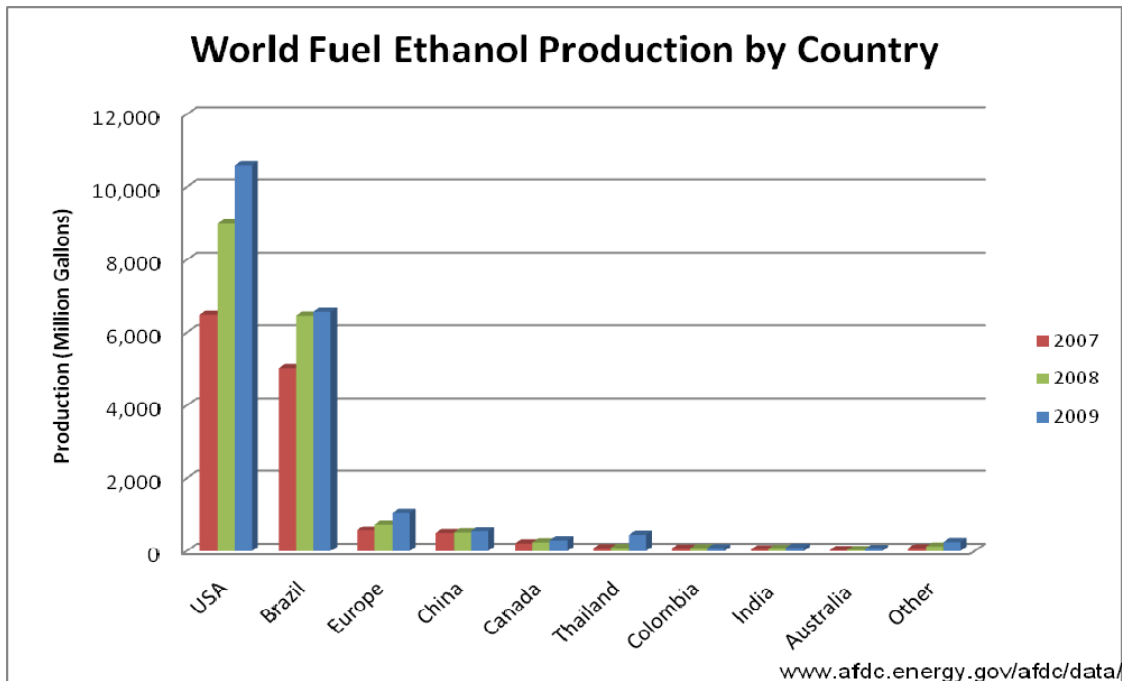


Table 1: Global Ethanol Production (Source: U.S. Department of Energy)

In Brazil, fuel mandates have been in place since 1976. In June 2007 Brazil's Ministry of Agriculture mandated that all gasoline contain a minimum of 25% ethanol fuel. In the United States more than half of the states have limited the use of MTBE fuel additives or banned them altogether, leaving ethanol as the best alternative for the gasoline producers to boost octane levels in their products. This has resulted in an increased use of E10, a gasoline blend with 10% ethanol, in the United States.

Similarly, Other parts of the world are increasing ethanol production on an annual basis. China is the third largest producer, and that India and Thailand are also making large investments in ethanol production suggests that Asia will be closing in on Europe as the next largest ethanol producing continent after the Americas. Countries in Africa are beginning to see the economic potential of this renewable energy source that can be harvested and used within their own borders. The number of ethanol plants continues to grow worldwide.

## **Background**

The feedstock for ethanol plants varies significantly and depends upon proximity of the source as well as the location. Brazil's feedstock is almost exclusively sugarcane whereas in the United States the feedstock is typically corn. Other sources such as wheat, rye, and barley are used in cooler climates like Canada and Eastern Europe. Each feedstock presents a different set of challenges that must be surmounted to make production both environmentally and economically feasible. Regardless of location or feedstock, by-products generated require further treatment or disposal. In corn-based processes, the distillery effluent is referred to as *stillage*. In the sugarcane-based processes, the effluent is known as *vinasse*.

Both stillage and vinasse present significant obstacles for ethanol producers. The large volume of these by-product streams alone, approximately ten times the volume of ethanol produced, requires ethanol producers to have equipment in place to treat the material for discharge or use in other industries. Costly techniques such as evaporation are used to remove water and concentrate the nutrients so that the stream can be used as incinerator fuel, fertilizer or even feed for livestock. New Logic Research offers a cost-effective solution for the removal of water from these streams using VSEP technology.

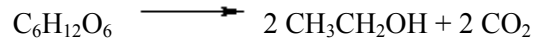
Ethanol is produced by the fermentation of monosaccharides such as glucose and fructose. The monosaccharides are typically formed through the hydrolysis of any number of biomass options. The biomass feedstock for ethanol production varies depending primarily on local economics and resources. Ethanol production can prove advantageous in that development of fuel production facilities can be optimized according to the resources of their own particular surroundings. Brazil and the United States use biomass sources that are high in carbohydrate content: sugarcane and corn respectively. Cellulose-based feedstock is possible as well, such as grass or woodchips. The drawback in using cellulose material as opposed to carbohydrate material is the cost of converting the cellulose-based biomass to a monomeric sugar that can be easily converted to ethanol through fermentation.

Regardless of the biomass source, the process of ethanol production or recovery is the same. The three main steps that are always present are: hydrolysis, fermentation and distillation. In some cases the first two steps—hydrolysis and fermentation—are carried out simultaneously. In all cases there is a solid residue as a byproduct in an aqueous stream after the ethanol has been fully recovered. This high solids aqueous stream is the stillage or vinasse depending on the type of process (corn-based or sugar-based production).

Hydrolysis : There are two types of hydrolysis used in ethanol production: enzymatic and acidic. Enzymatic hydrolysis uses organisms and, in some cases, synthetic enzymes specifically designed to convert carbohydrates to monosaccharides. Production facilities using carbohydrate-rich biomass typically use enzymatic hydrolysis. Acidic hydrolysis is typically used for cellulose-rich biomass.

Converting cellulosic material is more costly and more difficult than converting carbohydrates to monosaccharides.

Fermentation : Fermentation is carried out in a reactor with yeast components that convert the glucose or other monosaccharides to ethanol. The fermentation process breaks down one part sugar into two parts ethanol and two parts carbon dioxide:



Distillation: Distillation begins when the ethanol is removed from the water and solids by taking advantage of its lower boiling point. The ethanol at this stage is typically 96% pure (4% water). To create anhydrous ethanol, a second step is required. Whatever the derivation (corn or sugarcane), the effluent left behind can be concentrated and used for a variety of purposes such as livestock feed, fertilizer, or boiler fuel.

### Vibratory Shear Enhanced Processing (VSEP)

While membrane-based separations of liquids from solids have enjoyed increasing popularity over the last twenty years, the technology has an inherent challenge that affects all membrane devices: fouling. This long-term loss in throughput capacity is due primarily to the formation of a boundary layer that builds up naturally on the membranes surface during the filtration process. In addition to cutting down on the flux performance of the membrane, this boundary or gel layer acts as a secondary membrane reducing the native design selectivity of the membrane in use. This inability to handle the buildup of solids has also limited the use of membranes to low-solids feed streams.

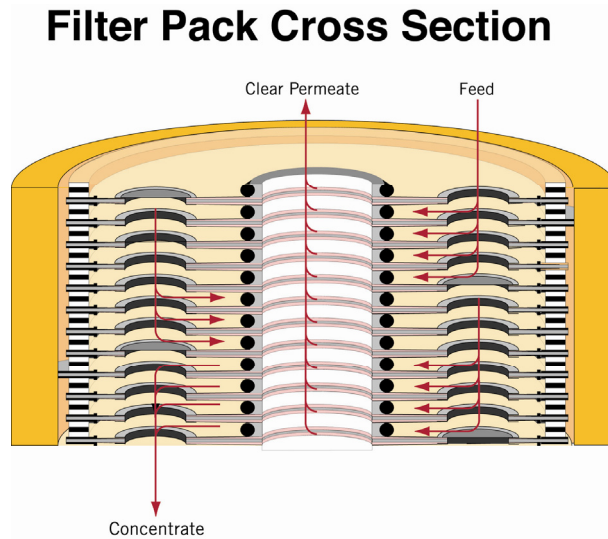


Figure 1: Basic VSEP Configuration

To help minimize this boundary layer build up, membrane designers have used a method known as tangential-flow or cross-flow filtration that relies on high-velocity fluid flow pumped across the membranes surface as a means of reducing the boundary layer effect (see Figure 1). In this method, membrane elements are placed in a plate-and-frame, tubular, or spiral-wound cartridge assembly, through which the substance to be filtered (the feed stream), is pumped rapidly.

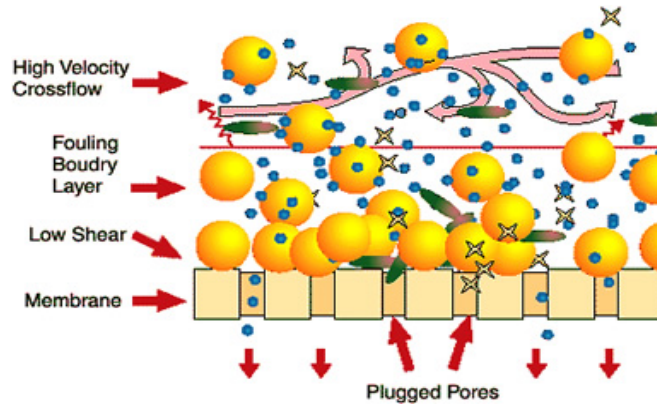


Figure 2: Basic Cross-flow Design

In cross-flow designs, it is not economic to create shear forces measuring more than 10-15 thousand inverse seconds, thus limiting the use of cross-flow to low-viscosity (watery) fluids. In addition, increased cross-flow velocities result in a significant pressure drop from the inlet (higher pressure) to the outlet (lower pressure) end of the device, which leads to premature fouling of the membrane that creeps up the device until permeate rates drop to unacceptably low levels.

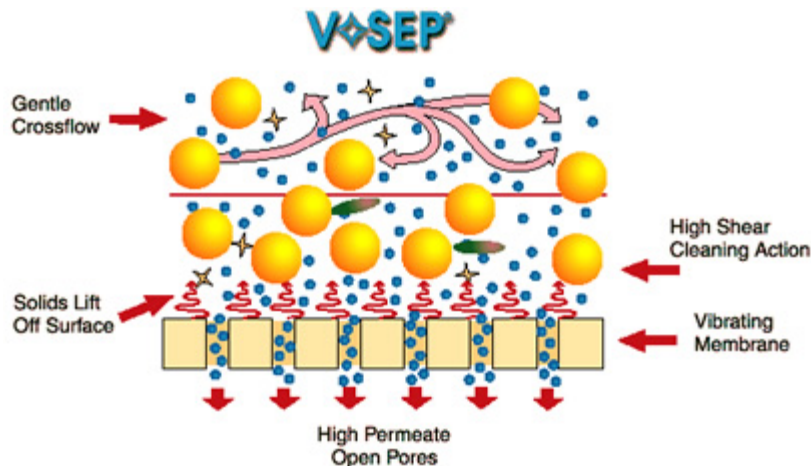


Figure 3

New Logic, however, has developed an alternative method for producing intense shear waves on the face of a membrane. The technique is called Vibratory Shear Enhanced Processing (VSEP). In a VSEP System, the feed slurry remains nearly stationary, moving in a leisurely, meandering flow between parallel membrane leaf elements. Shear cleaning action is created by vigorously vibrating the leaf elements in a direction tangent to the faces of the membranes.

The shear waves produced by the membrane's vibration cause solids and foulants to be lifted off the membrane surface and remixed with the bulk material flowing through the membrane stack. This high shear processing exposes the membrane pores for maximum throughput that is typically between three and ten times the throughput of conventional cross-flow systems (Figure 3)

The VSEP membrane filter pack consists of leaf elements arrayed as parallel discs and separated by gaskets. The disc stack resembles records on a record changer with membrane on each side.

The disk stack is oscillated above a torsion spring that moves the stack back and forth approximately 7/8 inches (2.22 centimeters). This motion is analogous to the agitator of a washing machine but occurs at a speed faster than that which can be perceived by the human eye.

The oscillation produces a shear at the membrane surface of about 150,000 inverse seconds (equivalent to over 200 G's of force), which is approximately ten times the shear rate of the best conventional cross-flow systems. More importantly, the shear in a VSEP System is focused at the membrane surface where it is cost effective and most useful in preventing fouling, while the bulk fluid between the membrane disks moves very little.

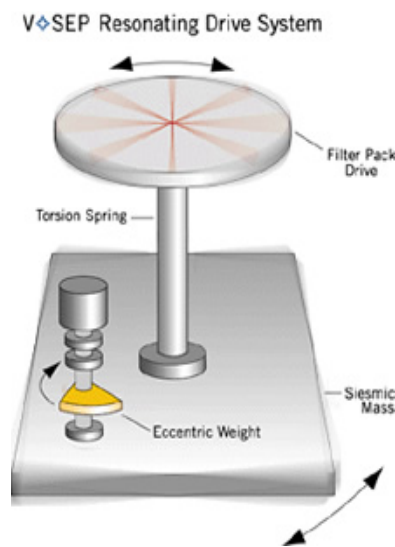


Figure 4: VSEP

Because VSEP does not depend on feed flow-induced shearing forces, the feed slurry can become extremely viscous and still be successfully dewatered. The concentrate is essentially extruded between the vibrating disc elements and exits the machine once it reaches the desired concentration level. Thus, VSEP systems can be run in a single pass through the system, eliminating the need for costly working tanks, ancillary equipment and associated valve fittings.

The disc pack holdup volume of a system with 1,400 ft<sup>2</sup> (130 sq. meters) of membrane area, is less than fifty gallons (189 liters). As a result, product recovery in batch processes can be extremely high. Waste after draining the stack is less than three gallons (11 liters).

#### VSEP System Operation:

At startup, the VSEP system is fed with a slurry and the concentrate valve is closed. Permeate is produced and suspended solids in the feed are collected inside the VSEP filter pack. After a programmed time interval, valve one is opened to release the accumulated concentrated solids. The valve is then closed to allow the concentration of additional feed material. This cycle repeats indefinitely.

Membrane selection is the single most important parameter that affects the quality of the separation. Other important parameters that affect system performance are pressure, temperature, vibration amplitude, and residence time. All of these elements are optimized during testing and entered into the programmable logic controller (PLC) which controls the system.

The operating pressure is created by the feed pump. VSEP machines can routinely operate at pressures as high as 1,000 psig (68.95 BAR). While higher pressures often produce increased permeate flow rates, they also use more energy. Therefore, an operating pressure is used that optimizes the balance between flow rates and energy consumption.

In most cases, the filtration rate can be further improved by increasing the operating temperature. The temperature limit on a standard VSEP system is 175° F (79°C), significantly higher than competitive membrane technology. Even higher temperature constructions are also available.

The vibration amplitude and corresponding shear rate can also be varied which directly affects filtration rates. Shearing is produced by the torsion oscillation of the filter stack. Typically the stack oscillates with amplitude of 3/4 to 1 1/4 inches (1.9 to 3.2 cm) peak to peak displacement at the rim of the stack. The oscillation frequency is approximately 53 Hz and produces a shear intensity of about 150,000 inverse seconds.

Feed residence time is set by the frequency of the opening and closing of the exit valve (valve one). The solids level in the feed increases as the feed material remains in the machine. Occasionally, a cleaner is added to the membrane stack and continued oscillation helps clean the membrane in minutes. This process can be automated and only consumes approximately fifty gallons (189 liters) of cleaning solution thus reducing cleaner disposal problems inherent with other membrane systems.

#### **VSEP and Solids Removal**

Concentrating the solids found in any distillery effluent can be challenging. The residual biomass yielded from ethanol production must be removed from the aqueous stream to have any significant value as incinerator fuel, fertilizer, or livestock feed. VSEP membranes are designed to handle high-solid liquid streams, using a patented vibratory technology that reduces the typical tendency of membranes to plug when processing high- solids streams. There are several viable process schemes for use of VSEP in the treatment of stillage or vinasse.

## Synopsis 1: VSEP Treatment of Vinasse

Pilot scale testing completed in Brazil during the month of November of 2010 demonstrated the ability of VSEP technology, equipped with reverse osmosis (RO) membranes, to treat vinasse both before and after anaerobic digestion. Batch concentrations of both the raw vinasse and the digested vinasse consistently reached 80% recovery, (a 5x concentration factor,) while maintaining high flux rates averaging 25 GFD (Table 2).

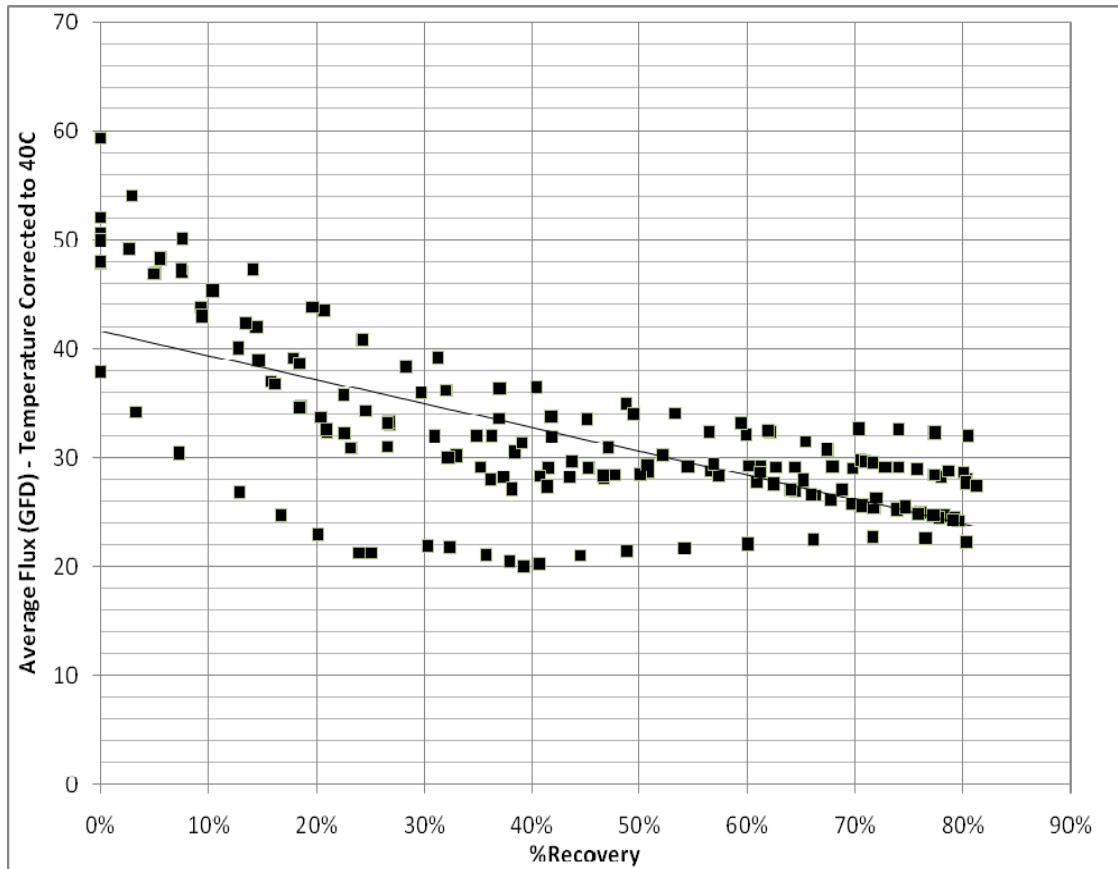


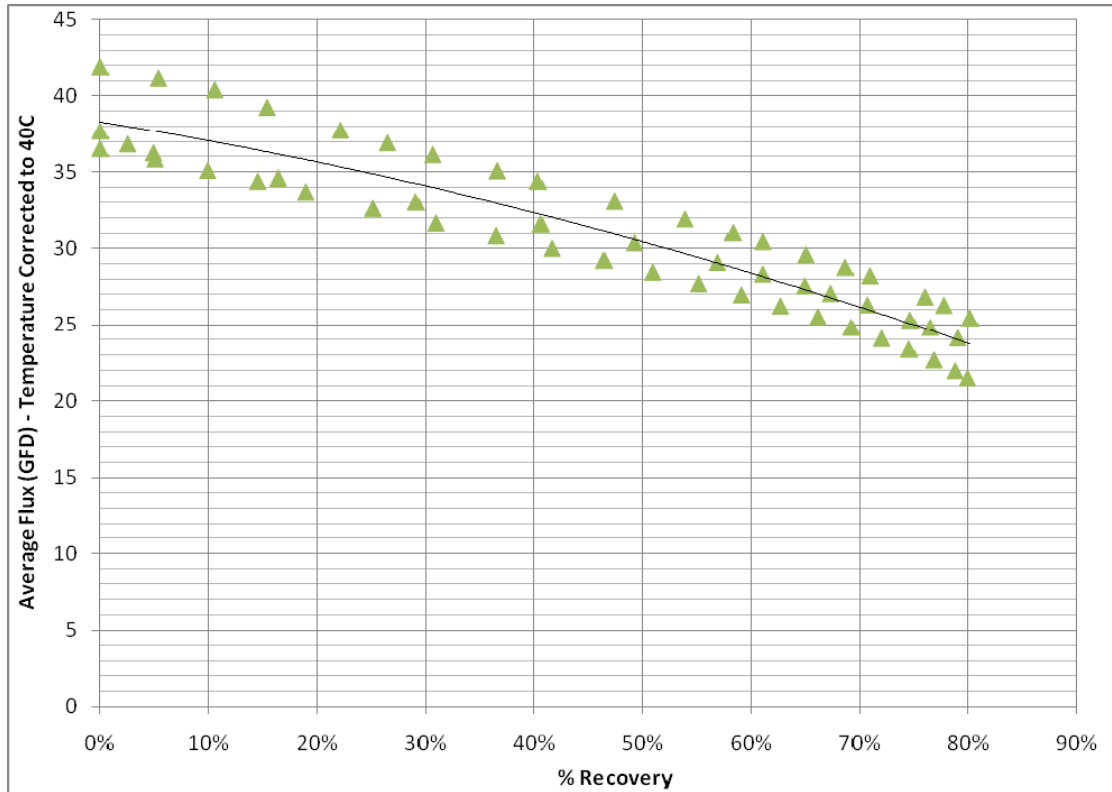
Table 2: Data collected on digested vinasse using RO VSEP

Use of a digester prior to VSEP allows the ethanol producer to recover methane gas from the digester. This additional energy output from the process may be desirable. In some cases, treatment of the vinasse is the primary concern and maintaining a lower overall cost for the facility prohibits the use of a digester. In such cases, VSEP equipped with an RO membrane is able to achieve the separation at a high recovery rate of 80% while achieving average flux rates at or around 25 GFD (Table 2).

The use of an RO membrane allows for high quality permeate. This use yields permeate that can be discharged or reused within the facility to improve water balance of production. Nutrients in the form of nitrogen, phosphate, and potassium, are concentrated effectively using VSEP RO technology (Table 2). This allows the production facility to send the concentrate to an evaporator prior to future use as a fertilizer or livestock feed supplement.



Table 3: Data collected on raw vinasse using RO VSEP



SAMPLE	pH	Conductivity	COD	Total Solids	Nitrogen	Phosphate	Potassium	Calcium	Magnesium
	(-)	(uS/ cm)	(mg/L)	(mg/L)	N	P2O5	K2O	CaO	MgO
					(mg/L)				
DIGESTED VINASSE FEED	7.84	11,971	17,680	21,396	720	170	4500	930	640
DIGESTED VINASSE CONCENTRATE	7.78	18,299	53,358	55,572	1560	480	150	2550	1790
DIGESTED VINASSE PERMEATE	7.63	959	148	**	40	30	600	30	10
RAW VINASSE FEED	4.77	7,706	25,339	20,706	520	110	3600	740	460
RAW VINASSE CONCENTRATE	4.68	14,861	67,788	108,570	1580	320	15000	2620	1460
RAW VINASSE PERMEATE	4.81	474	606	**	10	10	600	10	0

Table 4: Data collected on raw and digested vinasse  
 \*\* unmeasured

## Synopsis 2: VSEP Treatment of Thin Stillage

Most corn-based ethanol production plants use basic centrifugation to remove wet grain from the stillage leaving behind what is commonly referred to as *thin stillage*. The wet grain consists of the largest solids in the stillage that are easy to remove by centrifuge. They are then easy to dry for further use as incinerator fuel, fertilizer or livestock feed depending on the local economics and conditions. The thin stillage is much more difficult to dewater. The most common solution is to use an evaporator to remove a significant portion of the water leaving behind a thick syrup which is then sent to a final drying phase. The chief liability of this process is the high cost of evaporation. Use of a VSEP system equipped with ultra-filtration (UF) or nano-filtration (NF) membranes can reduce the costs associated with evaporation by reducing the burden of the evaporation system. The VSEP system can dewater the thin stillage prior to evaporation and subsequent drying.

Use of UF membranes for this application results in full retention of suspended solids while allowing dissolved solids to leave the system with the permeate (clean water). If partial retention of dissolved solids is desirable based on local economics and environmental conditions, NF membranes are used. Due to the variation in feedstock, fermentation and distillation by-products, flow rates and recovery rates will vary.

VSEP UF Treatment of Thin Stillage			
	Feed	Concentrate	Permeate
Volume	100%	20%	80%
TDS (ppm)	79,500	117500	70,000
TSS (ppm)	66,000	330000	ND

Table 5: Typical VSEP UF data treating thin stillage

## Summary 3: VSEP Treatment Prior to Distillation

With the help of Peder Wallentin of Nordcap, located in Goteburg, Sweden, a study was arranged and completed at Lund University. Lund researchers developed a method for efficient fermentation of wood fibers to produce ethanol using specifically-adapted yeast. Research completed by Mats Galbe, Linda Pilcher, and Christian Roslander of the Chemical Engineering Department also compared use of VSEP with use of a decanter centrifuge in removing solids after the fermentation process (Figure 5). The results proved to be crucial for the ethanol yield out of the process, confirming the efficacy of VSEP. While the results of fiber concentration for both technologies were positive, the advantage of VSEP was illustrated when examining the permeate that would move forward to distillation. The permeate from the VSEP was solids-free, while the permeate from the decanter centrifuge was not. This test used a MF Teflon membrane with a pore size of 0.2  $\mu\text{m}$ . With VSEP the experiment revealed a concentration in fiber solids from 3% to 18%; while generating a solids-free permeate.

VSEP use to remove solids residue proves advantageous over other technologies in several ways. VSEP is the only system that generates a solids-free permeate either prior to or after distillation and simultaneously achieves a high level of solids concentration. In addition, the VSEP works with no chemical supplement, avoiding high cost of chemical addition as well as preserving any nutritional value the concentrated solids may have. VSEP uses a Teflon membrane as the filtration media, a barrier technology for separation. When compared to other membrane technologies (such as tubular membrane systems), VSEP has the advantage of being able to tolerate (and also concentrate) high levels of suspended solids. While tubular membrane systems can handle higher levels of suspended solids than conventional spiral elements, they are unable to reach the same level of solids concentration as VSEP.

Based on the results of the Lund University study, a flux rate of 1.1 L/(min m<sup>2</sup>) can be expected. This converts to a flux rate of roughly 38 GFD (gallons per square foot per day). An 84 inch filter pack with 1300 square feet of membrane would be expected to produce a permeate flow rate of 34.3 GPM, or 49,392 GPD. During this experiment, fiber solids were concentrated from an initial value of 3% to an ending value of 18%. This represents a concentration factor of 6x.

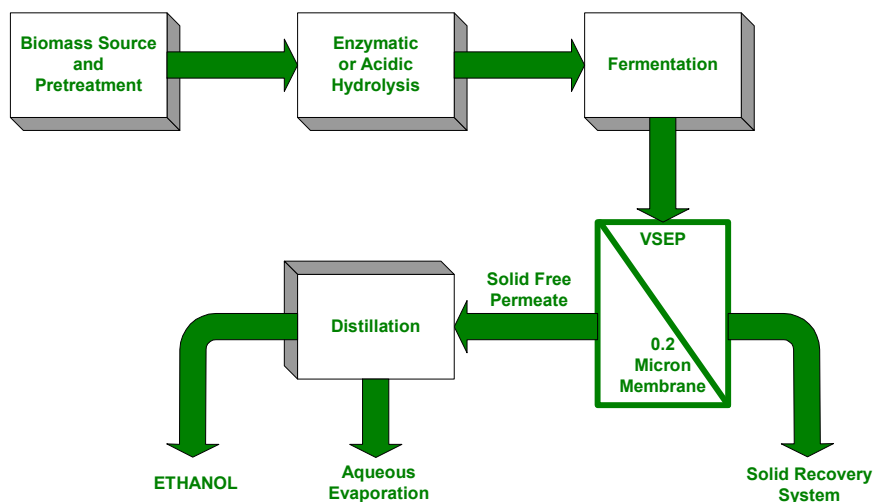


Figure 5: Use of MF VSEP prior to distillation

## Conclusion

A key point of difference with VSEP technology is its adaptability; that it is a highly customized solution allows the system to fit existing process flow schemes regardless of feedstock type or final solids. VSEP can be fully integrated into existing ethanol productions plants as well as in newly constructed facilities.

With regard to ethanol production, VSEP can be installed between the fermentation and distillation steps, or after the distillation step to concentrate the stillage or vinasse. The evaporation of the final aqueous stream may not be needed if a good use for the water can be found. The terminal treatment of the concentrated solids stream would depend on the concentrate's end use. Often the most efficient use of a solids by-product is to convert it into feed material for incinerator or boiler use. Evaporating all remaining water in the concentrated solids stream is needed prior to feeding the material to the burner for incineration. The unique ability of VSEP to concentrate the original solid waste stream greatly reduces the workload for the final evaporation step. And because of the cost associated with evaporation, this reduction of energy output translates directly into financial savings.

Because VSEP does not depend on feed flow-induced shearing forces, the feed slurry can be extremely viscous and still be dewatered successfully. This evolution in membrane technology, along with the ability to achieve high concentration of effluent make VSEP the only installation of its kind to achieve consistent, reliable results that remain unmatched by any static membrane system on the market today.

For case studies and schematics see the New Logic Research website at [www.vsep.com](http://www.vsep.com).



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