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DOW HYPER SHELL™ Elements Generate Significant Energy Savings in Ultrafiltration (UF) Whey Permeate Concentration Production

At-a-Glance

Project purpose:

- Compare energy consumption between mesh-wrapped elements and DOW HYPER SHELL elements in dairy RO concentration system

System:

- 10-stage, 300-element, 600-gpm, 8-inch whey permeate concentration system
- Constant 50 psi pressure drop across stages via pressure transducers and VFD

Feed:

- UF permeate of whey

Competitive elements:

- Mesh-wrapped elements

Key parameters measured:

- Bypass area
- Average amp draw on pump
- Energy consumption

DOW was invited by a major U.S. dairy producer to measure the performance characteristics of competing standard mesh-wrapped elements and DOW HYPER SHELL™ RO elements. The purpose was to compare the impact of these elements on fluid flow requirements and pump energy consumption during whey permeate concentration production. The results showed that the DOW HYPER SHELL™ RO elements delivered reduced flow requirements and lower pump energy consumption than the standard mesh-wrapped elements.



Introduction

As several publications have noted, dairy producers can enjoy significant energy savings by reducing/replacing evaporator need with reverse osmosis concentration systems.^{1,2} In fact, there are government incentives providing rebates to companies that have converted or reduced their energy demand by installing RO concentration systems.

What many in dairy processing may not realize is that companies can reduce their energy consumption and cost savings even further by selecting a reverse osmosis element that reduces fluid flow requirements while maintaining optimum dewatering efficiency. In an ongoing case study at a large dairy producer, the DOW HYPER SHELL™ RO element, with its patented hardshell exterior, has been shown to reduce flow requirements and pump energy consumption. The following projected cost savings were based on a study of a 10-stage, 300-element, 600-gpm, 8-inch whey permeate concentration system:

- 29% to 45% energy cost savings over competitive mesh-wrapped elements
- Up to \$438 per element annual cost savings
- Annual projected savings: \$12,972 per stage



Research Details

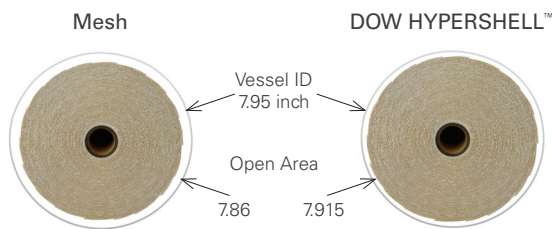
This case study was conducted at a U.S. dairy producer concentrating UF whey permeate. A competitive field trial was conducted based on the characteristics of bypass flow in the dairy plant’s sanitary concentration system, and an in-depth analysis of the system’s energy consumption.

Bypass flow is a “necessary evil” in sanitary concentration applications. It is the fluid that flows between the element and pressure vessel walls that is necessary for maintaining sanitary conditions. However, too much bypass flow reduces the dewatering efficiency of the element. Feed that goes around the element instead of through it does not get dewatered. Bypass flow increases the flow rate requirements of the system, putting extra demand on the system pumps and increasing the energy requirements and operating cost of the system.

DOW HYPERSHELL™ RO elements are equipped to reduce the flow requirements of a system by minimizing wasted bypass, yet still provide sufficient flow path for effective cleaning. This results in more feed being allowed to go through the element instead of around it. Figure 1 shows a schematic for the reduced bypass areas of DOW HYPERSHELL™ when compared with standard mesh-wrapped elements.

Figure 1. Comparing the bypass (open pipe area) of a pressure vessel when using a standard mesh-wrapped element versus using the DOW HYPERSHELL™ element.

HYPERSHELL™ element has 60% less bypass area



Parameter	Mesh	DOW HYPERSHELL™
Open Pipe Inch	0.11	0.035
Area Square Inch	1.11	0.43

Reduced Bypass Flow Equals Energy Savings

Centrifugal pumps used in the recirculation loops of sanitary RO concentration systems are typically sized to operate at the maximum flow requirement that the system would ever need. However, the maximum flow requirements of a multi-stage dairy concentration system can vary. Bypass area in pressure vessels, fouling and solids levels all can affect flow in the system. The maximum flows will be with high bypass area, lower solids, and at low fouling levels.

Capturing the available energy savings from a reduced bypass area requires using a pump with a variable frequency drive and an element that can effectively reduce bypass flow. To better understand this concept, and the basic operating characteristics of pumps and variable frequency drives (VFDs), see Appendix A.

Results

The system analysis is summarized below in Table 1. The energy costs during concentration were calculated for each stage, based on the affinity laws of centrifugal pumps using measured motor frequency output to each of the stage pumps VFDs (as calculated in Appendix A). Each stage in the study contained only one type of element: either a DOW HYPERSHELL™ element or a competitive mesh-wrapped element. The study took place in stages one through five of a 10-stage system. Stages six through 10 contained mixed mesh and DOW HYPERSHELL™ elements; therefore, they were not included in the study. Each stage maintains a constant pressure drop of 50 psi controlled by the VFD of the stage pumps as demonstrated by the stage pressure and baseline pressure in Table 1.

Table 1: UF Whey Permeate RO System

Feed	UF Whey Permeate
Baseline Pressure, psi	441
Feed Flow, gpm	600
Stages	10
PV/Stage	6
Elements/PV	5
Stage pumps, HP	50
Pump RPM at full speed	3500
Stage pumps, kW	37.3
Stage Pressure, psi	491
VFDs on stage pumps	Yes

Potential energy savings were calculated based on the following equation:

- Annual cost = (HP) * (.746 kW/HP) * (7300 annual operating hours) * (\$0.12 cost of electricity)

The HP was calculated from the affinity laws of centrifugal pumps:

$$HP_1/HP_2 = (rpm_1/rpm_2)^3$$

The speed of the pump was calculated from motor frequency of the pump measured by the VFD:

- A Fristam FPH 3542 has a speed of 3500rpm at 60Hz
- $rpm_2 = freq_2/60 * 3500$

DOW HYPERSELL™ Elements Generate Significant Energy Savings in Ultrafiltration (UF) Whey Permeate Concentration Production

Energy Analysis Data

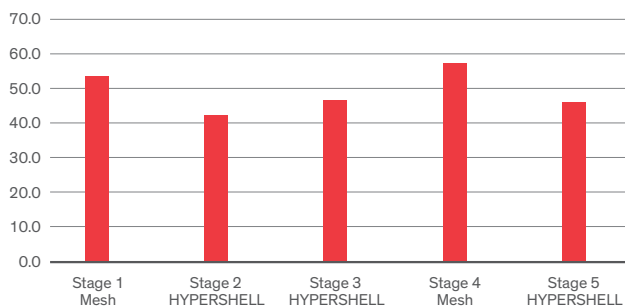
The energy analysis data is shown in Table 2 and Graphs 1 and 2.

The data in Table 2 and Graph 1 shows that stages 1 and 4, filled with standard mesh-wrapped elements, had an average pump amp draw of 54 and 58, respectively. By contrast, stages 2, 3 and 5, containing DOW HYPERSELL™ elements, had an average pump draw of 43, 47 and 46, respectively, an average 22% amp savings.

Table 2: Measured Output from VFDs

Stage/Element Type	Age of Elements Install Date	Motor Frequency, Hz Avg.	Pump Amp Draw Avg.
Stage 1 Mesh	6/20/2012	59	54
Stage 2 HYPERSELL	8/20/2013	48	43
Stage 3 HYPERSELL	6/8/2012	50	47
Stage 4 Mesh	8/22/2013	59	58
Stage 5 HYPERSELL	6/6/2012	52	46

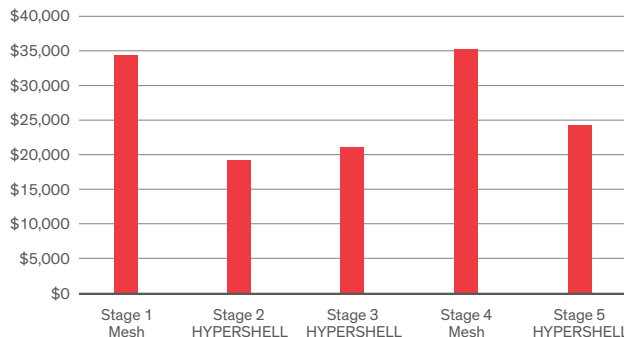
Graph 1: Average Amp Draw on Pump Full load=55.8



Avg. 22% Reduced Amp Draw with HYPERSELL Elements

Using the energy cost savings data shown in Table 2 and Graph 1, we can project annual energy cost savings for each stage, as shown in Graph 2. The average annual energy savings per element (mesh versus DOW HYPERSELL™ element) is \$438, which computes to an average savings of \$12,972 per stage.

Graph 2: Calculated Annual Operating Cost per Stage



Projected Average Energy Cost Savings

Appendix A

The rotational speed of a centrifugal pump powered by an AC induction motor has a direct relationship with the frequency of the power it receives. For example, using equation 1, a 60Hz 4 pole motor at full speed will have an rpm of $60 \times 120 / 4 = 1800$ rpm.

Equation 1: RPM = frequency x 120 / # motor winding poles

In North America, power is standardized on 60Hz frequency. A centrifugal pump operating off 60Hz AC power will operate at full speed of the pump regardless of flow requirements. However, if a VFD is used to convert and control the frequency of the power delivered to the pump, the speed of the pump may be varied.

We know from the affinity laws of centrifugal pumps that the speed of the pump varies linearly with the volume flow. If the pump shaft speed is reduced by 5%, the volume flow decreases by 5%.

Equation 2: Flow is proportional to shaft speed

$$\text{flow rate}_2 / \text{flow rate}_1 = \text{rpm}_2 / \text{rpm}_1$$

This may seem like an insignificant change to be of value. However, the affinity laws also state that power consumption is the cube of the change in shaft speed as seen in equation 3. For a 5% decrease in rpm, the power consumption decreases from 100% to 85%. This is a 15% savings in energy.

Equation 3: Power (HP) is related to cube of shaft speed

$$\text{HP}_2 = (\text{rpm}_1 / \text{rpm}_2)^3$$

The power consumption of the pumps for this case study was calculated using the affinity laws mentioned above and the pump speed as measured from the motor frequency. Pump speed was calculated from measured motor frequency output of the VFD by the below equation. A Fristam FPH 3542 has a rated speed of 3500 rpm at 60Hz.

Equation 4: rpm₂ = freq₂ / 60 * 3500

Annual Cost analysis was done by the following equation:

Equation 5: Annual Operating Cost = (HP) * (.746 kW/HP) * hours of concentration * cost of electric



For more information, call the Dow Water & Process Solutions business:

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1. <http://www.usdairy.com/Sustainability/About/Documents/CaseStudy-ReverseOsmosisFilterSystem.pdf>
2. Stabile, R.L. Economics of Reverse Osmosis and Multistage Evaporation for Concentrating Skim Milk from 8.8 to 45% solids. *Journal of Dairy Science* – August 1983 (Vol. 66, Issue 8, Pages 1765-1772, DOI: 10.3168/jds.S0022-0302(83)82004-9).

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