

10.32
Spring 2005
Problem Set 4
Due Friday, April 22, 2005

In class we have been looking at an ultrafiltration system for producing a protein product from the waste whey solution at a cheese plant. The whey produced from the manufacture of cheese is an aqueous solution containing the following solutes:

<u>Solute</u>	<u>Weight (percent)</u>
True protein (TP)	0.6
Non-protein nitrogen NPN	0.3
Lactose	4.9
Ash	0.8
Butterfat	0.05

The current plant generates 10^6 pounds/day of whey solution that is currently dried by evaporation, and subsequent spray drying, to a product containing 13.5 percent protein (total of true protein and NPN). This product is sold for \$0.15/pound as animal feed.

We are interested in making a protein product that contains a much higher percentage of protein. The current market for protein products is \$0.65/pound for 35 percent protein and \$1.50/pound for 50 percent protein. The lower amounts of lactose (higher level of protein) make the dry product more acceptable for human consumption. It may be possible to make even more money by concentrating the protein.

The higher concentration of protein can be achieved by ultrafiltration of the whey solution to separate lactose from the protein prior to drying. The membrane we are considering passes lactose and ash but rejects protein and fat. The rejection coefficients are:

<u>Component</u>	<u>R</u>
Protein	0.96
NPN	0.4
Lactose	0.09
Ash	0.15
Butterfat	0.99

The rejection coefficient is defined as

$$R = 1 - \frac{C_p}{C_c} \quad (1)$$

where C_p is the mass fraction of a component in the permeate and C_c is the mass fraction of the component in the concentrate. The flux rate through the membrane was determined to be

$$N'' = 5.4 - 2.1 \ln C_c$$

where N'' is in pounds per hour per square foot and C_c is the mass fraction of dissolved solutes in the concentrate. The higher concentration products can be achieved by ultrafiltration of the whey followed by use of the existing evaporators and spray dryer.

The permeate from the ultrafiltration process contains significant amounts of lactose. This solution can be evaporated to about 20 percent dissolved solids and given away as animal feed, or it can be shipped to a waste treatment plant for which the company will be charged a fee depending on amount of solution and concentration of solids.

The cartridges that are available each have 26.5 ft^2 of mass transfer area. The inlet pressure to a cartridge is 30 psig, and the pressure drop through the cartridge on the retentate side is 15 psi, and the pressure drop across the membrane is 25 psi. The cartridges are arrayed in parallel as shown in Figure 1 and the concentration of protein in the bleed is maintained by adjusting the feed and bleed rates. To reduce concentration polarization, the flow through each cartridge should be maintained at 25 gpm by the recycle loop.

The ultrafiltration units can be operated only 20 hours per day since four hours each day must be used to clean and sterilize the ultrafiltration system. The costs for cleaning materials, water, and disposal of waste are small relative to other costs for the system.

Additional Technical and Financial Information

Drying System

Performance of evaporator system	$2.5 \frac{\text{lbs water}}{\text{lbs steam}}$
Performance of spray dryer	$0.5 \frac{\text{lbs water}}{\text{lbs steam}}$
Cost of steam	$\$5/10^6 \text{ Btu}$
Heat of vaporization of water	$900 \frac{\text{Btu}}{\text{lb}}$

Cartridge Characteristics

Total transfer area per cartridge	26.5 ft ²
Inlet pressure	30 psig
Pressure drop on retentate side	15 psi
Pressure drop across membrane	25 psi
Flow rate of concentrate (to reduce concentration polarization)	25 gpm

Cartridge Cost and Lifetime

Cost of cartridge including gaskets, adapters	\$225
Useful life	1 year

Costs for Stages and Automation

Cost of a stage	\$1,250/cartridge
Cost/stage for multiple stages	\$10,000
Cost to automate	\$8,000/stage
Control panel	\$50,000
Cleaning system	\$65,000

These costs include stainless steel process piping that is 4 inch I.D. throughout the system. The average velocity must be no more than 15 ft/s to prevent denaturation of the protein by shear stress.

Other Costs

Deionized water	\$15/1,000 gal
Electricity	\$0.09/kwhr

- a) In class we worked through most of the details for making a product with 35 percent protein and evaluated the economics for the system. Is it possible to concentrate the protein to 80%? If not, what is the maximum protein concentration that can be achieved?
- b) The dissolved solid concentration in the bleed stream cannot exceed 15 percent, or the membranes will begin to plug. To alleviate this problem, diafiltration can be used. In diafiltration the feed to the system is diluted with deionized water so that the separation can be performed at a lower total dissolved solids concentration. A diafiltration system is shown in Figure 2. Is it an economically-wise decision to make a protein product with 50% protein using diafiltration?
- c) It is proposed that a two-unit system might require fewer cartridges and save money. In the two-unit system the bleed stream for the first unit would be fed to the second unit as shown in Figure 3. Each of the two units can have more than one stage in parallel and all stages should have the same number of cartridges. Evaluate the advantages and disadvantages of using a 2-unit system to make a 35% protein product. Estimate the product yield and the pumping power required. Compare this cost-effectiveness of this two-stage system to the one-stage system that was presented in lecture.

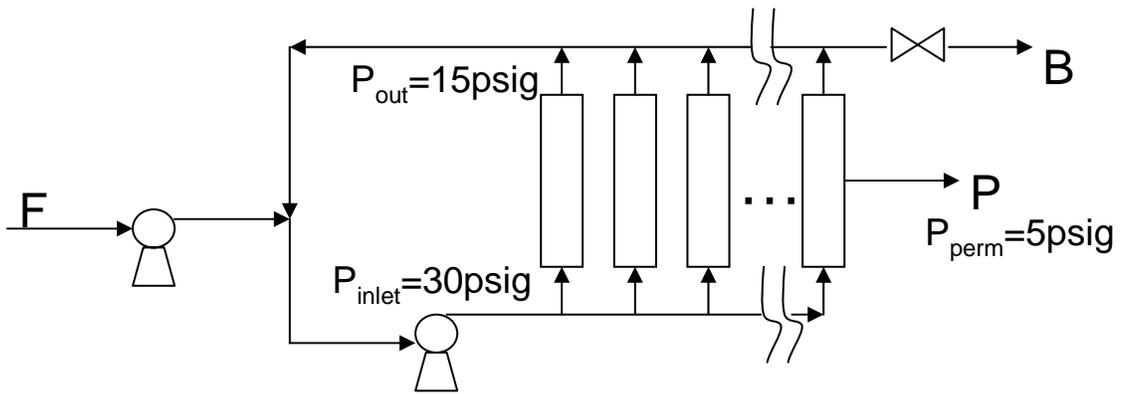


Figure 1. Schematic of cartridge configuration

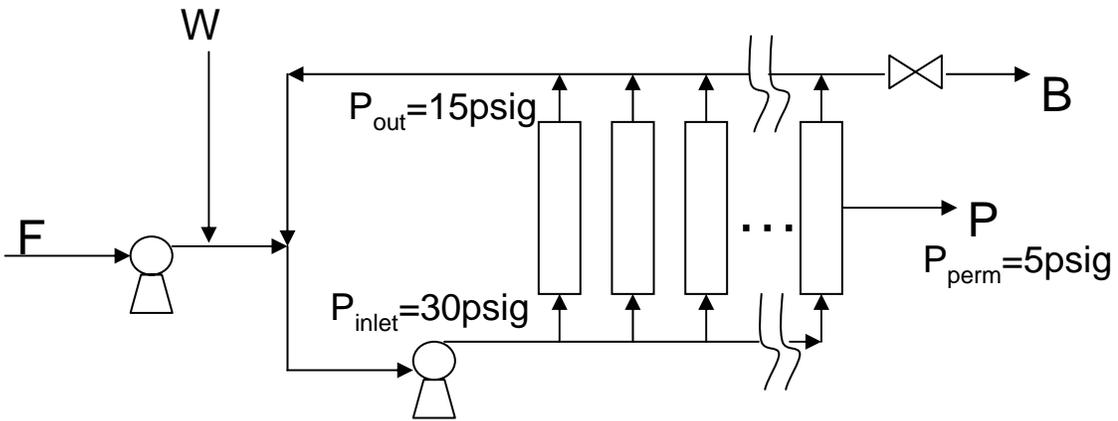


Figure 2. Diafiltration scheme

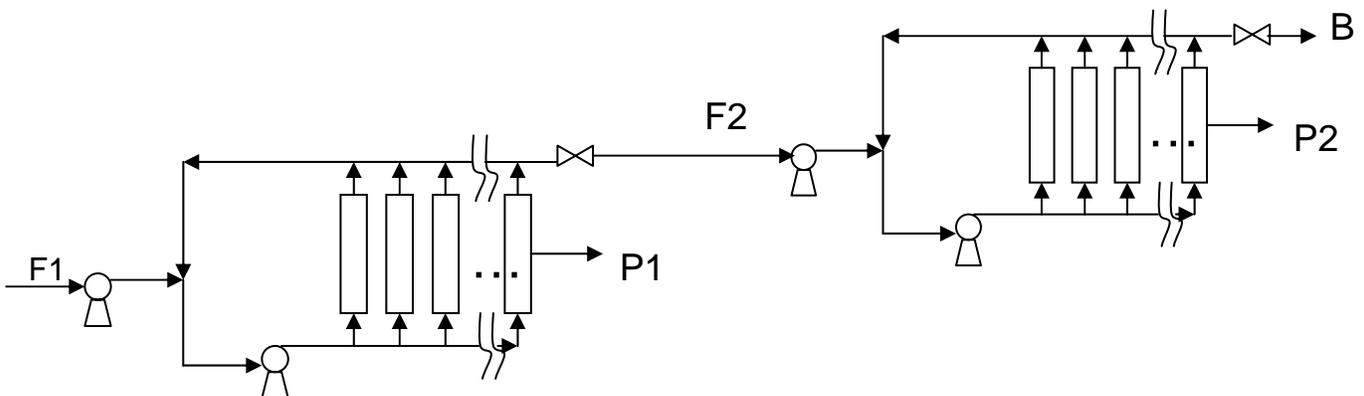


Figure 3. 2-Unit system