Reverse Osmosis & Nanofiltration Performance & Design Calculations

There are a handful of calculations that can be used for design considerations and to judge the performance of a reverse osmosis (RO) or nanofiltration (NF) system. This bulletin outlines the various calculations that can be useful when designing or determining the performance of a system.

SYSTEM PARAMETERS

A system has instrumentation that displays stream quality, flow, pressure and sometimes other data like temperature or hours of operation. In order to accurately measure the performance of a system, the following operation parameters are helpful to have:

1. Feed pressure
2. Permeate pressure
3. Concentrate pressure
4. Feed water analysis*
5. Permeate water analysis*
6. Feed flow
7. Permeate flow
8. Concentrate flow
9. Recycle flow
10. Operating temperature

* Feed and permeate water analyses will provide accurate solute concentrations. Frequently, feed and permeate conductivity readings are used to estimate the TDS (total number of inorganic salts) entering and exiting the system.

SALT REJECTION

Percent salt rejection reveals how effective the membrane elements are at removing particular dissolved solids and other contaminants. It does not reflect the performance of each individual membrane element, but rather how the system as a whole is performing. A well-designed system with properly functioning elements will reject the majority of most feed water impurities depending on the membrane type (please refer to the corresponding specification sheet for a particular element). To determine how effective the elements are at removing contaminants, use the following equation:

$$\text{Salt Rejection }\% = \frac{\text{Concentration of Feed Water} - \text{Concentration of Permeate Water}}{\text{Concentration of Feed Water}} * 100\%$$

The higher the salt rejection, the better the system is performing. A low salt rejection for the particular element may suggest that the membranes require cleaning or replacement (refer to MANN+HUMMEL Water & Fluid Solutions' various Troubleshooting Guides for more information).

SALT PASSAGE

Salt passage is simply the inverse of salt rejection; it is the amount of salts (expressed as a percentage) that are passing through the elements. The lower the salt passage, the better the system is performing. A high salt passage may suggest that the membranes require cleaning or replacement.

$$\text{Salt Passage (\%)} = 1 - \text{Salt Rejection (\%)}$$

RECOVERY

Percent recovery is the percentage of feed water which becomes permeate. A higher recovery rate means less feed water is sent to the drain as concentrate. However, if the recovery rate is too high for the system design, larger problems may arise due to scaling and fouling. System recovery is established in the system design, taking into consideration numerous factors such as feed water chemistry, pre-treatment and cross-flow velocity. Therefore, the proper recovery at which the system should operate depends on what the system was designed for. By calculating the system recovery, it is easy to quickly determine if the system is operating outside of the intended design. To calculate percent recovery:

$$\%\ \text{Recovery} = \frac{\text{Permeate Flow Rate}}{\text{Feed Flow Rate}} * 100\%$$

For typical system recovery rates, please see MANN+HUMMEL Water & Fluid Solutions' **Membrane Operating Guide – Recommendations for Water Purification** (TSG-O-012).

CONCENTRATION FACTOR

The concentration factor is related to system recovery and is an important equation for system design. The more water recovered as permeate (the higher the % recovery), the more concentrated salts and contaminants are collected in the concentrate stream. This can lead to higher potential for scaling on the surface of the membrane when the concentration factor is too high for the system design and feed water composition.

$$\text{Concentration Factor} = \frac{1}{1 - \text{Recovery}\ \%}$$

For example, if a system's feed flow is 100 gpm and permeate flow is 75 gpm, then the recovery is (75/100) x 100 = 75% and the concentration factor would be 1 / (1 – 75%) = 4. A concentration factor of 4 means that the water going to the concentrate stream will be 4 times more concentrated than the feed water. If the feed water in this example had 500 ppm TDS (total dissolved solids), then the concentrate stream would be 500 x 4 = 2,000 ppm TDS.

FLUX

Flux is the ratio between permeate flow rate and total active membrane area:

$$\text{Flux} = \frac{\text{Permeate Flow Rate}}{\text{\# of Elements in System} * \text{Membrane Area of each Element}}$$

For example, if a system is producing 17 cubic meters per hour (m^3/h) of permeate and comprises of 3 pressure vessels, each housing 6 elements (18 total elements) and the type of element has an active membrane area of 33.9 square meters (m^2) each, the system flux would be:

$$\text{Flux} = \frac{17\ \text{m}^3/\text{h} * 1000\ \text{L/m}^3}{18\ \text{elements} * 33.9\ \text{m}^2} = \frac{17{,}000\ \text{L/h}}{610.2\ \text{m}^2} = 28\ \text{lmh} \quad \text{or} \quad 28\ \text{L/m}^2/\text{h}$$

This means that 28 liters (L) of water is passed through each square meter of each element per hour. When designing an RO or NF system or determining whether a system is running at an acceptable flux, please refer to **Membrane Operating Guide – Recommendations for Water Purification** (TSG-O-012).

MASS BALANCE

A mass balance equation is used to help determine if the flow and quality instrumentation on the system is reading properly or requires calibration. Refer to **Troubleshooting – Evaluation of System Performance** (TSG-T-002) for more information regarding mass balance equations.

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STAGES & PASSES IN SYSTEM DESIGN

The terms "stage" and "pass" are often mistaken for one another, but it is important to understand the difference between the two. Stages treat the concentrate multiple times whereas passes treat the permeate multiple times. Below are images and descriptions of the two.

Stage

In a single-stage system, the feed water enters the system as one stream and exits the system as either concentrate or permeate water.

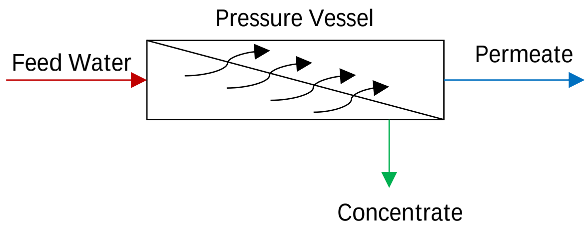

Figure 1. A single-stage (and single-pass)

In a two-stage system, the concentrate (or reject) from the first stage becomes the feed water to the second stage. The permeate water collected from the first stage is combined with the permeate water from the second stage. Additional stages increase the overall recovery of the system.

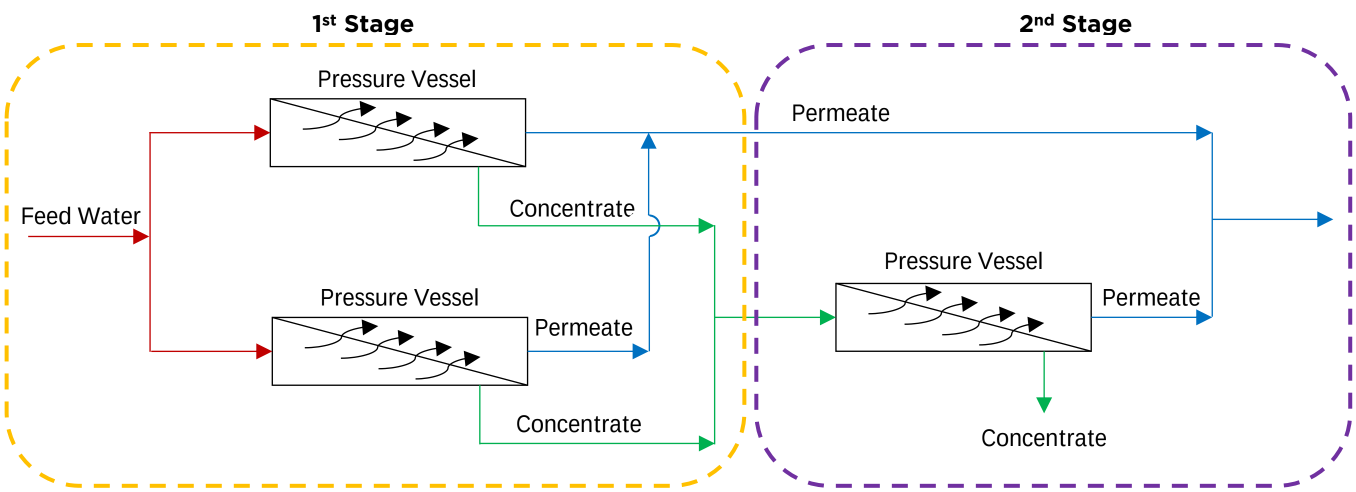

Figure 2. A two-stage system; where the concentrate from the first stage becomes the feed to the second stage.

Array

In a system, an array describes the physical arrangement of the pressure vessels in a multi-stage system. In a multi-stage system, each stage can have a determined amount of pressure vessels (which typically house 6 elements each). The reject of each stage then becomes the feed stream for the next successive stage. For example, the two-stage system displayed above is a 2:1 array, meaning that the concentrate (or reject) of the first two vessels is fed to the next single vessel.

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System with Concentrate Recycle

If the feed water chemistry and system design allows for it, a concentrate recycle stream can be utilized where a portion of the concentrate stream is fed back to the feed water of the first stage to help increase the system recovery as well as the cross-flow within the pressure vessels.

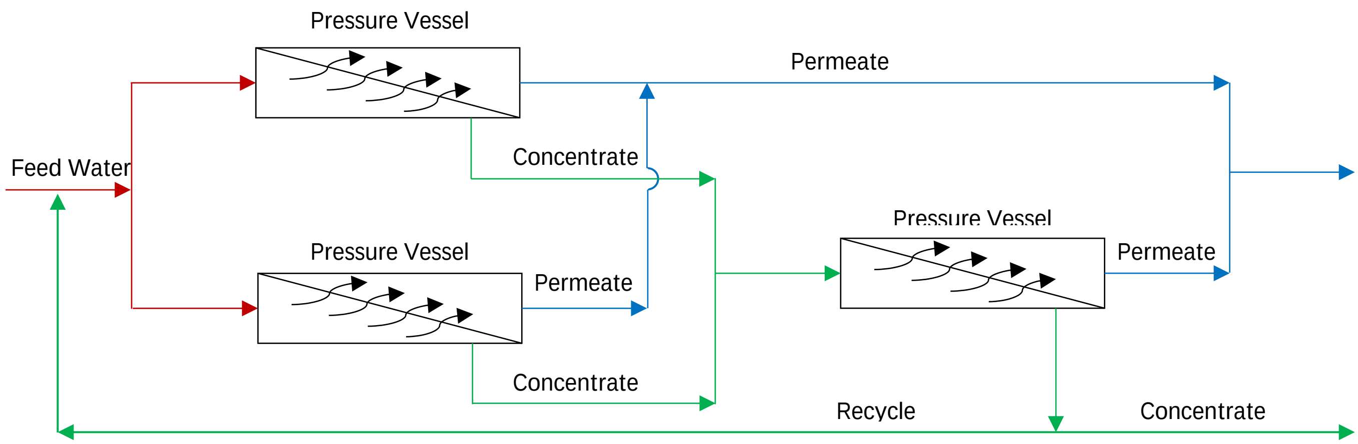

Figure 3. A two-stage system with a concentrate recycle stream back to the feed stream.

Single Pass vs. Double Pass System

Think of a "pass" as a stand-alone system. The difference then between a single pass system and a double pass system is that for the latter, the permeate from the first pass becomes the feed water to the second pass (or second stand-alone system). This results in a higher permeate quality because the water has essentially gone through two systems (the water has passed through the membrane twice). Some or all of the second pass concentrate may be recycled back to the feed to increase overall system recovery.

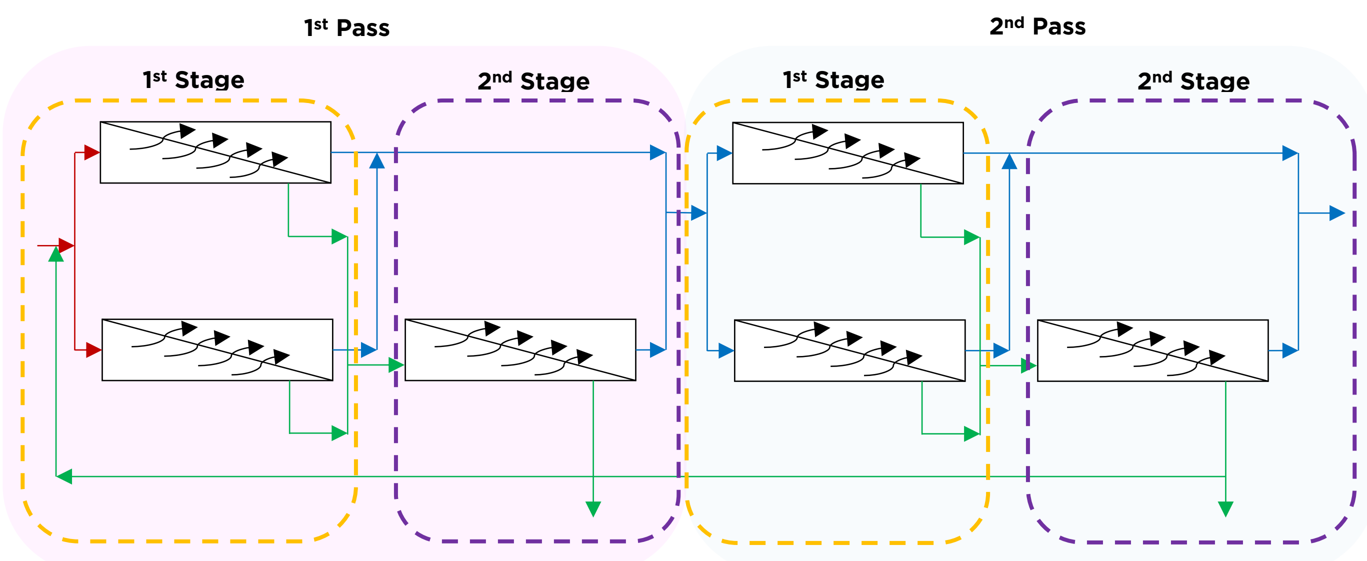

Figure 4. A two-pass system; where the permeate of the first pass becomes the feed to the second pass.

TROUBLESHOOTING

If the system is experiencing poor performance, please refer to MANN+HUMMEL Water & Fluid Solutions' line of Troubleshooting Guides at www.microdyn-nadir.com/en or contact Technical Service for more information or additional help.

If assistance is needed for designing a system, please contact Technical Service.

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