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Concentrating Nature's Bioactivity

The Benefits of High Temperature Tangential Flow Filtration

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Summary:

- SmartFlow's Patent Pending *ConSep II*™ can be operated at temperatures up to 80°C.
- Increasing the operating temperature of TFF processes can result in a drastic reduction in filter area required, up to around 50%.
- Operating at elevated temperatures can cut processing costs by reducing heating, cooling, and pump horsepower requirements.
- Higher operating temperatures can have additional benefits in product quality, enzyme activity, product safety, and cleaning.

Overview:

Traditional TFF spirals, hollow fiber filters, or tubular filters are typically rated to a maximum temperature of 45° to 55°C by the filter manufacturer. The temperature limit is generally due to the filter construction rather than the base membrane's temperature capability. By utilizing appropriate materials, TFF processes can be operated at much higher temperatures, lowering product viscosity. The viscosity effect on flux rate is widely recognized in the filtration industry, with manufacturers offering Temperature Correction Factors (TCF) to normalize the measurements of clean water flux rates in their membranes. Clean water flux rates increase significantly as the processing temperature rises from 40°C to 80°C. Because of this, operating at higher temperatures can significantly lower membrane area requirements and system costs due to increased permeate rates.

Introduction:

Membrane filtration is a proven, widely implemented technology for solid/liquid separation. The physical structure of the membrane creates a semipermeable liquid barrier, the performance of which is significantly influenced by the viscosity of the liquid passing through it. This viscosity is highly influenced by the temperature of the fluid.

Benefits from Operating at High Temperature:

SmartFlow has utilized the high temperature capabilities of the Patent Pending *ConSep II*™ modules to meet many customer needs and cost requirements. Some proven benefits include:

Improved Flux Rate: *ConSep II*™ modules enable a flux rate increase of up to 85% by increasing the temperature of the process material from 40°C to 80°C, in part due to the change in the viscosity of water. This increase in flux rate will significantly reduce the membrane area required for customer processes, lowering system cost. Further cost reductions arise from fewer filter holders, lower pumping requirements, and general downsizing of the pumping skid. The reduction in required pumping capacity results in lower OPEX energy costs and lower total cost of separation.

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Energy Savings: Customers with processing temperatures above 45° to 55°C must cool their solutions prior to any filtration step utilizing typical filter construction. This cooling creates significant energy cost and negatively impacts the process OPEX cost. Additionally, if the solution must be returned to a higher temperature after the filtration step, additional energy costs are incurred resulting in further impact to the process OPEX. Utilization of *ConSep II*™ filters eliminates these energy costs and their negative OPEX impacts. Furthermore, if downstream processing involves drying, filtration at elevated temperatures can reduce dryer size requirements and energy cost by reducing the heating load on the equipment.

Bacterial Danger Zone: In addition to the improved flux rate, operating at high temperature enables customers to perform filtration processes above the Bacterial Danger Zone. The United States Food Safety and Inspection Service (FSIS), defines the danger zone as roughly 40° to 140°F (4° to 60°C)[1]. Being able to perform continuous processes above the Bacterial Danger Zone allows food and fermentation-based producers to utilize *ConSep II*™ filters and avoid unwanted bacterial growth.

Enzyme Inactivation: Customers utilizing fermentation-based production processes have expressed concerns over enzymes in the fermentation or cellular solution degrading the target product during processing times. Elevating the process temperature over 70°C can aid customer efforts to eliminate product degradation resulting from enzymes of concern. For example, many proteolytic enzymes show optimal activity from 40° to 50°C, while operating at or above 70°C reduces these enzymes' activity to near 0%.

Enzyme Activity Optimization: In contrast to proteolytic enzymes previously discussed, amylase enzymes have been documented to operate most effectively at temperatures from 60° to 80°C. These enzymes are commonly used in brewing and in at least one commercial membrane detergent. With traditional TFF filters, operating in the optimum temperature range is not possible, but *ConSep II*™ filters invite full utilization of these enzymes.

Organism Kill Processing: Microorganism kill operations in food and industrial applications are typically effective over 70°C. In commercial fermentation using genetically modified microorganisms, the organism can be evaluated for the appropriate heat kill temperature and dwell time, and *ConSep II*™ filters can then be implemented as a seamless filtration and kill step.

Improved Membrane Cleaning: SmartFlow has observed that elevated temperatures typically improve the efficiency of membrane cleaning protocols. Detergents appear to be more effective, and contaminants come into suspension more easily. In addition, enzyme-based cleaners can be used at their peak efficiency, from the 40° to 50°C range of proteolytic enzymes to the 60° to 80°C of amylase enzymes.

Effect of Temperature on Filtration Performance:

Typical membrane cleaning procedures utilize a clean water flux test to track filter performance and fouling over time. Many TFF suppliers publish a Temperature Correction Factor (TCF) so customers can normalize their clean water flux data without necessitating the time or energy cost associated with adjusting to a specified temperature. Customers can therefore assess the cleaning efficiency and the filter performance, comparing it to new filter data or specifications, while still operating in the commercial environment at ambient or process temperatures.

With commercially available TFF filters typically having maximum operating temperatures in the range of 45° to 55°C, there were no published reference points to project the TCF for the high temperature *ConSep II*™ filter beyond 50°C.

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Temperature Correction Factor for *ConSep II*™ Filters:

It is noted that different TFF ultrafilters, nanofilters, and reverse osmosis filters have different TCF data based on the structure and properties of their respective semipermeable membranes. However, as most TFF filters have a maximum operating temperature of 45° to 55°C, this data was not useful in determining the TCF for the high temperature SmartFlow Technologies *ConSep II*™ filter modules, which support operating temperatures up to 80°C. By utilizing different manufacturer's TCF equations it was observed that the TCF curves converged and provided similar TCF values for temperatures from 40° to 80°C. Based on this observation, a literature search was undertaken to identify published generalized relationships of membrane flux to the dynamic viscosity of water[2,3] for microfiltration and ultrafiltration membranes. The equation[4,5]

$$TCF = \mu T / \mu 20$$

is commonly utilized, where µT is the viscosity of water at the process temperature, and µ20 is the viscosity of water at 20°C. This equation is used to project the TCF for the *ConSep II*™ filter line as shown in Chart 1. The data set utilizes 20°C as the reference point where the viscosity of water is equal to 1, as described in the literature for MF and UF membranes[4], independent of membrane type. The generated TCF curve can be used to understand the change in *ConSepII*™ filter flux rates at elevated temperatures that are attributable solely to the change in viscosity of water, as it does not account for influences of membrane polymer, pore size, trans-membrane pressure, or linear velocity in the flow channel.[5]

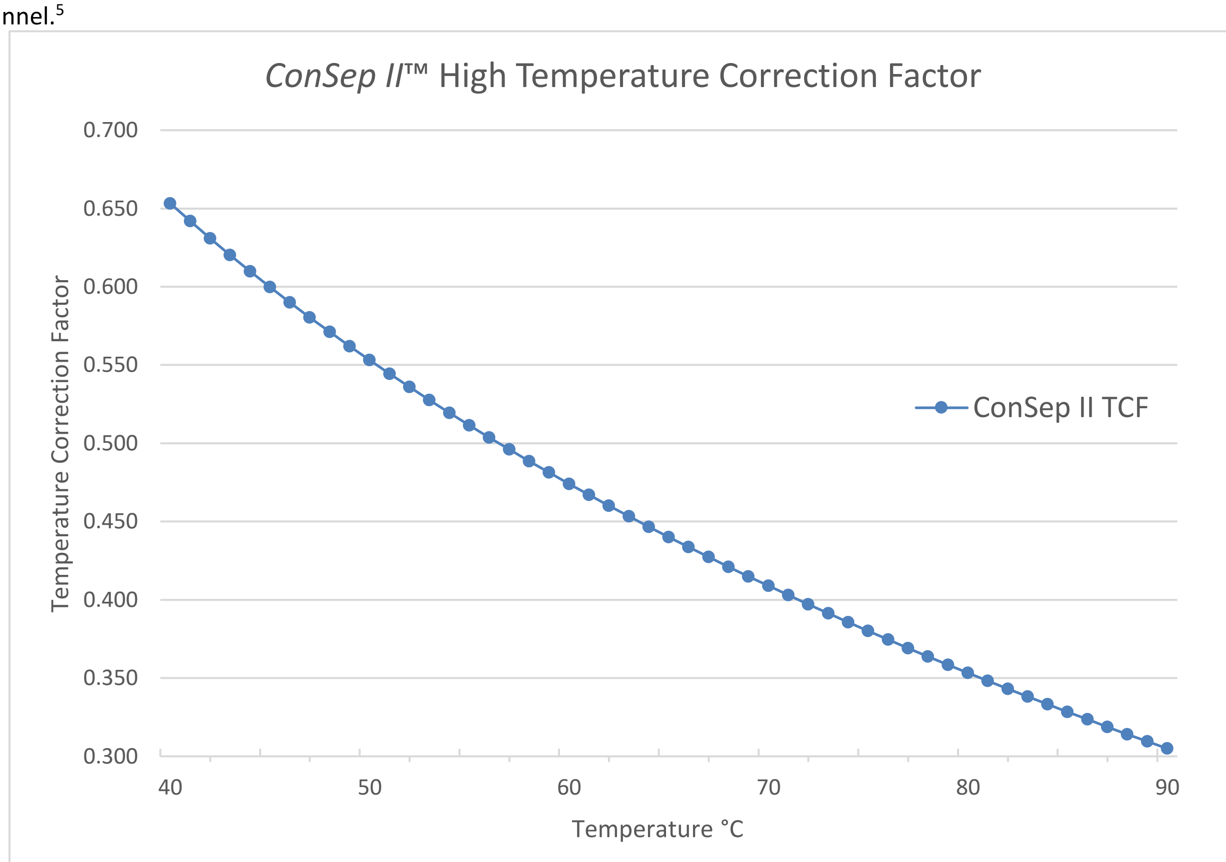

Chart 1: The SmartFlow TCF Curve to 90°C

Typical Application for high temperature filtration with *ConSep II*™:

SmartFlow examined the benefit of increasing the temperature on the flux rate in a brine clarification application. The brine was highly contaminated with both suspended and dissolved solids. The objective was to eliminate suspended solids and reduce dissolved solids.

Figure 1: The 6 Step SmartFlow Process Development Program

SmartFlow proceeded through its 6-step process development program (Figure 1) to examine the effects of velocity, pressure, and temperature on process efficiency, determining the optimal process parameters to achieve the most cost effective solution for the customer. After working with the customer to identify the problem and undergo a proof of concept (Steps 1 and 2), SmartFlow engineers began Step 3, Process Development and Optimization. Step 3 involves the membrane selection and optimization of process parameters for use in the Step 4 pilot demonstration, while simultaneously informing budgetary estimates for the system and membrane cost. For the purpose of this discussion, only the temperature and flux data from Step 3 will be presented. The test utilized a 150 kDa PES ultrafiltration membrane operating at 1 m/sec channel velocity and 15 psi TMP. The impact of temperature on flux rate is presented in Chart 2, with concentration, pressure and channel velocity held constant throughout the test.

A linear relationship was observed between the permeate flux rate and temperature. Applying a linear trend analysis to the data showed an R^2 value of 0.9858, indicating a close fit to the data. A 100% increase in flux rate was observed when increasing temperature from 41°C to 75°C, with permeate flow increasing from 91 Liters per Meter per Hour (LMH) to a

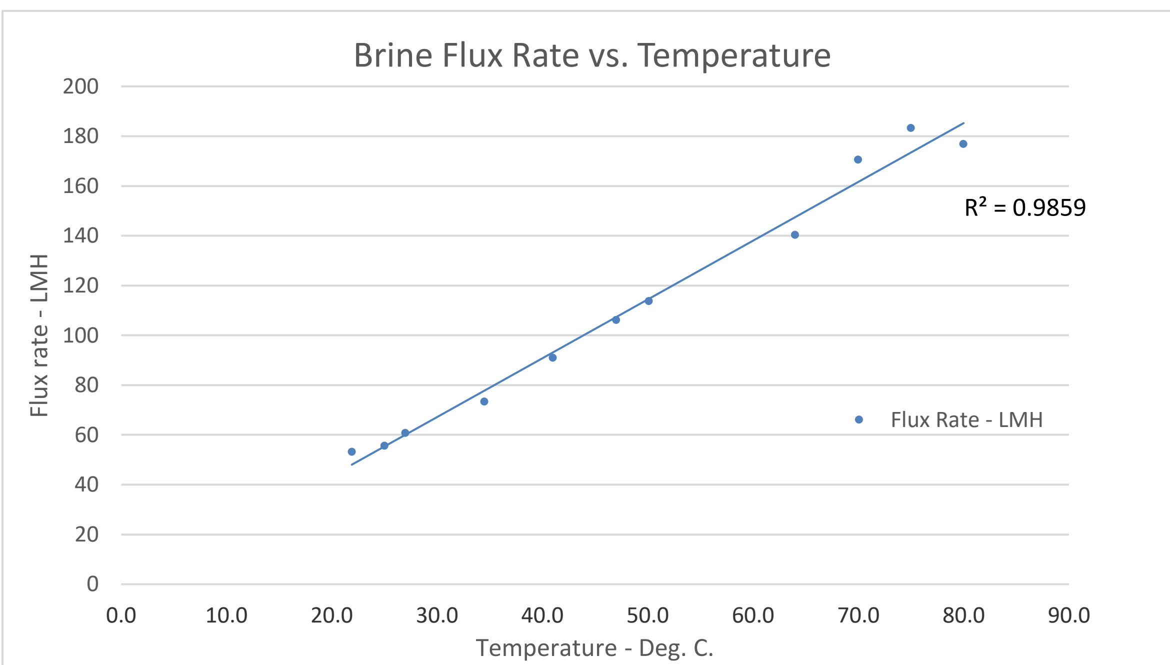

Chart 2: Temperature-Flux Relationship through a 150 kDa PES Ultrafiltration Membrane in the ConSep II° Format

maximum of 183 LMH. Because of this, operating at 75°C reduces the required number of *ConSep II*™ modules by one half when compared to operating at 41°C for the proposed production process.

Flux Rate Increase due to Water Viscosity Change: To evaluate the impact of water viscosity change on the brine solution process we compared the *ConSep II*™ module TCF to the observed data. A flux rate increase of 70% would be expected if it were due solely to the water viscosity change associated with the temperature rise from 41°C to 75°C. The difference observed demonstrates that not all flux improvements from increasing temperature are a result of the change in water viscosity. Complex solutions have multiple constituents which affect the viscosity. The solubility of constituents such as proteins, sugars, and salts can change with temperature, changing the viscosity of the solution. For example, a 20% solution of sugar will double the viscosity of water at 40°C while only increasing the viscosity by 50% at 80°C. This demonstrates the impact of dissolved solids on observed filtration rates and the importance of performing Step 3 process development testing. Step 3 testing quantifies the actual performance of the target solutions over the range of process conditions tested.

The cost implications of the improved performance at 75°C for this application include a 50% reduction in membrane area. For large volume systems the resulting system savings approach 50% as the fixed cost of system controls, electrical cabinets, engineering become a lower proportion of the total system cost. The reduction in system size will have a related reduction in OPEX cost as well, due to reduced pumping requirements resulting in lower energy draw, lower heating or cooling costs, smaller loop component costs, and reduced membrane replacement costs.

Discussion:

Temperature has a significant effect on filtration rate and process economics. Utilizing the extended temperature range of the Patent Pending *ConSep II*™ filtration modules, high temperature processing may be utilized, increasing flux rate and reducing system size requirements. In the presented data, the number of filtration modules required for production scale up were cut in half and system costs reduced by up to 50% by increasing the operating temperature of the process from 41°C to 75°C. OPEX energy costs are expected to be proportionally reduced as well due to the increased performance of the filter modules, reduced system costs, energy savings from downstream drying processes, and reducing the cooling costs incurred to prevent process temperatures in excess of 40° to 55°C necessitated by other TFF filters. Additional benefits of high temperature filtration include the potential to operate above the Bacterial Danger Zone, detrimental enzyme inactivation, and improved cleaning efficiency.

References:

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