APV

White Paper

APV GoldStream Systems

Pre-engineered membrane systems for recovery of white water

SPX
WHERE IDEAS MEET INDUSTRY

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Executive Summary

Membrane Filtration technology can be used in the dairy industry to recover milk and water from the first flush water after production called white water. The APV GoldStream process is a hygiene membrane process enabling use of the recovered milk stream in cheese or yoghurt or other products. Further the recovered water stream can be used afterwards either as process water or for CIP and many other water applications.

The APV GoldStream Membrane Filtration process is based on proven and environmentally sustainable technology that delivers consistent results, enabling dairies to improve utilization of milk intake in saleable products, and to save water and effluent treatment costs.

APV GoldStream Systems are pre-engineered fully self-contained and skid-mounted for rapid installation. They are available in four different sizes/capacities and are tested prior to delivery and come fully cabled ready for production.

The SPX Innovation Centre in Denmark offers pilot plant testing and application solution guidance services to help customers maximize their utilization of the recovered milk and water streams. Pilot testing can also be conducted on customers' own premises based on rental equipment with support from SPX Flow Technology experts.

A payback time of less than one year together with an enhanced environmental image make APV GoldStream a "goldmine" of potential savings.

Introduction to SPX Flow Technology

Vision and commitment

SPX's Flow Technology segment designs, manufactures and markets process engineering and automation solutions to the dairy, food, beverage, marine, pharmaceutical and personal care industries through its global operations.

We are committed to helping our customers all over the world to improve the performance and profitability of their manufacturing plant and processes. We achieve this by offering a complete range of products and solutions from engineered components to complete process engineering and design of advanced technology products and processing plants supported by world-leading applications and development expertise.

We continue to help our customers optimize the performance and profitability of their plant throughout its service life with support services tailored to their individual needs via a finely meshed customer service and spare parts network.

Customer focus

Founded in 1910, APV has pioneered groundbreaking technologies over more than a century, setting the standards of the modern processing industry.

Continuous research and development based on customer needs and an ability to visualise future process requirements drives continued mutual growth.

Introduction to APV GoldStream Systems

Over recent decades, Membrane Filtration has been established as a common unit operation, both in traditional dairy processing and for totally new and exciting applications, enabling the production of new, value-added dairy products.

Pasilac who joined APV in 1987 was the leading pioneer in the introduction of Membrane Filtration Systems and application solutions for the world dairy industry.

Pilot testing at the SPX FT Innovation Centre in Denmark by our own specialists and together with customers has led to a large number of innovative applications and process solutions, leading to new and exciting dairy products as well as significant improvements in performance of the membranes at the heart of the systems.

Additional system engineering innovations and enhancements over the years together with an installed based of more than 1200 Membrane Filtration Systems worldwide mean that SPX FT has a uniquely strong knowledge platform within Membrane Filtration engineering and processing.

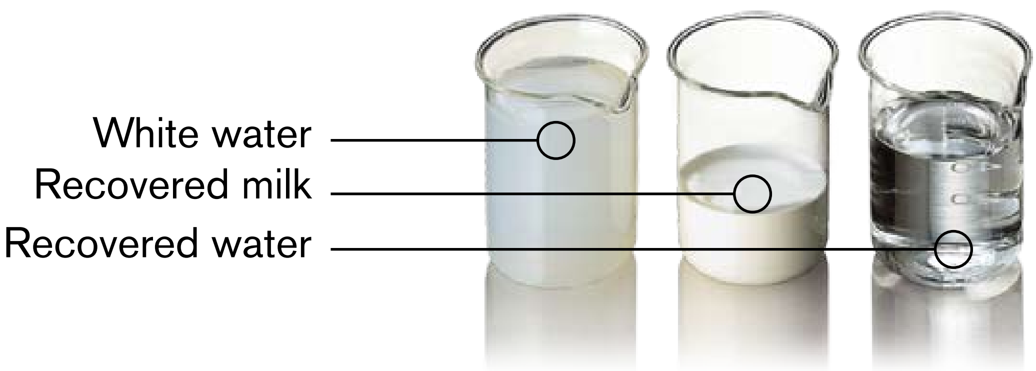
Our customers acknowledge and value SPX FT Membrane Solutions because of their high-quality engineered systems based on highly reliably and proven components and automation solutions, and uncompromising performance.

Environmental solutions leveraging Membrane Filtration are now a rapidly growing application area due to increasing industry focus on its environmental footprint and image. Membrane Filtration technology can be used for recovery of white water – the first flush water in the CIP process to recover milk and water. Membrane Filtration technology can also be used for polishing of Reverse Osmosis (RO) and Nanofiltration (NF) permeate for use as process water or cleaning. White water recovery and polishing of water streams is a financially and environmentally attractive opportunity for dairy producers and we believe that these technologies will be standard at most dairy companies in the coming years.

APV has designed a new series of pre-engineered Plug & Produce RO systems specifically for white water recovery and also for polishing applications. The APV GoldStream System brand embraces a new series of Membrane Filtration Systems, expressing the financial benefit and environmental values offered by the system by recovering the milk and water streams from white water. The name GoldStream expresses the value of a high-quality, high-performance and highly cost-effective hygienic system solution.

This white paper is intended to give readers who are not experts in separation technologies a tool with which to familiarize themselves with Membrane Filtration principles and systems as well as application opportunities in the dairy industry. The main focus, however, is on APV GoldStream solutions and the new advantages they offer our customers.

Turning white water into gold



APV GoldStream technology addresses market needs

As illustrated by Table 1, there are wide-ranging opportunities for Membrane Filtration applications in the dairy industry, especially in the following segments:

- Market milk and fresh products, drinks, yoghurt/ fermented products, and desserts
- Cheese – Fresh, soft, semi-hard and hard cheese types
- Ingredients – Milk and whey ingredients, primarily powder-based

The dairy industry is very focused on cost-effective and sustainable solutions to minimize waste and maximize utilization of all process product streams. These include recovery of all milk components, and reclaiming and recycling water streams (see Figs. 1 and 2). The key operational drivers for many businesses are usually based on cost/benefit considerations.

As climate change becomes more urgent, the need to fulfill the company's environmental management strategy and commitment is becoming an ever more critical driver. In other words, having a "green profile" is set to become extremely important in the future.

With a very short pay-back time, typically less than one year, along with full recovery of milk components and the water stream, the APV GoldStream process offers both financial savings and waste elimination. This makes it not only a sustainable solution, but also a uniquely profitable opportunity for the dairy industry.

The APV GoldStream skid-mounted systems comprise four pre-engineered Reverse osmosis (RO) systems, which enable not only full recovery of the milk and water streams, but also RO polishing of the RO permeate to obtain very high-quality soft water.

The amount of white water is typically 3 to 4 % of the milk intake. The capacities of the four APV GoldStream Systems range from smaller-scale production plants producing 150 m^3 of milk per day up to production of more than 1 million litres a day in 10 hours of operation, enabling use of the APV GoldStream for RO polishing as well.

More detailed conceptual and application information and opportunities are described later in this white paper. The following section is intended to help those not so familiar with Membrane Filtration to understand the technology including the principles, the membranes and the systems.

Separation technologies

An example of a separation process is when two or more substances in a solution are separated into their individual components. In its most simple form, the formation of a cream layer on non-homogenized milk directly from the cow is a separation process driven by gravity. Separation occurs automatically because the fat globules in the cream are lighter than the liquid phase of the milk.

DAIRY SEGMENTS / APPLICATIONS	MARKET MILK/FRESH PRODUCTS, DRINKS, YOGHURT, DESSERT	CHEESE: FRESH, SOFT > HARD	INGREDIENTS: MILK/WHEY
MF debacterisation	X	X	X
UF protein standardisation	X	X	X
MF protein fractionation	X	X	X
UF milk concentration	Yoghurt, dessert	Queso fresco Fresh cheese, feta, etc.	MPC 50 and 60 MPC 80 / 85
MP microparticulation	MP of WPC 60	MP of WPC 60	MP of WPC 60
UF whey concentration	WPC 35 / 60	MP of WPC 60	WPC 35 / 60 WPC 80 - WPI
NF conc./demineralisation	(demin. milk)	Whey/permeate	Whey/permeate
RO concentration	(Milk transport)	Whey/permeate	Whey/permeate Milk (transport)
RO polishing	(X)	RO/NF permeat	RO/NF perm. + cond.
RO white water	X	X	X
MF brine purification	-	X	-

Table 1. Membrane filtration applications in typical dairy segments

What is white water ?

The first flush water in the CIP process after production contains diluted milk components

- Raw milk white water from road tankers and silos
- Pasteurised white water from pipes, pasteurisers and tanks

Milk and water can be recovered using RO

- Results in reduced load on the effluent plant
- Recovery of valuable milk components
- Recovery of water used as process water for CIP or boiler feed or discharged

Stop pouring money down the drain!

Fig. 1: Recovery of milk and water from white water

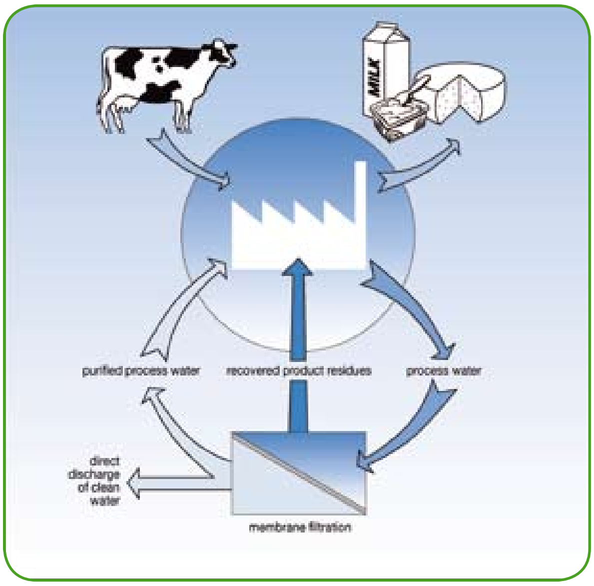


Fig. 2: Waste elimination and recycling of water streams

There are many different separation processes, each of which employs a particular technology and particular equipment. It can be easier to understand the nature of these technologies and their role if we split them into 'families' as shown in Fig. 3.

Membrane Filtration is a molecular separation process. The technology will sometimes compete with and sometimes be complementary to other separation technologies. In many cases other processes are used for pre-treatment of liquids prior to a membrane process, e.g.:

- RO/NF competing with/complementary to Evaporation and Ion exchange or Electrodialysis
- Conventional filtration (back filters) and milk clarifiers and separators used as pre-treatment prior to Membrane Filtration

Mechanical separation by gravity

- Sedimentation
- Flotation

Conventional filtration (dead-end)

Mechanical separation by centrifugal force

- Separators and decanters
- Hydrocyclones

Separation by phase change

- Evaporation
- Drying
- Crystallisation
- Distillation

Separation by extraction

- Liquid - liquid
- Solid - liquid
- Supercritical (SCE)

Separation by adsorption

- Activated carbon

Molecular separation

- Reverse osmosis (RO)
- Nanofiltration (NF)
- Ultrafiltration (UF)
- Microfiltration (MF) (cross-flow)

- Dialysis
- Electrodialysis

- Gas separation
- Pervaporation

- Chromatography
- Ion exchange

Fig. 3: **Examples of separation processes**

Membrane Filtration - Definitions

Membrane Filtration processes are pressure-driven, molecular separation processes used to obtain concentration, fractionation, clarification and/or even sterilization of a liquid. The separation is determined by the membrane characteristics (molecular weight cut-off value – MWCO) and the molecular size of the individual components present in the liquid.

Membrane Filtration changes the volume and/or the composition of a liquid, as the feed is divided into two new liquids of altered chemical/microbiological composition:

1. The retentate (what is rejected and concentrated by the membrane, e.g. proteins), and
2. The permeate (i.e. filtrate that passes through the membrane, e.g. water and minerals)

The volume of permeate produced by a certain membrane surface area per hour is called flux (measured in l/m²/h or simply "lmh"). The volumetric concentration factor (VCF or CF) is the ratio between the incoming feed volume and the exiting retentate volume.

Rejection is 100%, when the component is fully concentrated by the membrane (cannot pass the membrane). Rejection is 0%, when the component passes freely through the membrane, giving an identical concentration on both sides.

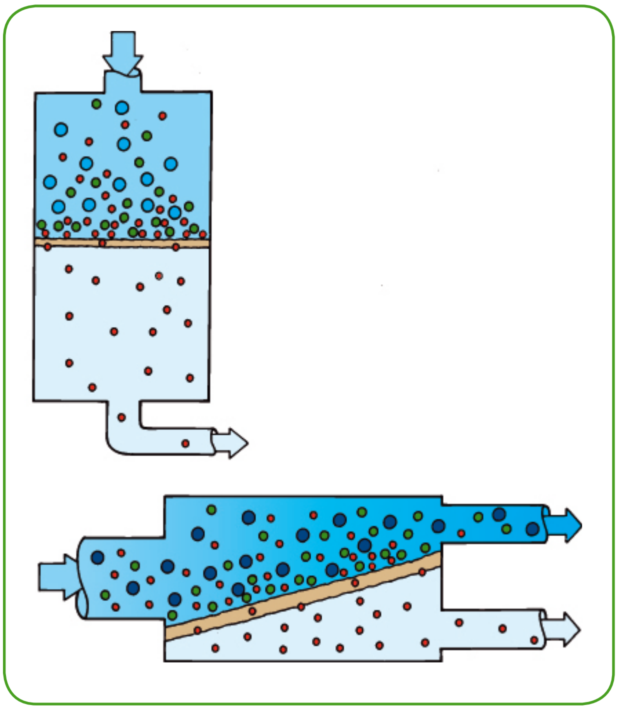


Fig. 4: Conventional or dead end filtration versus cross flow filtration

The driving pressure is the trans-membrane pressure (TMP), which is the pressure difference between the mean pressure on the retentate side (high) and the mean pressure on the permeate side (low or zero).

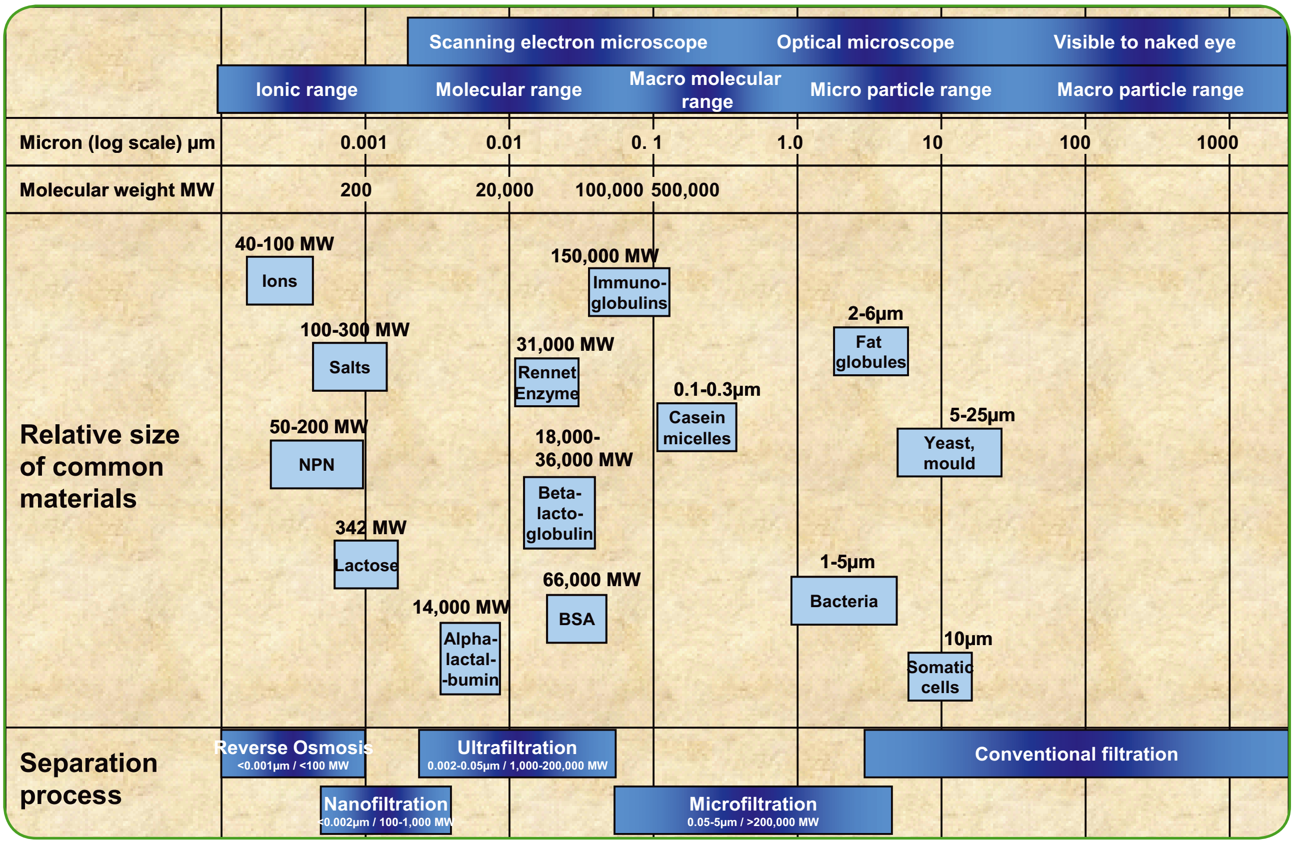


Fig. 5: The filtration spectrum for milk components

All Membrane Filtration processes are cross-flow filtration processes (feed flow parallel to the membrane surface, also called tangential flow). This is because a high velocity and shear rate across the membrane surface is essential to prevent build-up of retained materials that reduces run times and flux, and may also alter separation characteristics. High cross-flow velocities are especially important in UF (Ultrafiltration) and MF (Microfiltration) systems.

Fig. 4 shows a comparison between conventional filtration (dead-end filtration) and cross-flow Membrane Filtration. In a conventional filtration, a slurry is separated into a liquid and a more solid, concentrated phase. Typically a filter cake builds up, and eventually filtration stops (or slows down) due to resistance in the cake layer leading to lowered capacity.

Cross-flow Membrane Filtration differs from conventional filtration in two ways:

First of all, separation/concentration is performed at molecular level, whereas conventional filtration is typically performed with slurries consisting of liquid and solid particles.

Secondly, the term "cross-flow" refers to the fact that the "filter cake" is continuously removed by applying cross-flow over the membrane surface.

This minimizes capacity decrease and extends production time.

Filtration spectrum for milk components

So, how can we separate at molecular level? Fig. 5 illustrates this with the "filtration spectrum" of milk.

Milk contains four main groups of components in terms of size (Bacteria + fat globules, Casein micelles, whey proteins, lactose + NPN + minerals). If we visualize a membrane as a sieve, it is obvious that we should be able to separate these molecules into the various sizes of the components – that is if we have a membrane with "holes in the sieve" of a well-defined size.

Successful separation is therefore dependent on both membrane characteristics and the difference in size of the molecules in the liquid.

Membrane Processes

Concentration

In true concentration all total solids are retained since only water can pass through the membrane (as in evaporation and drying processes).
Example: RO and the APV GoldStream system.

Fractionation

Changing the chemical composition by concentrating some components, while others remain unchanged.
Example: NF, UF and MF.

Clarification

Changing a turbid liquid into a clear solution by removing all suspended and turbid particles.
Example: UF and MF – e.g. MF clarification of cheese brine

Sterilisation

Removing all microorganisms from a liquid.
Example: MF.

Referring to Fig. 6 to 9 the various membrane processes will be explained in the following sections.

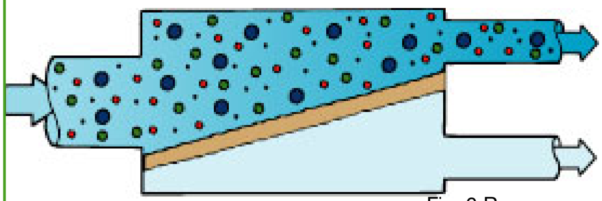


Fig. 6 Reverse osmosis

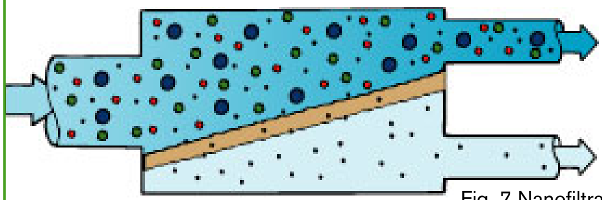


Fig. 7 Nanofiltration

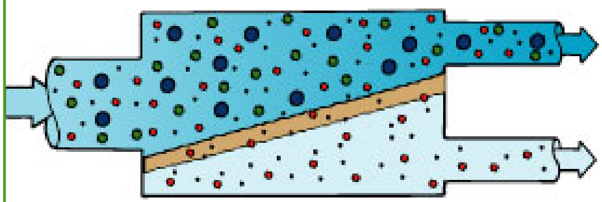


Fig. 8 Ultrafiltration

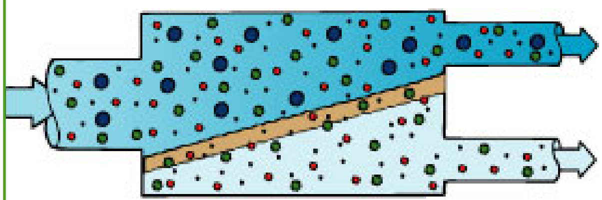


Fig. 9 Microfiltration

Particles, micro-organisms, suspended solids
Large dissolved molecules
Small dissolved molecules
Salts
Water

Reverse osmosis

In Reverse Osmosis practically all total solids components are rejected by the membrane, allowing only water to pass through.

Since practically all ions (apart from H+ and OH-) are also rejected by the membrane, the osmotic pressure in the retentate will increase, requiring high-pressure pumps to overcome the osmotic pressure. The amount of permeate produced is often referred to as "recovery". 90% recovery means that 90% of the feed is recovered as permeate (equal to 10x concentration).

Low molecular components such as organic acids and NPN components are not fully rejected by the membrane, especially when they are uncharged (non-ionic), typically in acidic environments. This is the reason why COD levels in the permeate are higher when processing acidic products (e.g. lactic acid whey) compared to sweet products (e.g. sweet whey). The maximum achievable solids by RO are in the range of 17-25% solids for whey and UF permeates.

For RO of milk the maximum solid content is typically 25 % Solids Non Fat (SNF). As the energy cost increases with increased solids content it is recommended to check feasibility at higher levels of solids content.

White water will typically be processed in a batch process at 5 to10°C and it will typically be concentrated back to the normal milk composition at approximately 12.5 to 13.5 % TS depending of the fat content.

The term RO Polishing (RO-P) is used for RO processing of RO or NF permeate streams or condensate from evaporators. RO-P is based on an ordinary RO system that is used to polish water streams by removing small substances in order to generate high-quality water from milk products also known as 'cow water'.

The APV GoldStream system can be used for RO polishing of initially recovered water (RO permeate) to produce high quality soft water.

Nanofiltration

NF is very similar to the RO process. NF membranes, however, are slightly more open than in conventional RO. NF allows passage of monovalent ions such as Na+, K+ and Cl-, whereas divalent ions like Mg++ and Ca++ are almost completely rejected by the membrane. In this way the NF process demineralizes the feed, typically by 30- 40%. The degree of demineralization is the percentage removal of minerals (or ash) from the permeate feed.

Fig. 10: Various membranes used for dairy applications

Ultrafiltration

UF has many applications. Basically, however, it is a process for concentration of protein (and milk fat). In the dairy ingredients industry UF is used for concentration of whey proteins from whey into Whey Protein Concentrate (WPC) products, or for concentrating milk proteins from skim milk into MPC products.

The protein content can be concentrated to up to approx. 30% protein, and in many cases the retentate can be spray-dried directly without an evaporation step. Diafiltration is necessary for higher purity products such as WPC 80 (80% protein in the powder or in the solids). In Diafiltration, water is added to the retentate to increase "washing out" of dissolved substances such as lactose and minerals to the permeate.

Microfiltration

Basically, there are two microfiltration processes: Bacteria removal /"cold sterilization" for removal of bacteria and spores from milk for cheese and powder, and for Extended Self Life (ESL) milk and cheese brine.

Fractionation (also called microfiltration fractionation – MFF or the SPX Pro-Frac™ process) is used to fractionate whey proteins from casein prior to cheese making and for high purity casein micelles powder and high purity WPC or Whey Protein Isolate (WPI) ingredients.

Pre-treatments prior to membrane processing

Membranes, especially spiral wound (SW) elements, are sensitive to suspended particles, and cleaning of the membranes may be difficult if these particles are not removed prior to entry to the Membrane Filtration plant. In whey processing a whey clarification step is thus necessary to remove cheese fines, and a separator is necessary to remove whey fat.

Pasteurising the feed to prevent high bacteria counts in the retentate is also recommended.

A bag filter or metal strainer may also be installed to protect membranes from large particles in the feed.

Pre-treatment of white water will be discussed later.

Capacity, Run Time and Fouling

A membrane is always exposed to fouling. This will lower the permeate flux and thus plant capacity. In RO/NF processes fouling may be compensated by gradually increasing the pressure (TMP) to ensure constant plant capacity. This is more difficult for UF membranes, since raising the feed pressure will increase the flux for a short period only, after which it drops back again to the level obtained before the feed pressure was raised. A UF plant may start up at 20 to 50% higher capacity than the average capacity it was designed for. Usually average capacity is reached after 3 to 4 hours and flux decrease will be less significant during the remaining production time.

Run times are usually 10 hours for warm processes (50°C) and 20 hours for cold processes (10°C).

Run times are limited by fouling, bacteria concentrations (or even growth) or/ and compaction of the boundary layer (e.g. protein gel layer or fat, which may alter separation characteristics).

Table 2 shows the characteristics of membrane process parameters.

Membrane elements and module design

Membranes are either made of polymers (organic) or ceramics (inorganic). Organic membranes are typically in the form of a spiral-wound element, and ceramic membranes are typically in the form of tubular elements.

Organic Membranes

Fig. 10 shows the various membranes used for dairy applications.

Spiral-wound elements are most often used, since they are cheapest per square metre, compact, easy to replace and comply with standardized dimensions.

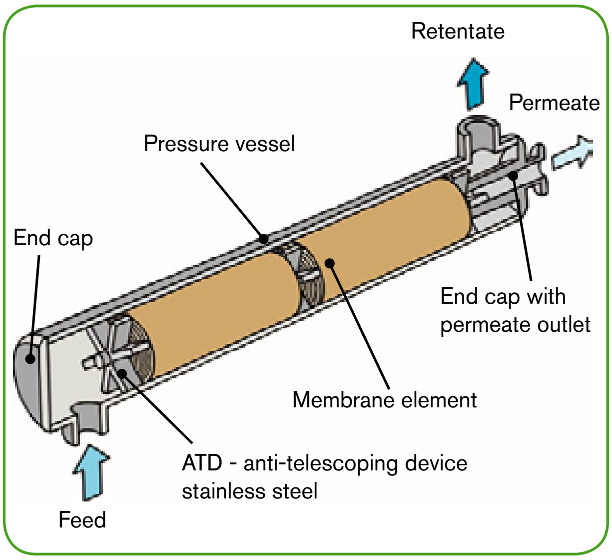


Fig. 11: The Spiral wound module with the spiral-wound elements divided by anti-telescoping devices made in stainless steel.

However, they are not suitable for liquids containing large quantities of suspended particles. These can get trapped inside the element construction (spacer net), or in very viscous products.

The elements are 3.8" (4"), 6.3" (6") or 8.0" (8") in diameter and 38" or 40" long. An element designated "3840" means diameter 3.8" and length 40". A further defining attribute is the height of the spacer net, which is measured in "mil" (1/1000 of an inch). If the viscosity of the liquid increases – e.g. during protein concentration – the spacer height must be selected accordingly.

SW Module and loop configurations: SW elements are operated with a pressure drop of 0.8-1.2 bar per element (for 8" elements max. 1.0 bar). To avoid telescoping of the spiral, an ATD (Anti-telescoping device) must be placed at the end and between the elements. SW elements can be mounted in series inside a housing (also called a pressure vessel or module). Spacer height, flux curves, pump performances and pressure drops determine the configuration of a SW plant.

	RO	NF	UF	MFF	MF
Pore size (nm)	0.1 - 1	0.5 - 2	0 - 60	50 - 200	800 - 1,400
MWCO	<100	100 - 500	5,000 - 20,000		
Typical pressure (bar)	30 - 40	20 - 30	3 - 8	0.1 - 0.8	0.1 - 0.8
Typical temperature (°C)	10 - 30	10 - 30	10 or 50	50	50
Applications	Concentration	Demineralisation/ concentration	Protein concentration (WPC/MPC)	Protein fractionation Whey fat removal (WPI)	Bacteria removal Cheese milk ESL milk

Table 2: Characteristics of membrane process parameters and applications for the individual membrane processes

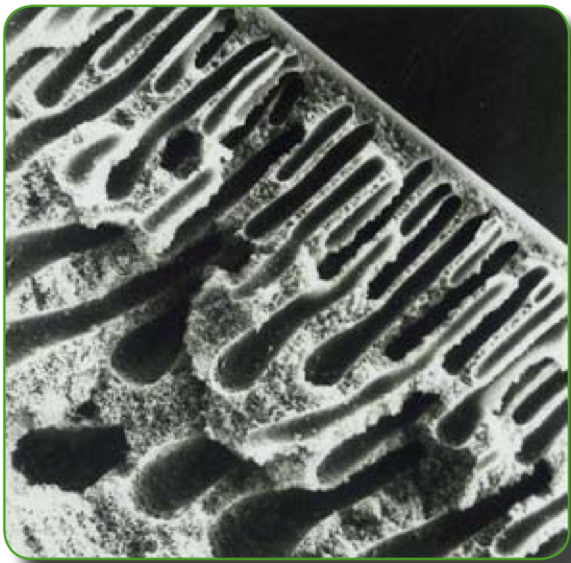


Fig. 12: Close-up of a UF membrane

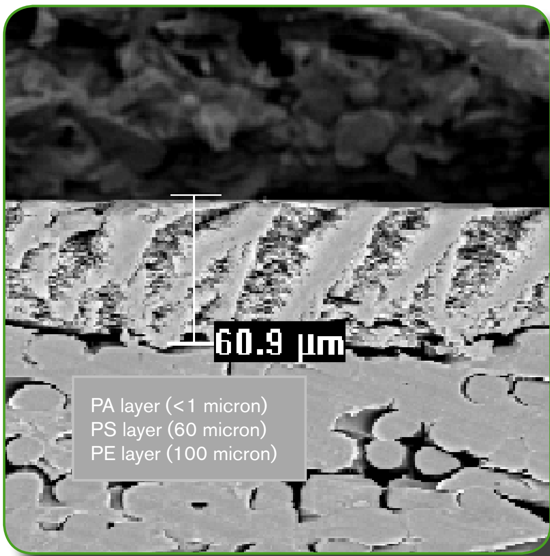


Fig. 13: RO membrane

Plate & frame (P&F): module 37 (M37) is the only P&F module still in use and only used for high-viscosity products such as cream cheese (Philadelphia type). This module can achieve high protein concentration levels (more than 29%), when operated with a positive pump up to 12 bar. The cross flow rate should be 25 l/plate/min.

Inorganic membranes (ceramics): unlike the polymeric membranes (especially RO/NF and UF), the ceramic material is very resistant to heat and chemicals. Ceramic membranes will last for typically 5-10 years or more. However, they are much more expensive and generally require more pumping energy. Their ceramic nature makes them sensitive to mechanical vibrations (should always be installed vertically) and thermal shock.

Tubular membranes: ceramic membranes are tubular with the feed circulating inside tubular channels. The diameter of these channels is 3, 4 or 6 mm and is selected according to the viscosity of the product. The main application for ceramics is MF, since the ceramic element can be operated with permeate back-pressure in order to achieve a low TMP, which is crucial for successful results. The standard element is the Gradient Pressure (GP) element in which the permeate back pressure/resistance is integrated inside the membrane structure.

Membrane materials

A number of materials can be used for the manufacture of membranes. Organic polymers and ceramic materials are used particularly in the food and beverage industries. These industries need to use materials that are food compliant and able to withstand the conditions needed to maintain hygienic food production. This often means relatively tough cleaning and sanitizing conditions.

Polymers are high molecular weight compounds built up from monomers. Monomers are in different basic types and furthermore combined (polymerized) in a number of ways to enable different membrane material functionalities. The "woven" structure of the polymers can be adapted to provide a membrane pore structure that allows some molecules to pass while retaining others. The pore size of a specific membrane can be controlled through the choice of polymer and certain physical/chemical characteristics during production of the membrane.

Membranes are often made of several layers. They can, for example, consist of a thick porous support layer and a denser layer on top to give the membrane certain attributes. RO and NF membranes can feature a third, very thin top layer.

Fig. 12 shows a close-up of a UF membrane. It shows that the membrane has actual pores in a "sponge" like structure.

Fig. 13 shows an RO membrane. Basically the membrane is a UF membrane with a very dense top layer.

Typical membrane polymers in the hygienic industry are:

- Polysulfone (or polyethersulfone) (PS/PES) are the most common types of UF membranes. They are also widely used as support membranes for NF and RO membranes and have a relatively high chemical resistance, combined with good thermal properties.
- Polyvinylidene (PVDF) is typically used for MF membranes. It has very good chemical and thermal properties.

- Polyamide (PA) is typically used as top layer membrane for RO. PA is not so resistant – especially against oxidizing agents such as chlorine.

Ceramic membranes

Aluminum oxide, titanium oxide and zirconium oxide are the most common materials used for ceramic membranes. Most ceramic membranes are made for MF, based on sintered aluminiumoxide. These inorganic membranes have extremely good chemical and thermal resistance.

Characterisation of membranes

One of the important things when choosing a membrane for a specific purpose or application is the "cut-off" value of the membrane stated by the supplier. Certain materials (such as PS) can be made with various pore sizes.

In the dairy industry, a typical cut-off value for UF is 10,000 Dalton. This is due to the fact that whey proteins are typically larger than this, whereas lactose minerals etc. are much smaller. This means that, in principle, the membrane retains all the whey protein. All molecules smaller than 10,000 Dalton can pass the membrane freely (for example lactose with a molecular weight of approx 350).

However, there will always be a certain pore size distribution that results in some rejection of lactose for example, and some passage of whey protein.

For MF membranes, the cut-off value is more often defined as the physical size of the pores.

RO membranes – and to some extent NF membranes – have no actual pores in the active membrane.

In these membrane types membrane "cut off" is more commonly defined as rejection of a specific salt (typically NaCl in the case of RO, and MgCl2 in the case of NF).

NF membranes can also be characterized in terms of percentage rejection of an organic compound such as lactose.

Given the fact that not all membrane suppliers use the same characterization method, it is not always possible to compare 2 membranes directly based on their cut-off values.

SPX FT sources membranes from the major international membrane suppliers, and works closely with them to develop new and improved membranes. However, all membrane types sold by SPX FT must pass a validation test in our Innovation Centre to ensure that the membrane fulfills our performance requirements. In addition, the membrane is tested on a larger commercial scale before being released for sale by SPX.

SPX FT is an application specialist and our choice of membranes will be based on our extensive experience. The physical quality and optimal performance of the membrane for a given application will always have priority over the acquisition price.

General System design in brief

There are basically 2 main designs or modes of operation of industrial scale membrane systems:

- Single pass or continuous operation
- Multi pass or batch operation

In a batch process (see Fig.14) the feed stream is concentrated over a tank e.g. protein standardization in the raw milk silo. Once the stream is slightly concentrated in the membrane plant, it returns to the tank and mixes with the rest before once more proceeding to the membrane plant. The process stops when the right concentration is achieved in the feed tank.

Batch mode operation of a membrane system

In a continuous plant the feed stream, e.g. milk or whey, enters the base line via the feed pump and proceeds via the loop booster pumps to the loops where it will be re-circulated a number of times.

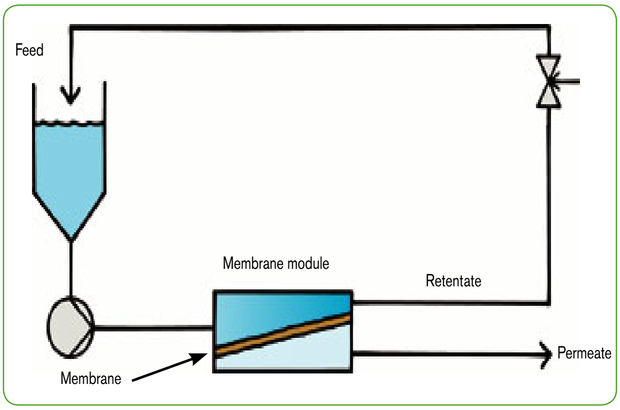


Fig. 14: Batch mode operation of a membrane system

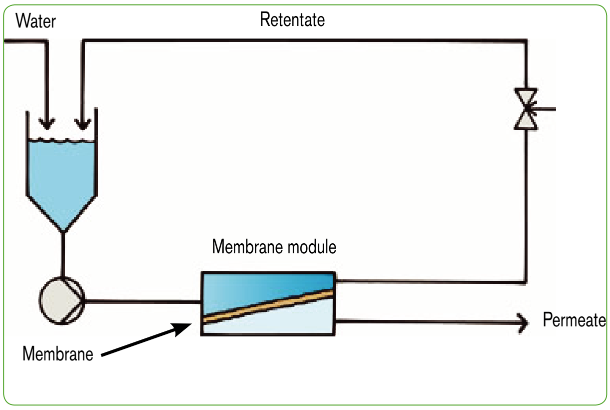


Fig. 15: Continuous mode of operation of a membrane system

As the permeate continuously leaves the system from each loop, the retentate (concentrate) becomes more and more concentrated until it reaches its final level of concentration, which is controlled by the retentate valve through which it continuously leaves the membrane plant.

Continuous mode of operation of a membrane system

A batch is the most efficient way of using the membrane area. However practical issues, such as the volume that needs to processed as well as the concentration level and logistics, will determine the most suitable mode of operation. The continuous process is by far the most used mode of operation in the Dairy industry (Fig. 15).

Fig. 16 and 17 show the Flow layout of an RO/NF and a UF system.

There are two main differences between the two systems. These are basically the differences between low and high pressure systems. RO/NF is operated at high pressure up to a total system pressure of 40 bar in the case of RO and typically 25 bar for NF, compared to 3-8 bar in UF.

This means that RO/NF systems require high-pressure feed pumps to provide the necessary feed pressure to the base line.

Another difference is the balance tanks. UF often employs a double balance tank enabling controlled overflow from the permeate tank to the feed tank.

In an RO/NF system, capacity is easily regulated through pressure. In a UF/MF system, the low feed pressure (typically 1-3 bar) calls for more ways to control capacity, as the pressure regulation range is more limited. The double balance tank design enables permeate flow back into the plant, if the capacity of the plant is too high.

The booster pumps inside the plant (in the "loops") are used for re-circulating the feed at a higher rate than is possible by the feed flow alone, thereby obtaining improved cross-flow.

APV GoldStream Systems and APV Solutions

After this general discussion of membrane technology, we will proceed specifically to discuss APV GoldStream Systems, applications and conceptual solutions for the recovery of white water. First of all, however, it is relevant to introduce white water and the solution opportunities.

White water

The first flush water in an in-line cleaning process (CIP) after production contains diluted milk components. This flush water is called "white water". The white water can be raw milk from road tankers, milk silos or pasteurized white water from pipes, pasteurizers, storage tanks and other processing equipment.

The total volume of white water varies from dairy to dairy depending on production as well as the number and efficiency of flush and production logistics, etc. However, a typical level is in the range of 3 to 4% of the milk intake. A dairy plant with a milk intake of 1 million litres per day will typically produce 30 - 40,000 litres of white water per day consisting of one third milk and two-thirds water. Annually this equates to 4.2 million litres of milk and 8.4 million litres of water.

Traditionally little could be done with the white water due to its high water content. Consequently the water was sent down the drain, in many cases significantly increasing the chemical oxygen demand (COD). This is not a favourable option when you consider the annual value of 4.2 million litres of milk and the cost of water and effluent treatment. Milk has a very high biochemical oxygen demand (BOD_5) load and converted into its population equivalent, 30 m3 white water corresponds to waste water from 15,000 people.

The composition of white water will vary considerably, depending of the product and degree of water dilution during the flush. Table 3 shows an example of white water composition based on dilution of milk with 2/3 of water, and the milk and water streams after concentration back to the normal composition of the milk. In the case of specific applications, e.g. for yoghurt production, the milk might be concentrated to a higher level for protein standardization of the yoghurt in order to improve viscosity and avoid whey separation.

Utilisation of the recovered milk and water

A new environmentally friendly technology enables effective processing of white water by concentrating the milk back to its original composition or higher, depending on the use of the recovered milk.

COMPONENTS IN %	FEED WHITE WATER	RETENTATE MILK	PERMEATE WATER
True protein	1.05	3.15	0.00
NPN	0.05	0.12	0.02
Lactose	1.53	4.58	0.01
Acid	0.07	0.20	0.00
Total Ash	0.25	0.73	0.01
Fat	1.17	3.51	0.00
Total solids	4.12	12.29	0.04

Table 3: Example of composition of white water and the milk and water streams

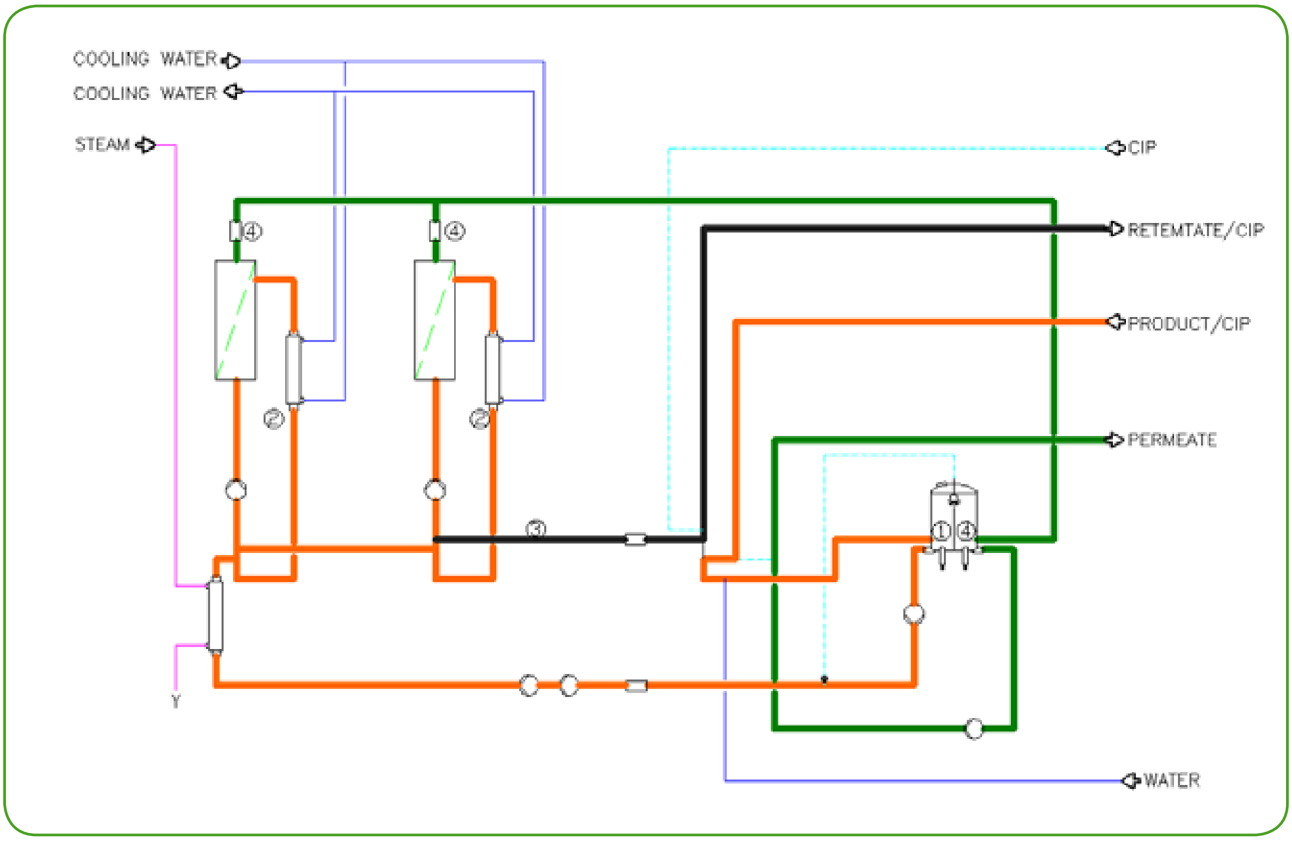


Fig. 16 RO/NF system - general example of flow diagram

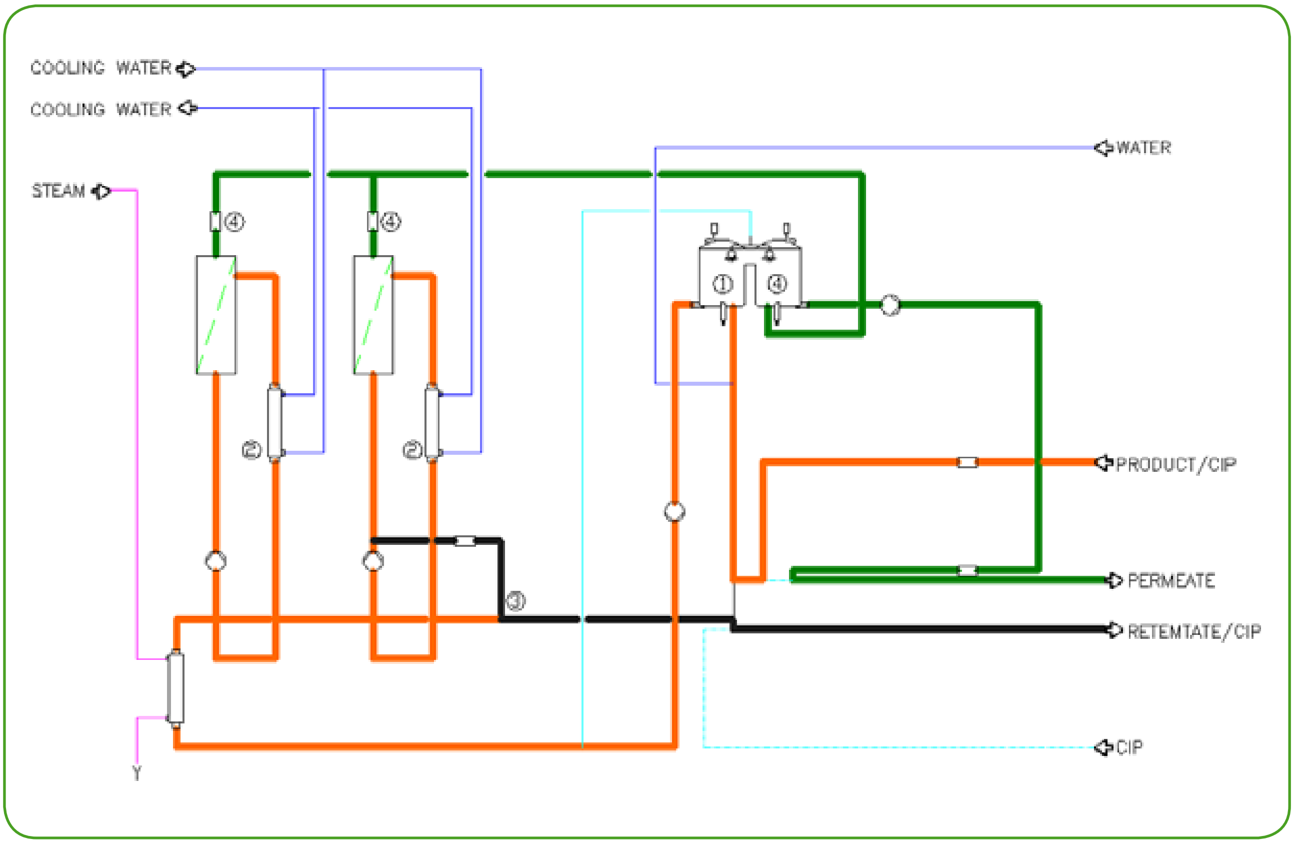


Fig. 17: UF system - general example of flow diagram

The APV GoldStream process is a hygienic dairy process based on proven RO technology, and enables the milk to be used for cheese, yoghurt, ice cream and flavoured milk, but not for natural milk drink.

The RO permeate or water stream can be used directly for CIP purposes. Alternatively it can be polished in the flexible Plug & Produce APV GoldStream system to a COD level of approximately 10 ppm. This very high-quality, demineralized soft water might also be used as:

- Process water for cheese and lactose wash water as well as Diafiltration
- Water for cheese cooling before brining and additional brine water
- Water to supply boilers or cooling towers
- Water to supply CIP systems including final rinses
- Seal water on pumps

Depending on the use of the water, a downstream treatment might be needed – e.g. pasteurization or cold disinfection by Electrolysis for process water and UV light or preservation by Oxonia (H_2O_2) for other purposes.

Fig. 18 shows the APV GoldStream white water recovery and RO-Polishing as a batch RO Process

APV GoldStream System design

Skid-mounted APV GoldStream Membrane Filtration Systems are available in 4 RO versions as shown in Table 4. The version number refers to the approximate capacity over 10 hours of operation. Capacity will vary, however, depending on product compositions, inputs and outputs, and operation parameters. SPX FT application specialists will guide and support you in choosing the optimum APV GoldStream version to suit your specific needs.

APV GoldStream - RO5
APV GoldStream - RO15
APV GoldStream - RO30
APV GoldStream - RO45

Table 4: APV GoldStream versions

Examples of the pre-engineered APV GoldStream RO skidded systems appears from the 3D drawings Fig. 19.

APV GoldStream RO system

APV GoldStream RO Systems are fully skid-mounted on a stainless steel frame complete with automation panel and waterproof, skid-mounted IP 66 frequency converters. The Plug & Produce units are fully cabled and electronically tested in our workshop prior to delivery.

The RO System is designed for batch operation and linked to the white water feed silo or storage tank. Figure 20 shows the concept including an RO permeate silo and a silo for RO-P permeate to be used for RO polisher water in case this option is chosen.

As shown in Fig. 20, the APV GoldStream RO System consists of the following main sections:

The feed systems

The feed pump sends the feed product – white water or RO permeate – into the base line (1) via a stainless steel security filter, ensuring that no impurities enter the membranes. The pressure in the base line is boosted by the high pressure pumps to 20-22 bar and controlled by the frequency converters on the feed pumps. The base line also features a tubular heat exchanger to heat the CIP chemicals during the CIP process.

The recirculation loops

When the product enters the recirculation loop (2), the pressure is boosted by the recirculation booster pump to approximately 24-26 bar. The cross-flow over the membrane causes separation and concentration of the feed product into permeate and retentate.

The separated permeate stream exits to the permeate tank (3) via the permeate outlet flow transmitters.

The retentate stream (the concentrate) is recirculated a number of times over the membranes for separation and concentration before exiting through the retentate system (4), which features a flow transmitter and the retentate control valve.

In the recirculation loop a tubular cooler ensures a consistent pre-set temperature during production and CIP. The flow, pressure and temperature in the system are automatically regulated and controlled by the automation system.

The retentate system

The retentate leaves the RO plant through the flow transmitter and retentate valve (4). The concentration ratio is automatically controlled as a ratio between the permeate and retentate outlet. The retentate is led back to the feed or storage tank and the solids level increases over time until the target level is reached.

The permeate system

The permeate leaves the individual membrane modules through a loop collection pipe and passes a flow transmitter (3) before it is led to the permeate

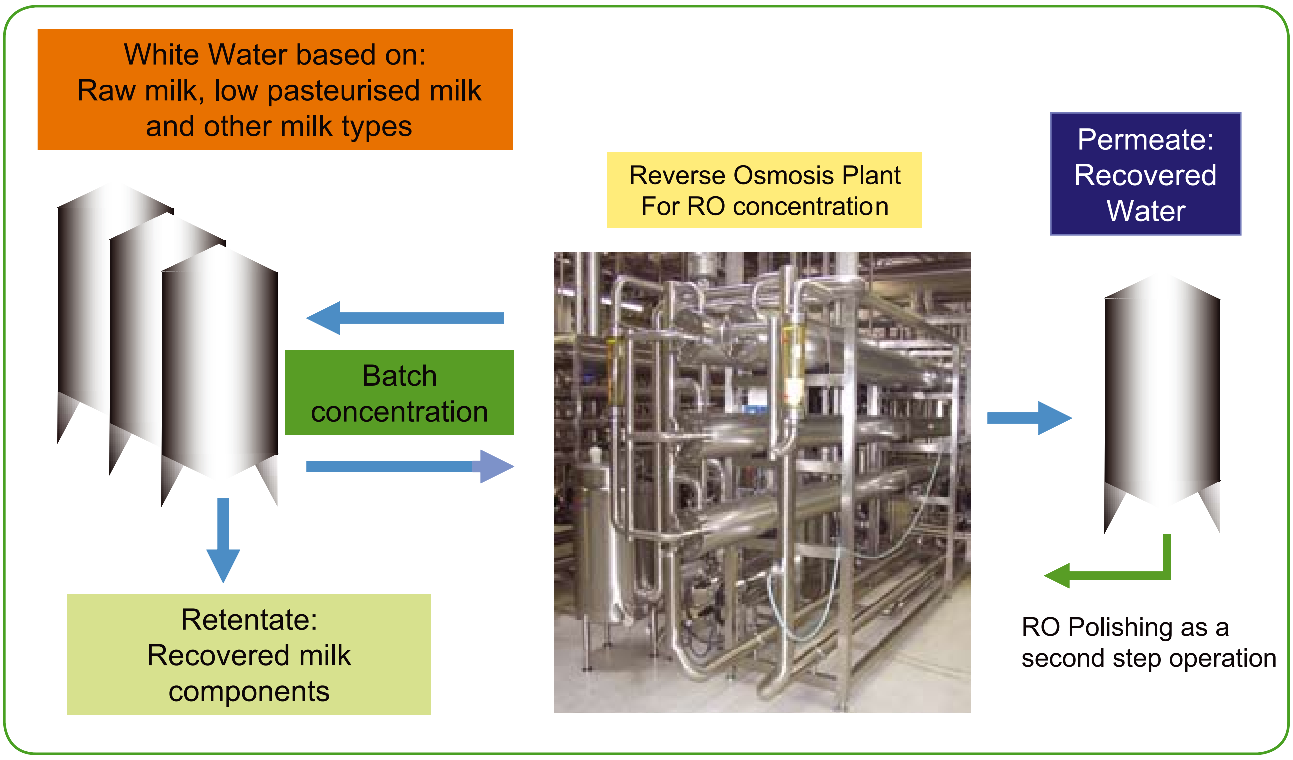


Fig. 18: APV GoldStream white water recovery and RO polishing as a batch RO process

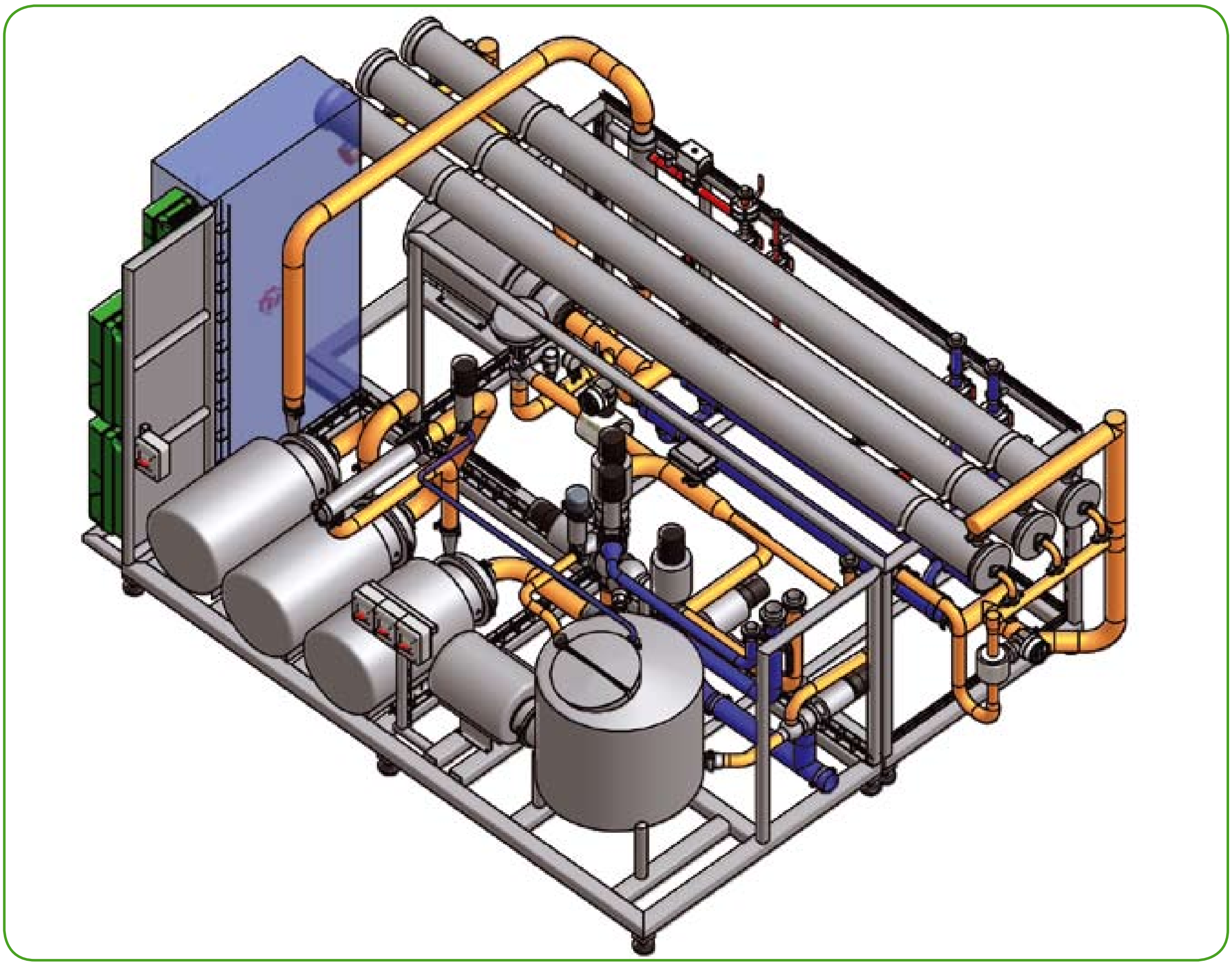


Fig. 19: APV GoldStream skidded systems

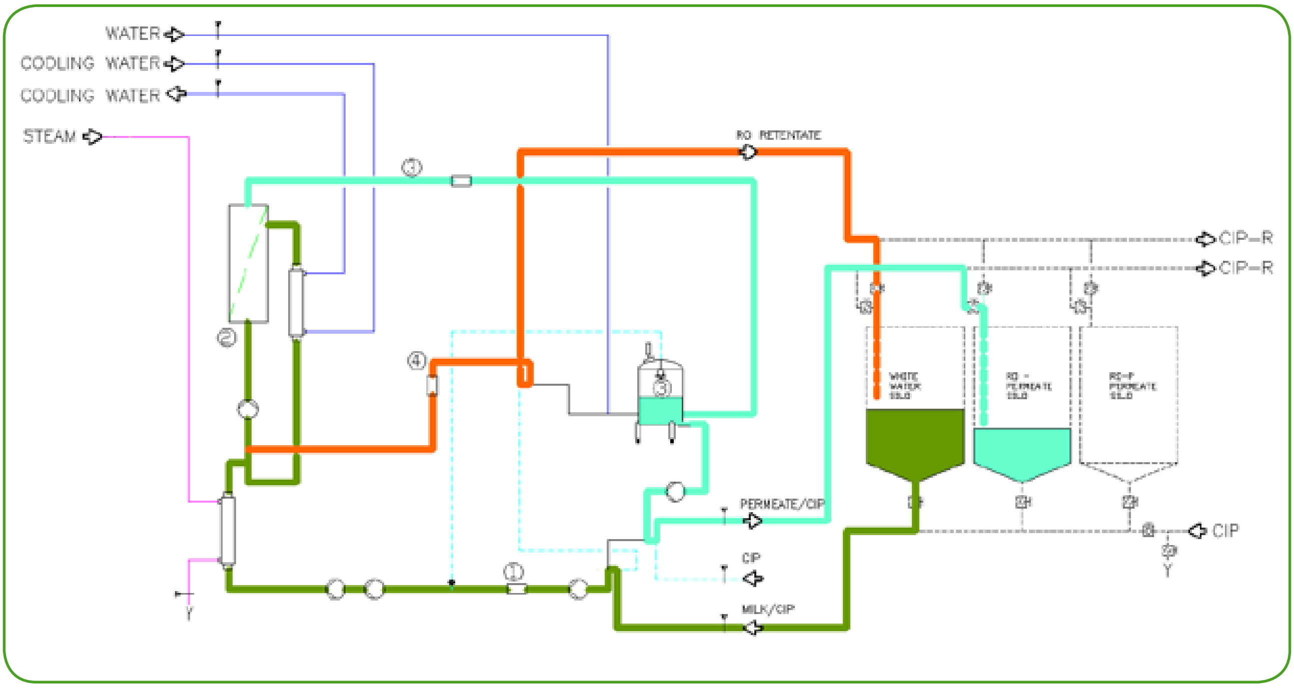


Fig. 20: APV GoldStream integration concept

collection balance tank (3) where the level is automatically controlled. The permeate is pumped from the permeate collection balance tank to the permeate storage tank or alternatively let to a drain. A conductivity meter (CT) is placed in the permeate line to monitor conductivity in order to secure the highest possible plant performance and the lowest possible COD level. The CT sensor activates an alarm in the event of membrane leakage.

Automation solution

APV GoldStream Systems employ a pre-engineered semi automatic control system with optional extra features. The splash-proof control panel on the Membrane Filtration plant skid is made of stainless steel.

The control panel contains a Siemens CPU with ET200 digital/analog input/output cards for the items on the skid and a Profibus connection to the skid-mounted Frequency Converters.

The plant is operated from a Siemens touch operator panel mounted in the door of the control panel.

The control system contains automatic CIP programs with 7 identical steps. Each step consists of preheating, manual dosing of a CIP agent, circulation with the CIP agent including cooling, and a flush.

The control system includes PID regulators and On/Off regulators. Each regulator is shown on the screen. The regulators are controlled by the operator or the PLC logic.

The APV GoldStream Automation Solution has built-in safety features in the form of alarms to ensure high operational security and optimum plant performance.

Motor controls: all pumps are equipped with splash-proof Frequency Converters placed on the skid.

Optional functions

- Automatic CIP dosing (instead of manual dosing). The selected agent is dosed at each step in the CIP program by a pre-set flow amount controlled by a maximum dosing time alarm.
- Communication link via Profibus to an external control system. This enables remote control of the plant and plant data collection from an external control system.
- Additional operator SCADA system consisting of a Wonderware Intouch PC for operator room placement. This enables remote operation, easy plant overview, surveillance and plant data collection including trend curve screens for easy production optimization and troubleshooting.

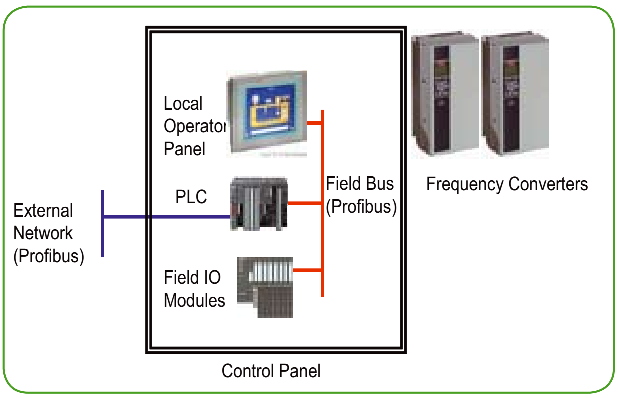


Fig. 18: Control system architecture

CIP system and procedure

The CIP procedure for the APV GoldStream RO Systems using organic membranes requires special cleaning chemicals such as P3-Ultrasil from Ecolab, Divos from JohnsonDiversy, or Ro- Dan from Novodan in order to ensure proper cleaning with removal of all fouling materials from the membranes. This is necessary to ensure a high microbiological standard as well as optimal membrane filtration performance.

SPX FT has very extensive experience of membrane system cleaning in connection with the production of various dairy products. Thorough descriptions of CIP procedures are part of the plant documentation of all delivered systems

CIP water quality is also very important for optimum CIP and to avoid damage to membranes.

The water used should be within the specifications shown in Table 5 below.

If the silica content is less than 5 mg/l, higher levels of iron (max. 0.2 mg/l) and manganese (max. 0.05 mg/l) may be acceptable in some cases.

Water hardness higher than 15°dH may be acceptable, but the CIP procedure will have to be modified accordingly (higher dosage concentrations, extra addition of EDTA/NTA, etc.).

The chlorine content should be max 5 mg/l in order to avoid development of chlorous gas when cleaning with acid.

After flushing the CIP chemicals are added manually into the feed tank and the systems will run the pre-set CIP program automatically.

Optionally the skids can be delivered with an automatic CIP chemical dosing system.

Collection of white water and integration

White water can have many different origins

PARAMETER	UNITS	RO ORGANIC MEMBRANE
Iron (Fe)	mg/l	<0.05
Anganese (Mn)	mg/l	<0.02
Aluminium (Al)	mg/l	<0.05
Silica (SiO2)	mg/l	<15
Chlorine (Cl2/HOCl)	mg/l	<0.1
German Hardness	°dH	<15
Fouling index	SDI	<3
Turbidity	NTU	<1
Total plate count 22°C Total plate count 37°C	per ml per ml	<1000 <10
Coli forms	per 100 ml	<1

Table 5. Water quality guidelines for CIP

depending on milk processing:

- Milk Reception – raw milk from tankers and silos
- Milk Pasteurizing and Preparation for processing and storage
- Drinking Milk Processing
- Cheese Production
- Powder Production

The APV GoldStream solution is based on a hygienic dairy process enabling utilization of both the milk and water stream in the production of quality dairy products. The quality of the white water and the pretreatment prior to RO are important aspects and will be described later on. The following is an example of hygienic collection of white water.

Fig 22 shows an example of how to integrate the APV GoldStream process in a Market Milk dairy plant. The white water is collected from pasteurizers, milk and cream product storage tanks, and pipes and filling lines. Raw milk could also be collected separately.

The CIP return lines or specially designed collection lines are used for collecting the various types of white water. Interface product, i.e. the first part of the milk products containing water, is collected separately, however, as it is only slightly diluted with water.

The other part is white water with varying degrees of dilution depending of the systems it is collected from, is directed into the white water collection tank.

Final pasteurization of a given Market Milk product entails pushing the product to the product storage tank using a pre-determined volume of water. A freezing point measurement of the milk using a laboratory Cryoscopy analyzer can be used to determine the water push volume setting for the actual pipe line to ensure that no water diluted milk enters the product storage tank.

The water volume is measured by a flow meter. When the pre-determined volume has been reached, the milk stream is diverted to the Interface product collection tank via the CIP return pipe line or a specially designed collection line depending on the logistics.

A conductivity meter is used for indirect measurement of the solids level or freezing point of the various white water streams. The mS set points correlate to the solids level or freezing point and determine the direction of the interface milk and white water as follows: (XX referes to the chosen set point)

- Collection as Interface milk product > xx mS (Low degree of water dilution)
- Collection as white water < xx mS (Medium to high degree of dilution)
- Leading to drain < xx mS (Very high degree of dilution)

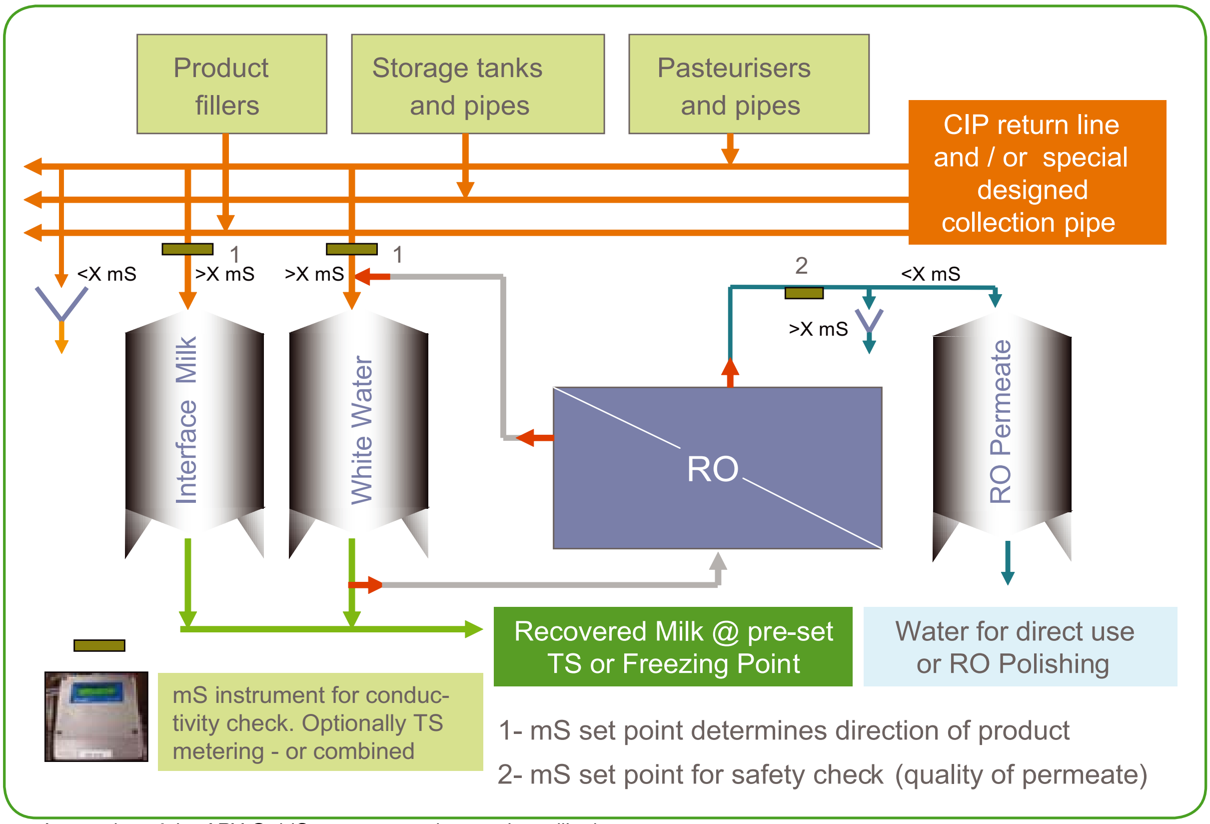


Fig. 22: Integration of the APV GoldStream system in a market milk plant

The correlation between the mS level and Total Solids level should be checked product by product in order to optimize this process.

As an example the conductivity of milk (undiluted) is approximately 6mS. Slightly diluted milk above 4.5 mS is collected as an Interface Product and milk products with a conductivity of around 0.8 mS to 4.5 mS are collected as white water. The last phase of the flushing containing a very high amount of water with less than 0.8 mS is lead to the drain.

The conductivity of Cream with 40 % fat is approximately 1mS. Here, for example, the white water set points can be between 0.3 and 0.8 mS.

Typically, recovered milk from the fillers will go to the Interface collecting tank where it can be slightly diluted with water to achieve a predetermined freezing point of e.g. – 0.450˚C, and used for cheese or yoghurt or mixed with the recovered milk from the APV GoldStream process.

White water is concentrated using a batch process in the APV GoldStream RO plant back to its normal milk composition or to a higher level of solids. If mixed with the Interface milk, the concentration level can be set to a level ensuring a normal milk composition in the mix product. Alternatively the recovered milk could be concentrated to a higher level of solids for use in yoghurt or fermented milk products.

Total solids or the freezing point can be used to determine the degree of concentration or, put in another way, the amount of permeate to be removed from the white water in order to achieve the required solids level or composition.

The freezing point in normal milk will vary a little from region to region. In Denmark the average freezing point is -0.522˚C, varying between -0.516˚C to -0.545˚C.

A sample from the white water tank is taken to the laboratory in order to determine the freezing point. Subsequently the amount of permeate to remove from the tank is keyed in the control system by the operator. The RO system continues concentration until the set volume of permeate has been removed.

The permeate can be ideal for use as first flush water and to top up the CIP chemical tanks, as it is soft water.

Pre-treatment of white water

Pre treatment of the white water prior to membrane filtration is important for the performance of the membrane system as well as the microbacteriological quality of the generated product stream.

- The white water must be free of sediments and any additives.
- The white water must be fresh milk with a pH level of 6.6 – 6.7.

- Pasteurized milk: max. temperature of 72°C for max. 15 seconds and max. 2°C in Delta-T.
- If containing fat: separation for fat removal is beneficial, but not essential.
- Raw milk white water requires pre-filtration in bag filters.

Particles, fines, free fat and denatured whey proteins as well as partly acidified milk will impact the performance of the membrane plants in the form of fouling. Build up of a layer on the membranes will impact filtration efficiency. In the worst case it might block the membranes and necessitate membrane replacement. This is normally not a problem, however, if good manufacturing practice is observed.

White water recovery is a hygienic dairy process

APV GoldStream RO complies with hygienic food standards. High product and water quality, however, requires daily CIP of all upstream and downstream equipment and pipes in order to avoid biofilm.

Recovered milk should be pasteurized.

While the recovered water will contain a small amount of organic milk components, it can be used for CIP and boiler feed without post-treatment. It is recommended to cool store the water at max. 8 - 10°C and to use the water on a daily basis for CIP of tanks and pipes.

Pasteurization is recommended for process water (e.g. cheese wash water). UV light treatment or preservation by Oxonia (H_2O_2) or Sodium Hydrogen Sulphite can be used for other purposes. New methods for cold disinfection are under development.

Plant capacity and size selection

The APV GoldStream RO system can be operated at different temperatures, typically at 5-6˚C, 8-10˚C, or even at 50˚C. The temperature depends on the type and quality of the product. Plant capacity will depend on the operating temperature and the type and quality of the product, as well as the composition of the white water and the degree of concentration.

As an example, skim milk at 10˚C will result in approximately 30% higher capacity compared to whole milk white water with the same degree of concentration. Raw milk at 5˚C will result in 15% lower capacity compared to whole milk with the same degree of concentration.

White water from high pasteurization temperature products such as UHT milk will result in a significant lower flux rate or capacity due to denatured proteins. Separate collection and treatment at the end of the production process are recommended for this kind of product. Cream pasteurized at high temperature is less sensitive due to its lower protein content and heat protection of the protein by the fat.

Acidified products like yoghurt and other fermented products can also be recovered. However, all potential sediments and particles need to be removed and a lower capacity compared to fresh milk can be expected.

As the types and composition of white water will vary significantly, SPX sales specialists will support and guide customers in selecting the solution best suited to their needs as well as the most optimum plant size including potential utilization of the APV GoldStream System for RO polishing of the generated RO water.

Highly profitable and a green image

The APV GoldStream process is a highly profitable solution as the value of the recovered milk is equal to the price of raw milk. Savings of water and effluent treatment costs also enhance profitability. The pay-back time, taking capital outlay and operating costs into account, is typically less than one year.

Table 6 shows a waste solution scenario compared to a recovery solution using APV GoldStream technology based on a daily milk intake of 1 million litres. The figures are based on 360 days of production per year with an interest rate of 5% and depreciation over three years.

The calculation is based on 10 hours operation per day for white water recovery. Additional use of the APV GoldStream RO System for polishing of the RO permeate will result in extra value.

WASTE SOLUTION (1 MILLION LITRES OF MILK INTAKE/DAY)			
PRODUCTS	COST PRICE IN €	DAYS/ YEAR	COSTS IN K €
10,000 litres milk	0.25/l	360	900
20,000 litres well water	0.65/m³	360	5
30,000 litres waste water	2.50/m³	360	27
Total costs per annum			932
RECOVERY SOLUTION			
Value of milk, water and waste savings			932
Capital and operation costs			220
Gain per annum			712
Return of investment (ROI) in months			7

Table 6: A waste solution scenario compared to a recovery solution using the APV GoldStream System

Reclaiming milk based water

When using Membrane Filtration to process milk or whey to make protein concentrates, a substantial amount of milk-based water (Cow Water) is obtained in the form of RO or NF permeate or condensate respectively.

This Cow Water represents a new, value-added milk component and can be reclaimed by using the RO polishing system mentioned above. This adds a new dimension of value to the milk and significantly cuts water and waste treatment costs as well as adding value to the green profile of the dairy.

Fig. 24 shows a solution including UF for WPC/MPC, NF/RO of the UF Permeate and RO Polishing of the RO Permeate – and also RO Polishing of the Evaporator condensate.

The RO permeate from sweet whey or UF permeate will typically have a COD level of 170-200 ppm. However, it can be used for flushing of membrane plants and general flushing. The last flush, however, should be with fresh water.

The RO permeate can be polished by further RO processing using the same RO system as for whey concentration. This enables a reduction of the COD level to < 20 ppm.

This very high-quality demineralized soft water can be used as:

- Process water for cheese and other products
- Water for cheese cooling before brining and further brine water
- Water to supply boilers or cooling towers
- Water to supply CIP systems including the final rinses
- Seal water on pumps

Depending on the use of the water, a downstream treatment may be necessary, for example pasteurization or cold disinfection by Electrolysis for process water and UV light or preservation by Oxonia (H_2O_2) for other purposes.

RO Polishing of Evaporator condensate

Production of milk and whey powder involves generation of a substantial amount of condensate from evaporation. Based on skim milk powder production and evaporation to 50% solids, the volume of condensate amounts to more than 80% of the skim milk volume. This means that processing of one million litres of skim milk per day results in more than 800,000 litres of condensate.

Increasing water and wastewater treatment costs mean that it can be extremely advantageous to reclaim the condensate (Cow Water) and polish it in a RO system for use as process water or other purposes.

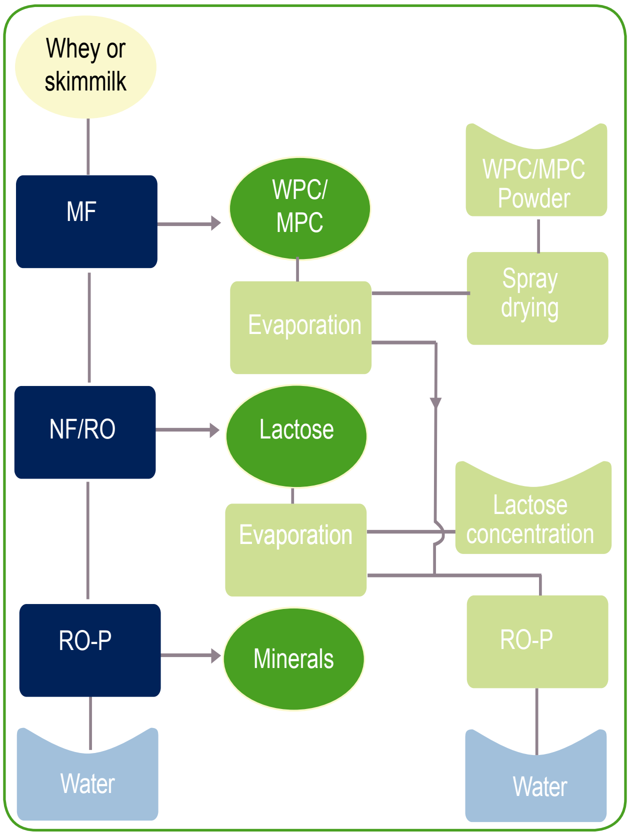


Fig 24: Example of RO Polishing of Condensate

Table 7 shows examples of compositions of RO Polisher feeds originating from condensate, RO and NF processing and RO Polisher permeate.

SPX can help you

In some cases it is advisable to perform some tests in order to verify the expected result before investing in a Membrane Filtration solution.

The SPX FT Innovation Centre in Silkeborg, Denmark, offers state-of-the-art plant equipment enabling you to conduct trials based on pilot membrane systems and other relevant pilot equipment.

SPX also offers rentals of membrane Pilot Plants for testing on your own premises based on your own raw materials and products. In addition, SPX also offers the services of experienced technologists to assist in testing, train your operators, and offer additional advice and guidance in connection with your specific white water recovery or water stream polishing applications.

COMPONENTS \ PRODUCTS	CONDENSATE (FEED)	RO PERMEATE (FEED)	NF PERMEATE (FEED)	RO POLISHER PERMEATE
True protein %	0.00	0.00	0.00	0.00
Non-protein nitrogen %	0.01	0.06	0.10	0.01-0.05
Lactose %	0.00	0.02	0.05	0.00
Acid %	0.01	0.00	0.00	0.00-0.01
Total ash %	0.01	0.01	0.25	0.00-0.01
TS %	0.03	0.06	0.41	0.01-0.07
pH	6.5-8.5	6	6	
COD ppm	30-40	80-250	1,000-1,800	5-180

Table 7: Examples of composition of various Polisher feeds and the Polisher permeate

Conclusion

In addition to being a proven and environmentally sustainable technology, the APV GoldStream process delivers highly attractive financial advantages in connection with:

- Recovery of milk components from white water
- Recovery of the water stream from white water
- Reclaiming and RO Polishing of the RO water and condensate streams
- Recycling of water streams as process water of other attractive applications
- Reduced water intake and waste treatment costs
- Reduced load on the effluent plants

A very short payback time together with an enhanced environmental image make APV GoldStream Membrane Filtration Systems a “goldmine” of potential savings.

The APV GoldStream process has already delivered excellent results that have attracted enormous interest in the dairy industry. This success means that the APV GoldStream Membrane Filtration System is set to become a standard solution in most dairies in the future.

The APV GoldStream System is available in four different sizes/capacities. These pre-engineered standard skid-mounted systems are based on proven components, membranes and control instruments, as well as materials of uncompromising quality such as ASI 316 Stainless Steel to ensure the highest hygienic standards.

Features and benefits of APV GoldStream Systems:

- Attractive financial solution with a payback time of less than 1 year
- Skid-mounted, self-contained Plug & Produce systems
- Pre-engineered, standardized systems with an attractive cost/value ratio
- Tried and tested performance
- Uncompromising system quality and process reliability
- Hygienic dairy processing standard
- Reduced water and waste treatment costs
- Smaller environmental footprint with a green image
- First class local SPX Flow Technology and Service Support

SPX also offers excellent Pilot Plant Testing and application solution guidance service to help customers maximize their utilization of the recovered milk and water streams. In addition, customers benefit from a value-added environmental solution that reinforces their green profile in addition to the financial benefits offered by APV GoldStream Membrane Filtration solutions.

Fig. 25: APV GoldStream System for RO-polishing

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