Removal of bacteria and spores from milk, using membrane filtration
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EXECUTIVE SUMMARY

Removing bacteria and spores from milk using filtration makes sense in cases where the temperature surviving flora is a limiting factor and a high temperature treatment of the full milk flow is not appropriate.

The most successful filtration technology area until now is microfiltration using ceramic membrane elements. These membrane elements have a rather “precise and narrow” pore size distributions and they are resistant to most cleaning chemicals as well.

The major applications in the dairy business today are cheese and drinking milk microfiltration. The skim milk is filtered and the cream phase is given a high temperature treatment. In cheese making, the filtration process can make it possible to produce cheese without relying on nitrate for preservation. The shelf life of fresh white drinking milk types can be improved when the number of bacteria and spores has been reduced using microfiltration.

In some cases bacteria and spore removal using membrane filtration is also used in milk and whey process lines for dairy ingredients. Often there are tight limits to the bacteria content of these products and they are at the same time sensitive to heat treatment and this is where membrane filtration comes into the picture.

In general the product will get an improved bacteriological quality making it suitable for a wider market approach.

The microfiltration process is sensitive to variations in the feed pretreatment and quality. It is therefore necessary to evaluate the whole process line to make the most value of the investment.

SPX Flow Technology is ready to contribute with expertise to support your process development and product improvement projects. We understand the need for “standing out from the crowd” and can offer development agreements to have Your process “pilot tested” under optimised conditions e.g. in the SPX Innovation Centre in Silkeborg, Denmark. It is also a possibility to purchase or rent a pilot unit in order to perform pilot testing in-house on the “real” feed product.

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 wide range of products and solutions from engineered components to design of complete process plants supported by world-leading applications and development expertise.

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

CUSTOMER FOCUS

Founded in 1910, APV, an SPX Brand, 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.
Cross flow micro filtration can be used for removing bacteria and spores from skim milk. It is a process where a flow parallel to the membrane surface keeps the membrane surface free from blockage by the components which are held back by the membrane. Like with other membrane separation processes the flux or the efficiency of the membrane is influenced mainly by the feed quality, the retentate quality and the flow and pressure conditions at the membrane surface. In a production environment an efficient cleaning of the membranes after production is of highest importance.

Bacteria cells have about the same physical size as the fat globules of the milk. It is therefore difficult to separate the two in an efficient way using membrane filtration. For this reason the milk is typically separated into a skim milk phase and a cream phase. The skim milk is filtered and the cream is given a temperature treatment where after the two can be mixed back together. The retentate or the bacteria phase from the filter can be reintroduced into the stream in different ways to reduce process losses.

The temperature/time combination of the cream phase heat treatment is often designed to give a reduction equal to what is obtained by the filtration of the skim milk. The heat treatment of the cream is normally performed with indirect heating in a plate heat exchanger. If the bacteria phase from the filter is reused after a high temperature treatment one must expect e.g. a higher level of protein denaturation in the final product.
Membranes with pore sizes in the micro filtration pore size range are relative sensitive to fouling caused by the trans-membrane pressure drop. Changes in the size distribution of casein micelles and fat globules can affect the membrane performance. Colloids with a size close to the cut-off value of the membrane will get caught and obstruct the passage of smaller components. This will put extra load on the still unblocked membrane area and increase the danger of further blocking of the membrane pores.

Unwanted changes in the physical or chemical conditions in the skim milk can affect the efficiency of the membranes. The degradation of the milk components can be the final factor pushing the membrane beyond its limit. Attempts to influence the bacteriology of the raw milk before filtration (eg through addition of chemicals) will in many cases also influence the physical and chemical conditions in the milk and thereby the membrane efficiency.
GENERAL MEMBRANE PRINCIPLES

Table 1. Example of factors influencing membrane capacity

<table>
<thead>
<tr>
<th>CAPACITY PARAMETERS</th>
<th>RUNNING TIME</th>
<th>MEMBRANE FLUX</th>
</tr>
</thead>
<tbody>
<tr>
<td>GOOD RAW MILK QUALITY</td>
<td>↑</td>
<td>↑</td>
</tr>
<tr>
<td>TIGHTER MEMBRANE MATERIAL</td>
<td>↓</td>
<td></td>
</tr>
<tr>
<td>EFFICIENT MILK FAT SEPARATION</td>
<td>↑</td>
<td>↓</td>
</tr>
<tr>
<td>LOW AIR CONTENT OF MILK</td>
<td>↑</td>
<td></td>
</tr>
</tbody>
</table>

It can be beneficial to change filtration temperature on the run during production to optimize running time. In such cases the filtration temperature is changed within the temperature range where the separator maintains its efficiency. SPX has developed special temperature profiles to stress the micro flora in the filter loop itself and thereby control membrane fouling.

The membranes used for the process can be made from ceramic materials where the fine grained membrane layer itself is more or less "melted" onto the more coarse membrane support layer. The skim milk will typically flow through flow channels running in the length of the membrane. The skim milk passes the pores in the membrane surface and flows through the support layer and into the permeate void of the membrane housing. The thickness of the support layer that the skim milk has to pass will vary since the flow channels are typically distributed with different distance to the outside of the membrane. The differences in flows in the membrane support structure can be a reason for differences between the efficiencies of the membrane elements with different flow channel designs.

Fig 5. Ceramic membrane layer
© TAMI Industries S.A.S

Fig 6. Ceramic membrane element support structure
© 2013 Pall Corporation
Ceramic membranes are typically tolerant to stronger CIP detergents and higher temperatures than normal organic membranes. This is a beneficial feature when working with high concentrations of bacteria.

Further experience shows that ceramic membranes have a more accurate cut off-value in the critical area around 1 µm than most other membrane types used for dairy applications today.

Worldwide there are only a small number of suppliers of food grade dairy ceramic membranes for this application. There are differences between the designs and build ups of the elements but the membrane plant itself will look more or less the same when using elements from the main suppliers.

Ceramic membranes are sensitive to vibrations and can break if a physical impact like vibration is applied to the side of the membrane element. This is one of the reasons why they typically are installed in a vertical manner. Tensions from sudden temperature changes can also endanger membrane integrity.

The normal lifetime of a ceramic membrane element is long compared to a spiral wound membrane element. Typically the lifetime of ceramic elements is more than 3 times longer than the lifetime of spiral wound elements.

It is possible to bubble test the ceramic membranes for leakages or cracks. This is done by applying pressurized air to the permeate side of the membrane and watch the bubbles appearing from the flow channels. This test is however not a 100% verified membrane integrity test and it is therefore also necessary to do a careful monitoring of the bacteriological quality of the skim milk permeate during production.
Membrane filtration is used for production of drinking milk with improved shelf life. The psychotropic spore formers like some Bacillus species can be a limiting factor in fresh drinking milk products. The milk products produced are most often white milk products. Adding ingredients upstream can in many cases have an influence on the efficiency of the membranes. The improved shelf life milk products produced using micro filtration are often rated as more "fresh" tasting than similar milk products prepared using thermal treatment. Compared to equivalent thermal processes the filtered milk can best be compared to products made using direct steam product contact and very short holding times. The filtration process has in comparison with the direct thermal treatments the advantage of lower steam consumption and more efficient removal of heat resistant spores. Many consumers find it appealing that both living and dead bacteria has been physically removed from the product.

Normally the membranes used for drinking milk products have a more precise pore size distribution than the ones used for cheese milk. The drinking milk products are competing against the UHT products and there is always a driver towards longer shelf life and thereby tighter membranes. For cheese milk preparation one strives to use as open a membrane as possible and at the same time ensure sufficient removal of spores and bacteria.

The drinking milk filtration lines can be designed in many different ways depending on the local conditions and demands. Bacteria and spores can be removed through a retentate stream and through the desludge stream from the separator(s). It is important to reduce the volume of these streams to a minimum to reduce product loss.

![Diagram of milk filtration process](image-url)
Often it is possible to remove the bacteria and spores in a volume stream of about 0.3% to 3% of the milk stream depending on the line solution. The membrane itself will typically have a Volume Concentration Factor (VCF) of 10 up to 200. The MF process can be designed for 1 or more stages to maximize the utilization of the installed membrane area.

\[
VCF = \frac{\text{Feed volume flow}}{\text{Retentate volume flow}}
\]

Fig 9. Calculation of VCF

Using mainly the cream separator/bacteria separator for removal of the bacteria and spores can reduce the necessary filter concentration level. The separator/bacteria separator step will however have to be dimensioned for this possibility.

The cut off value of the membrane elements used for this application is around 1 µm. Some of the largest casein micelles are just small enough to pass through the membrane. It is therefore important to use the right line set-up especially using the tightest membranes. Special thermal protein/mineral stabilizing pretreatments may be necessary to optimize the results. Depending on the membrane cut-off value the level of bacteria and spore removal is typically around 99.9 – 99,999% from the feed skim milk to the membrane permeate. On top of this there is nearly always a downstream legal pasteurization which will give a further bacteria reduction of 95-98%. The downstream legal pasteurization provides a phosphatase negative product and it serves as back up product safety measure.

The final shelf life of the drinking milk product is also dependent on the downstream handling and the filling technology applied. Using aseptic or ultra clean solutions will improve the possible obtainable shelf life of the products.

With the tightest membrane types and the most advanced downstream solutions the shelf life of the white milk products would typically be around 3-4 weeks at 6-8°C or 5-6 weeks at 4°C.
The removal of bacteria and spores from cheese milk can be interesting for a number of reasons as explained below.

Removing some types of spore formers from the cheese milk will decrease the risk of unwanted gas production and resulting cheese spoilage. In Northern Europe humid conditions during the harvest season can result in a high load of spore formers in a stable environment and hence in the raw milk. There are other techniques available for the removal of the spores. The choice of technique can be based on a comparison between cost and bacterial reduction figures.

Nitrates can be used instead of bacteria removal to avoid cheese spoilage. The addition of nitrates to yellow cheese milk and the resulting whey are however in many countries unwanted or even not legally permitting. The whey processors are often putting pressure on the cheese producers to install equipment to remove the spores rather than adding nitrates.

Other cheese types with relatively high pH, high water content and/or low salt content are sensitive to growth of an unwanted microflora. Such cheese products can also benefit from cheese milk with a very low initial bacterial count. Either the resulting extra shelf life benefit the local market or the products can be shipped to more distant markets.

The membrane line design used in a cheese installation depends on a number of parameters just like the lines for drinking milk. For this reason the same line design variations can be used for cheese lines (please see Fig.8).

For cheese milk, the membrane used will most often have a pore size just above 1 µm. The level of removal of bacteria and spores would be in the area of 99,5 – 99,9% before legal pasteurization. After having removed the bacteria and spores from the skim milk it typically enters a standardization device where the cream phase can be added. Often it is only the cream volume needed for the milk standardization which is given a special high temperature treatment. The rest of the cream phase is either cooled before further treatment or it is pasteurized at normal pasteurisation conditions after a short buffering period.

The microfiltration plant can be equipped for different automation levels. Normally it is integrated in a line where it is to process all skim milk coming from the upstream line. Due to a requirement for special CIP cleaning agents and CIP programs the membrane system is cleaned independently from the rest of the line.

In order to make the most of the microfiltration plant it is necessary to treat it with caution and watch for signs of fouling. A daily record of process parameters should be kept to maintain knowledge of how the plant operates with in the normal variations.

Fig 10. Example of daily records
If the filtration plant is showing signs of a gradual decrease of performance there will in many cases be a need for an improved cleaning procedure. It will in most cases be necessary to consult the supplier of the cleaning chemicals for assistance in order to solve the issue. In severe cases it can be necessary to send the membranes for special cleanings which cannot be performed on site. Some membrane producers offer e.g. a special "membrane burning" process where all organic material in the membrane is removed in a hot oven.

<table>
<thead>
<tr>
<th>PRODUCT DISPLACEMENT</th>
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<tbody>
<tr>
<td><strong>PRE-RINSE</strong></td>
</tr>
<tr>
<td><strong>WATER FLUSH</strong></td>
</tr>
<tr>
<td><strong>MAIN CLEAN</strong></td>
</tr>
<tr>
<td><strong>WATER FLUSH</strong></td>
</tr>
<tr>
<td><strong>FINAL STAGE</strong></td>
</tr>
<tr>
<td><strong>WATER FLUSH AND STERILISATION</strong></td>
</tr>
<tr>
<td>1% CAUSTIC TYPE CLEANING AGENT</td>
</tr>
<tr>
<td>2.5% CAUSTIC TYPE CLEANING AGENT</td>
</tr>
<tr>
<td>0.6% ACID TYPE CLEANING AGENT</td>
</tr>
<tr>
<td>ACID OR PRESERVATIVE CAN BE ADDED IF THE PLANT IS NOT CONTINUING DIRECTLY INTO PRODUCTION STAGE</td>
</tr>
</tbody>
</table>

Table 2. Example of cleaning program

**ALTERNATIVE PROCESSES**

There are other technologies available for improving the bacteriological quality of milk. As alternatives or additions to filtration SPX can offer both thermal and centrifugal (removal with special separators) processes which can cover the needs in many cases. The right choice depends on a lot of factors. The thermal processes can generally be designed to reduce the number of living bacteria to a preset extend but it can in some cases also change the sensory properties of the end product. Using special separators it is "as a rule of thumb" possible to reduce the total number of bacteria and spores around 90% for each machine installed in the line. This means that it can be necessary to install more than one machine to get the necessary reduction of bacteria and spores.

**CONCLUSION**

As can be seen from the above there are a number of considerations to make in connection with the choice of process parameters for a microfiltration line for bacteria and spore removal from milk. SPX is one of the leading suppliers of line solutions for the dairy industry and can support in all phases for making the right choices for Your process.