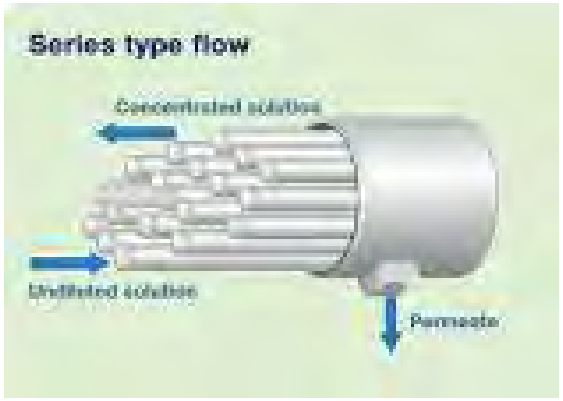
MEMBRANE PROCESSES FOR FOOD INDUSTRY AND BIOTECHNOLOGIES

STRUCTURE OF LECTURE

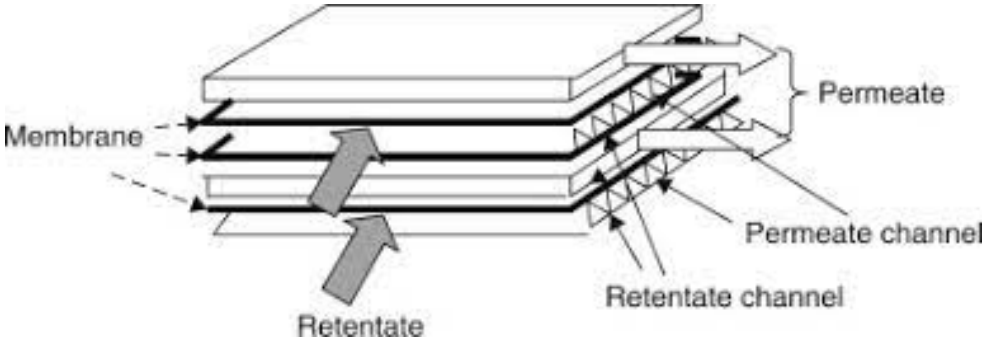
- 1. Conditions for membrane separation;
- 2. Diafiltration;
- 3. Affine ultrafiltration;
- 4. Membrane separation for biotechnologies;
- 5. Membrane separation for food industry.

MEMBRANE MODULES

Tubular module

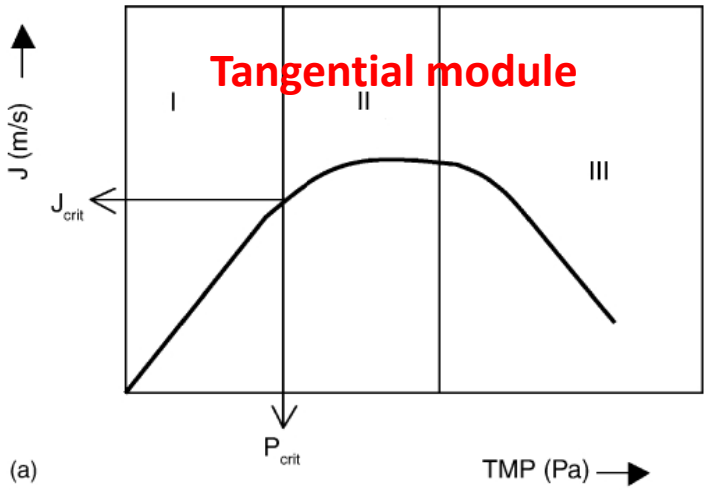


Flat plate module



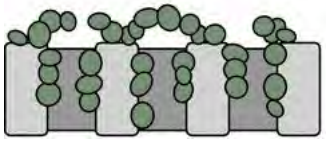
These cross-flow modules are traditionally used in food industry, since it is easy to clean them.

Typical effect of pressure on the permeate flux over filtration processes in dairy industry

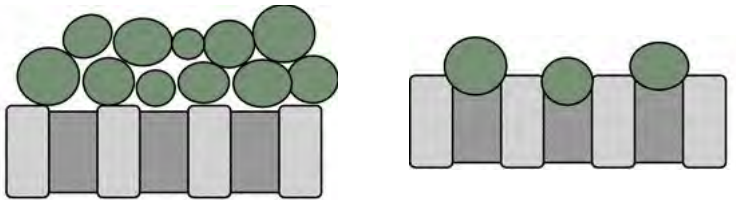


Regime I. No considerable fouling.

Regime II. Cake formation, pore constriction.



Regime III. Cake compaction, pore blockage



OPERATION CONDITIONS

Time of the membrane separation

The time of membrane separation is strictly regulated. Normally it is 10-20 h. Just after the finish, cleaning and disinfection of the membrane system must be performed.

Ionic strength

Increasing ionic strength of the solution provides aggregation of colloidal particles, this facilitates their separation.

This approach is possible, when:

- No requirements to salt content in a target product,

-- Desalination of the target product is possible and appropriate from the economical point of view.

Temperature

- **The temperature must be kept at the predetermined level.**

As a rule, the temperature is about 10^{o} C.

Pressure

In the case of MF and UF processes, the pressure is about 0.5-1 bar to avoid polymerization of some compounds.

STRATEGY OF FOULING CONTROL AND CLEANING MEMBRANES

Fouling control for the membranes, which are used in food industry

Method	Working principle	Possible disadvantafes
High cross-flow velocity	**Enhance transport by turbulent flow, low pressure**	**High power consumptions, high investment and operation costs**
Spacers	**Enhance transport close to membranes**	**Difficult cleaning, increased power consumptions**
Backwashing	**Remove cake by pressure reversing**	**High operation costs**
Pulsating cross-flow	**Velocity fluctuations in the feed**	**Difficult to control pressure waves in large systems**
Air flow	**Increase mixing close to membrane**	**Difficult to control air bubble size, foaming and denaturation**
Cleaning particles	**Increase mixing close to membrane**	**Run-out of membranes and pump**
Sonication	**Prevention of precipitation**	**Power consumption and heating, damage of sensitive compounds**
Vibration modules	**Increase mixing close to membrane**	**High investment cost**
Electric field	Keeping charged particles far from membrane	**Electrolysis, gas production, heating, power consumptions**

STRATEGY OF FOULING CONTROL AND CLEANING

Fouling control for the membranes, which are used in food industry

Cleaning has a significant impact on process operations and the commercial viability of the process. It is accomplished by physically removing the gel layer and/or foulants, for example by backflushing, and/or by using a specific cleaning solution containing appropriate detergents and/or chemicals. The cleaning treatment must effectively remove and/or dissolve the gel layer and/or foulants while not exceeding the mechanical or chemical limits of the membrane.

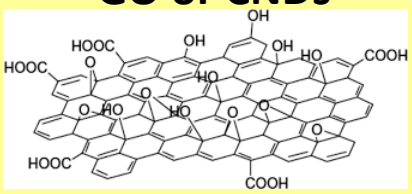
Disinfection is the necessary stage of cleaning.

Requirements to membrane materials

- Chemical stability,
--No modifiers, which destroy the components of liquids of biological origin.

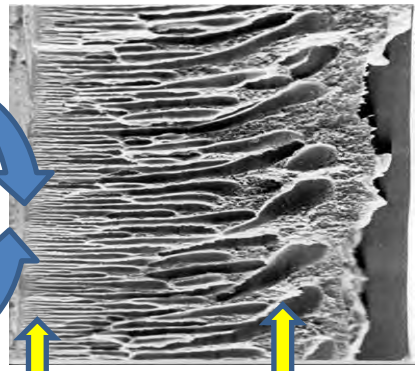
MODIFIER

GO or CNDs

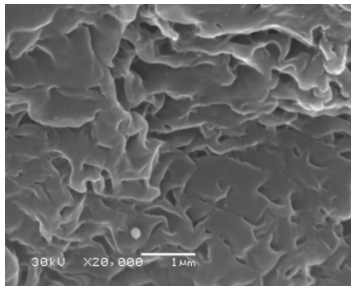


Inorganic ion-exchanger (binder)

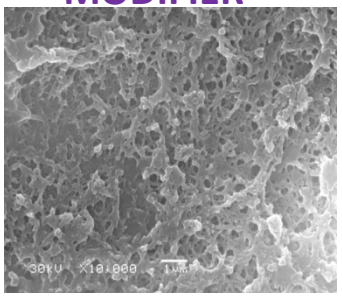
POLYMER FILTRATION MEMBRANE



Active layer



Active layer + MODIFIER

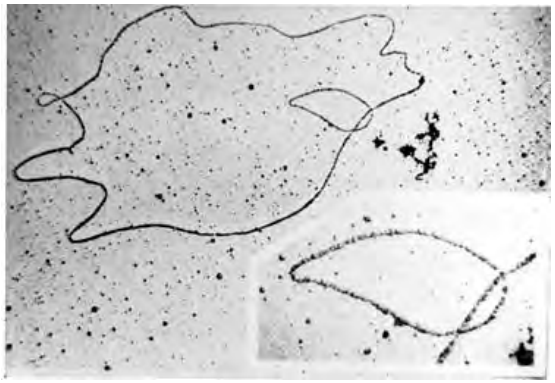


SEPARATION OF PLASMID DNA FROM RNA BY ULTRAFILTRATION

Needs of plasmid DNA

Plasmid

Plasmids are circular doublestranded extrachromosomal DNA that are produced by many bacteria and also by some eucaryotes, often at high copy numbers.



Gene therapy and preparation of DNA vaccines require large-scale production of highly purified plasmid DNA from fermentation broth. Plasmid DNA is isolated from the fermentation broth. Downstream purification is needed to remove cellular debris, host cell proteins, genomic DNA, RNA, and endotoxins.

Ion exchange chromatography are used extensively in current separation systems, these methods are expensive and time-consuming. Membrane separation is much core attractive.

M_{pDNA}= 130000 kDa M_{RNA}= 0.04-1 kDa M_{gDNA}≈1000 kDa

Membranes can reject large plasmids.

Problems of pressure-driven processes

Elongation of plasmid molecules → their leackage through the membrane → →decrease of yield.

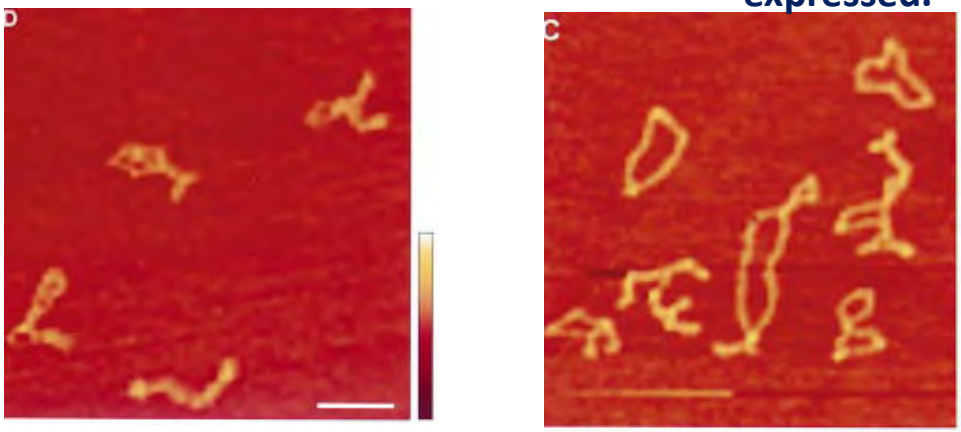
Interaction of plasmid molecules with contaminants → decrease of purification degree.

SEPARATION OF PLASMID DNA FROM RNA BY ULTRAFILTRATION

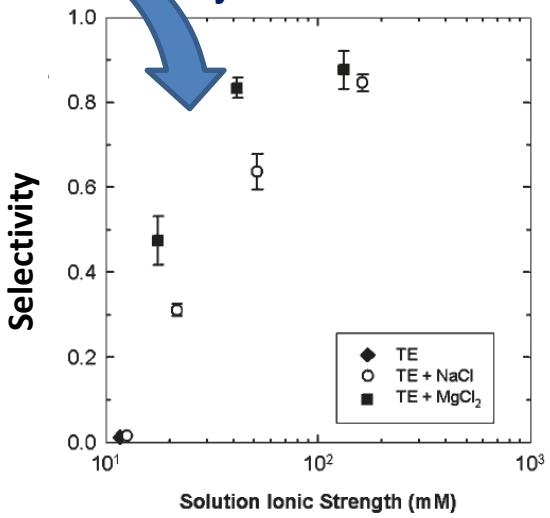
DNA show typical behavior for colloidal systemsm for instance, aggregation in salt solutions.

+$MgCl_2$

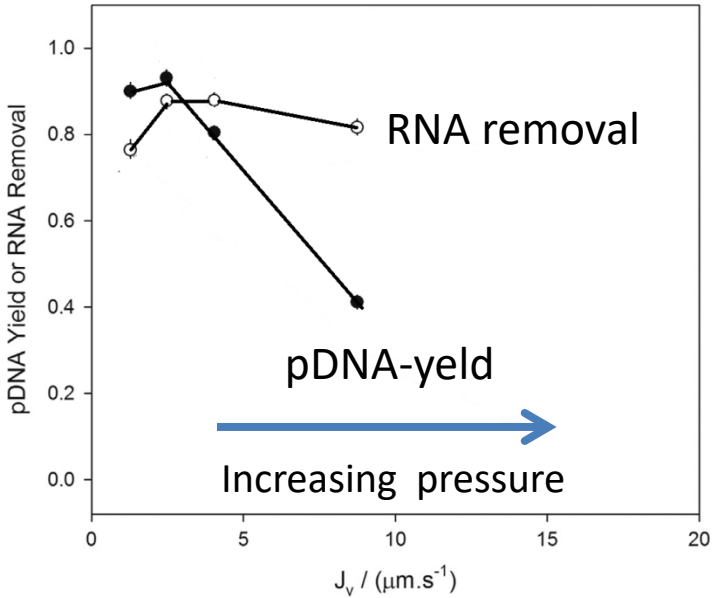
Aggregation enhances pDNA rejection. The effect of double-charged ions is expressed.



Effect of ionic strength on pDNA rejection



Effect of pressure on pDNA-RNA separation

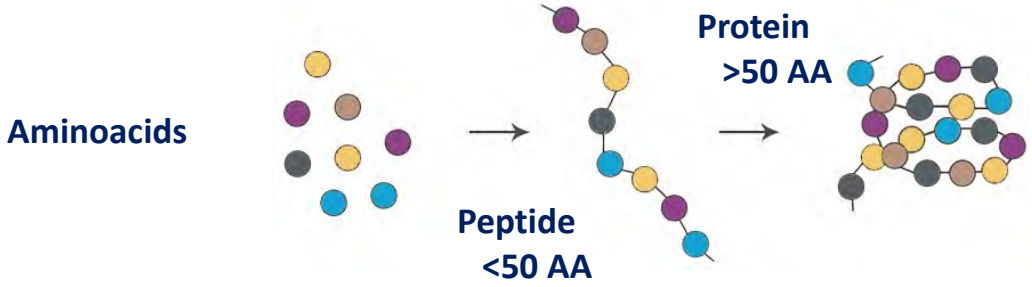


Key factors affected DNA-RNA separation

Pore size (25 nm is the optimal size)

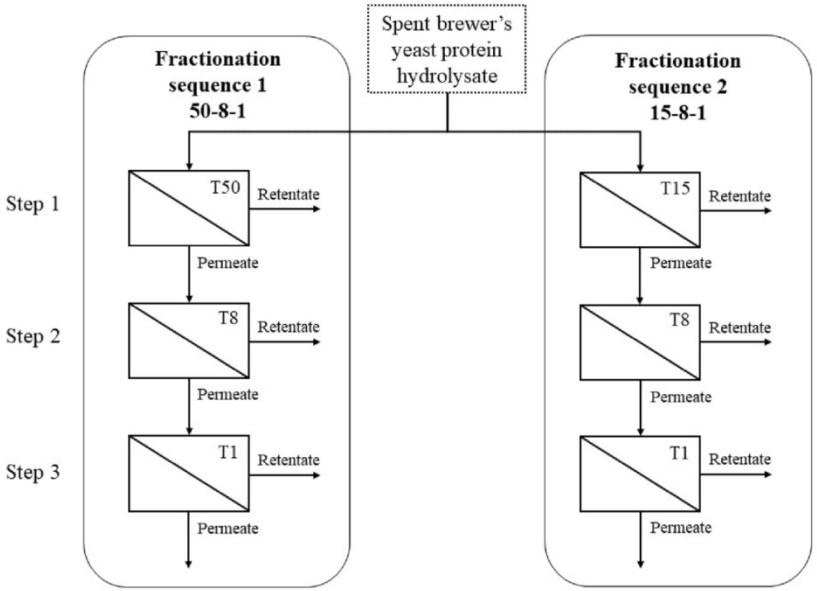
Pressure

SERIAL FRACTIONATION OF PEPTIDES FROM SPENT BREWER'S YEAST HYDROLYSATE



Membranes with cut-off of 50, 15, 8 and 1 kDa were used.

Scheme of fractionation

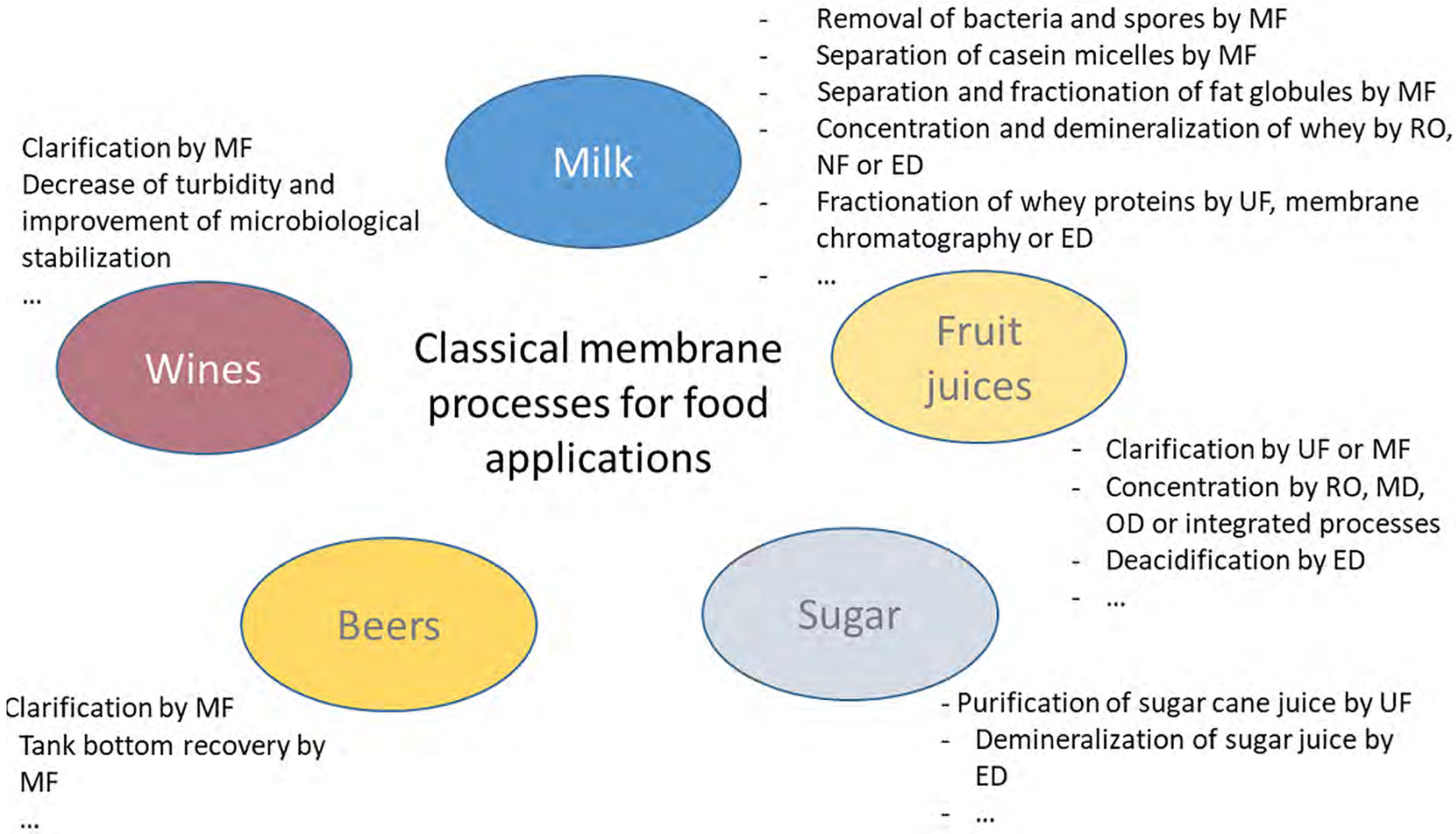


Permeate 3 containing the smallest peptide particles can be used as food ingredient. Concentrate 2 contains the largest fraction of Bioactive peptides (5 kDa and smaller).

Particle size

Sequence	MW<1	1<MW<7	MW>7
Initial	59.0	29.8	11.2
50-8-1			
Concentrate 1	50.0	30.8	19.2
Concentrate 2	62.3	29.6	8.1
Concentrate 3	79.0	19.0	2.0
Permeate 3	91.7	7.0	1.3
15-8-1			
Concentrate 1	51.0	32.2	16.8
Concentrate 2	66.0	28.7	5.3
Concentrate 3	80.3	17.1	2.6
Permeate 3	88.7	7.9	3.4

MEMBRANE PROCESSES IN FOOD INDUSTRY

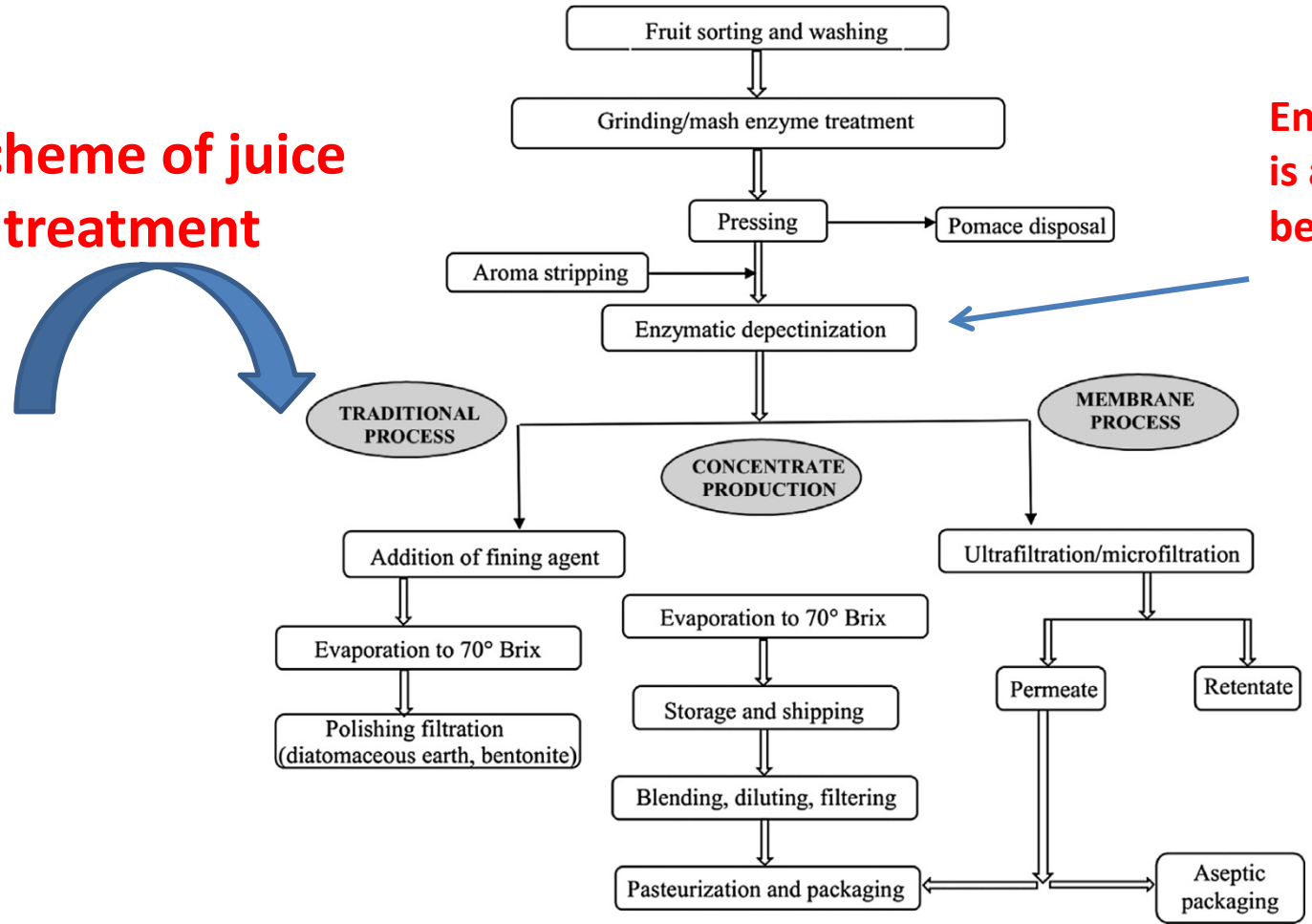


TREATMENT OF FRUIT JUICE

Fruit juice treatment

- **Clarification (MF, UF)**
- **Concentrating (RO)**
- **Deacidification (ED)**

Scheme of juice treatment



Enzymatic pretreatment is a mandatory stage before the membrane treatment

TREATMENT OF FRUIT JUICE

Membrane materials

Citrus juices can be very aggressive to some membrane materials (polyamide, polysulfone polyacrylonitrile) . Poly(vinylidene fluoride) membranes are recommended.

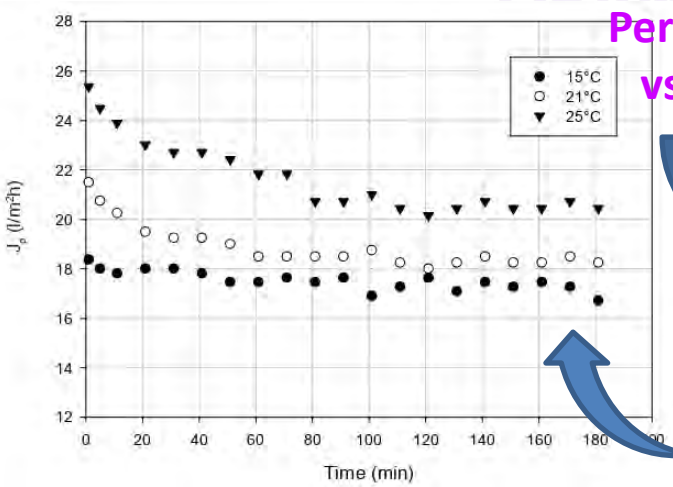
JUICE CLARIFICATION

Fruit juices are characterized by natural turbidity due insoluble substances, such as pectin, starch, and cells from the juice. Depending on the application of the fruit juice, clarification process is required. For example, clarified fruit juices are needed for the production of clear beverages (soft drinks, natural aromatic waters, alcoholic beverages, cold teas, etc.), candies (melting products), and pastries (natural essences, translucent fruit sauce).

Conventional clarification usually involves batch processes, such as enzymatic pretreatment, clarification with bentonite, gelatin or diatomaceous earth, and pasteurization.

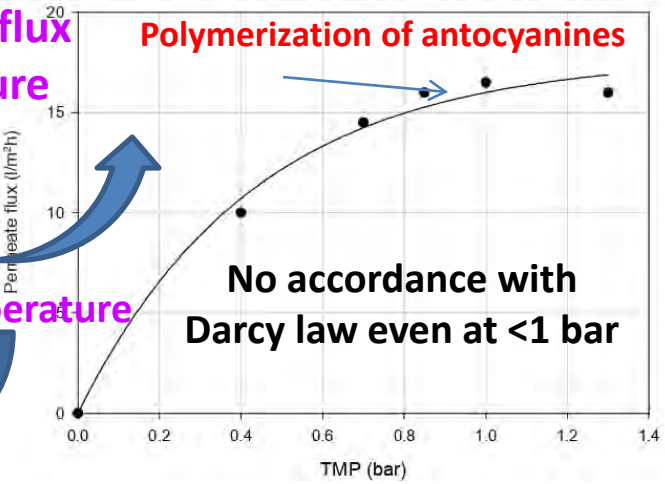
MF and UF are alternatives to traditional clarification techniques. The advantages of MF and UF are increased juice yield, possibility of operating in a single step, fevrease of ensyme consumption, decrease of operating times, elimination of needs for pasteurization, and production with a continuous process.

ORANGE JUICE CLARIFICATION



Permeate flux vs pressure

vs temperature



Polymerization of antocyanines

No accordance with Darcy law even at <1 bar

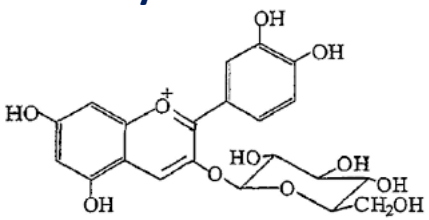
Commercial product

Composition of orange juice

Substance	Feed	Permeate	Concentrate	Balance, %
Total soluble solids, g/ 100 g	12.0	11.2	13.5	100.0
Suspended solids, %	10	0	>50	91.6
Ascorbic acid, mg l^{-1}	701	642	640	98.5
Antocyanins, mg l^{-1}	60.4	54.7	60.6	92.0
Narirutin, mg l^{-1}	46.7	46.7	46.7	100.0
Hespendin, mg l^{-1}	33.9	33.6	31.1	99.7

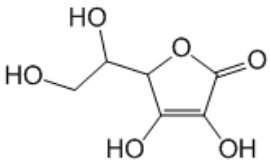
Flavonoids

Anthocyanine



Cyanidin-3-O-glucoside chloride

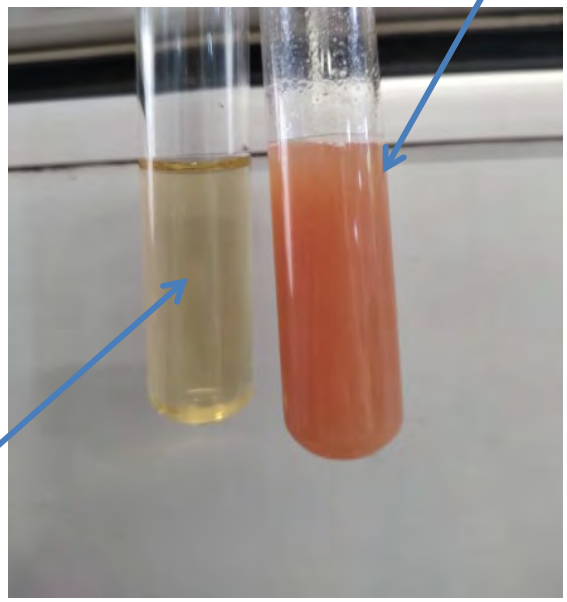
Ascorbic acid



Ascorbic acid and anthocyanines are partially adsorbed by membrane.

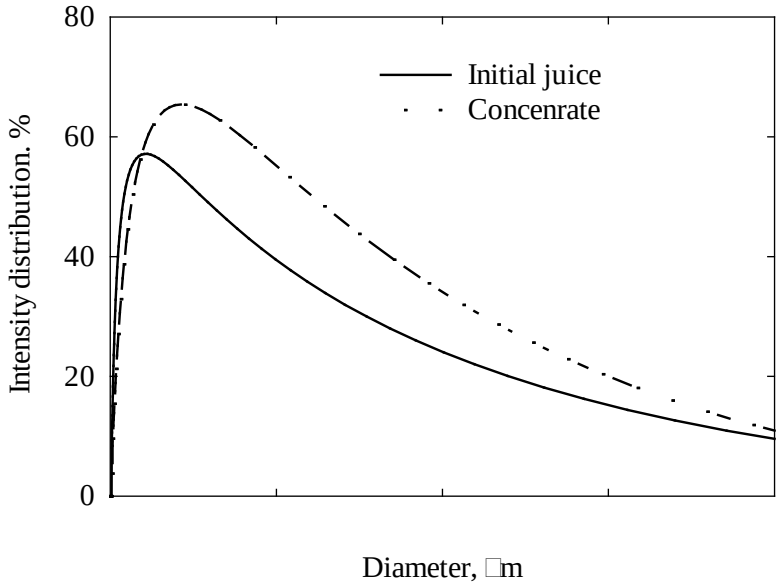
GUAYAVA JUICE CLARIFICATION

Pristine juice



Clarified juice

Effect of pressure on the particle size



Selectivity of the modified MF membranes is 33-73%.

The concentrate can be used for the production of confectionery

CONCENTRATING FRUIT JUICE

Fruit juices are usually concentrated to allow easier and cheaper storage, transportation, and distribution, as well as better conservation. The classical methods of juice concentration, such as thermal evaporation, usually employ high temperatures to remove water. However, heat can cause undesirable changes in the product sensory and nutritional properties, such as color and flavor changes, and reduction in the nutritional value. Membrane concentration processes are alternatives to thermal evaporation. They are able to concentrate juices at room temperature, causing little or no damage to the product.

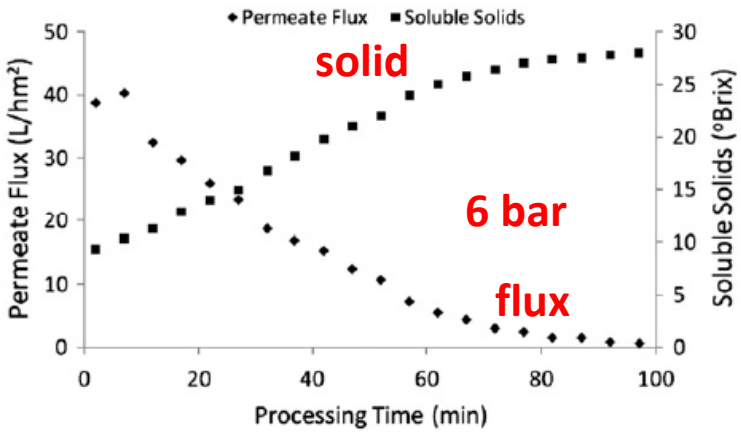
Concentrating apple juice using reverse osmosis

Juices are concentrated in 3-4 times.

Physico-chemical characteristics of apple juice

Analysis	Feed	Reverse osmosis
pH	3.83[a]	3.79[b]
Soluble solids (°Brix)	8.7[c]	28.1[b]
Total solids (g kg^{-1})	92.2[c]	291.1[b]
Titratable acidity (g kg^{-1})	20.2[c]	64.4[b]
(g kg^{-1} dry matter)	219.1[a]	221.2[a]
Total phenolics (mg GA kg^{-1})	495.3[c]	1393.7[b]
(mg GA kg^{-1} dry matter)	5372.0[a]	4787.7[b]
Antioxidant activity (mmol TE g^{-1})	5.9[c]	13.2[b]
(mmol TE g^{-1} dry matter)	57.4[a]	45.3[b]

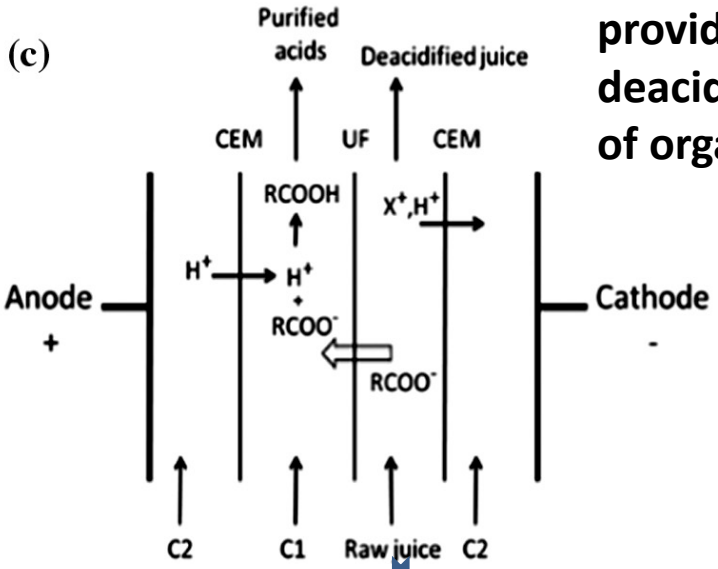
Permeate flux and content of solids in apple juice



ELECTROMEMBRANE PROCESSES FOR PH CORRECTION.

Example. Cranberry juice deacidification

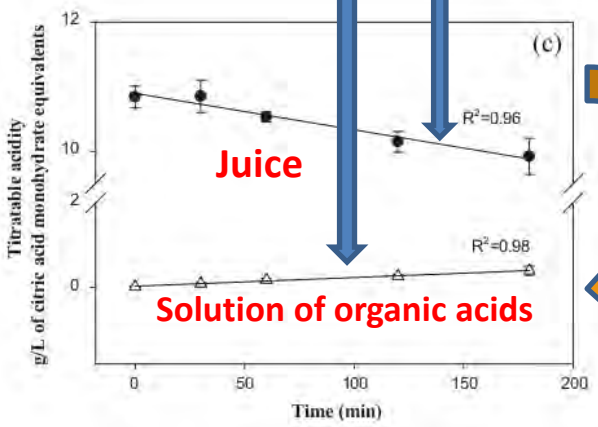
Ion transport through membranes



Advantage. The method provides not only juice deacidification, but also recovery of organic acids.

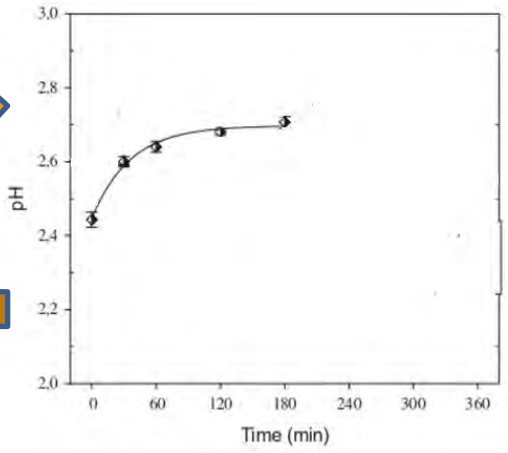
Several configuration of membrane system are used. The system can involve cation-exchange, anion exchange, bipolar membranes, as well as a membrane, which possesses no ion exchange properties, for instance, ultrafiltration separator.

Disadvantage. Low efficiency of the method. Theoretically it is possible to intensify the process by increasing current. In this case, juice is acidified, since migration of H^+ ions from the concentrating compartment to "juice" compartment is more intensive.



Change of total acidity

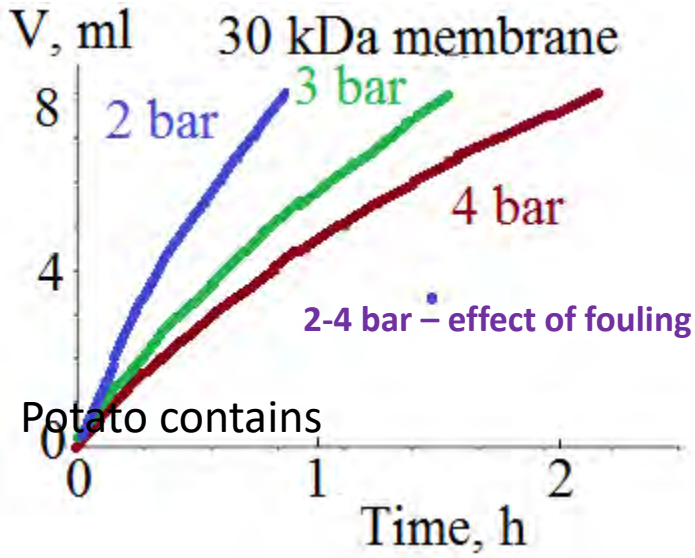
Change of pH

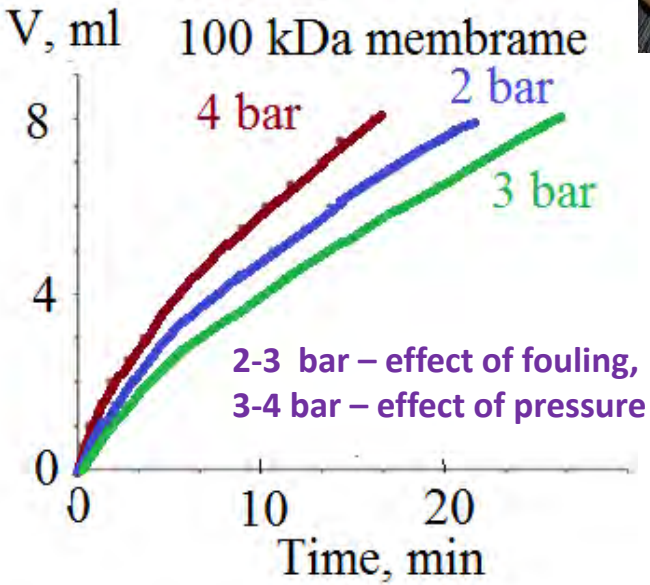


SEPARATION OF PROTEINS FROM POTATO JUICE

Potato's protein (patatin, 39-45 kDa) is effective for muscles, it supports the body's metabolism and lowering blood pressure. One medium-sized potato contains about 4 g of protein (2.2 g/100 g) and 80% of liquid.

Effect of membrane material on filtration of potato juice





Potato contains

Fouling of the membrane with smaller pores (30 kDa) enhances with increasing pressure (from 2 to 4 bar). Regarding the membrane with larger pores (100 kDa), the eggects of both pressure and fouling are expressed.

Recovery of proteins from potato juice

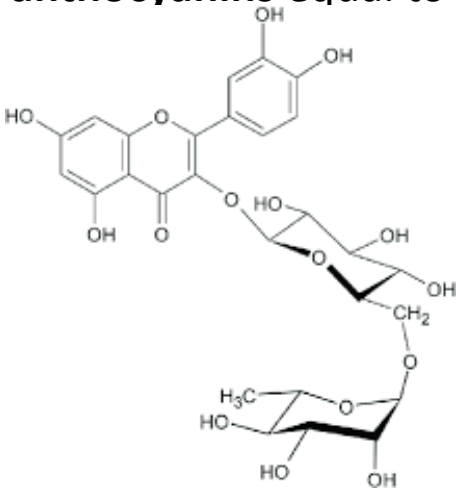
	Feed	100 kDa		30 kDa	
		Permeate	Concentrate	Permeate	Concentrate
Protein, μg ml^{-1}	535	420	830	5	1010

MEMBRANE TREATMENT OF OLIVE RESIDUES

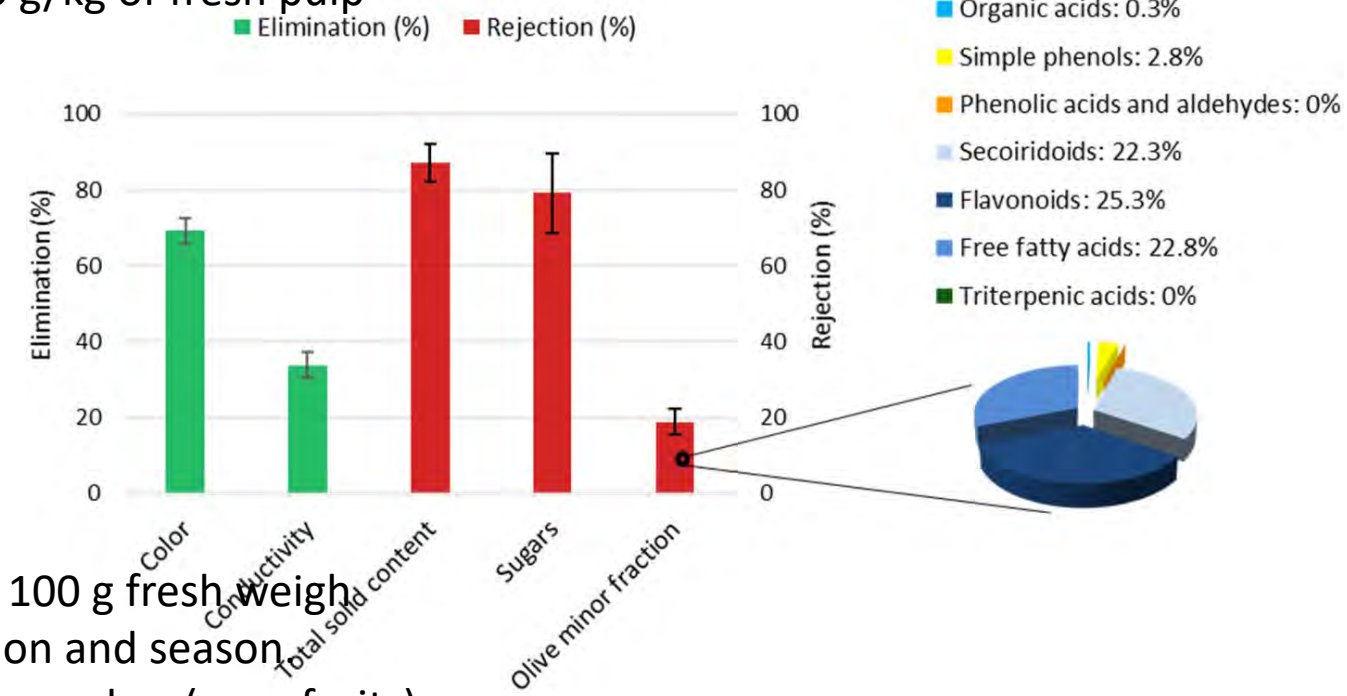
Recovery of anthocyanines

The biophenols and other compounds present in the olive derived products are associated with effective antioxidant properties. Their antiaging effect and their associated prevention against cardiovascular diseases and neoplasia processes have also prompted a high interest in applying these bioactive compounds in the pharmaceutical and cosmetic fields.

anthocyanins equal to 1.25 g/kg of fresh pulp



Que-3-rutinoside



Its content is 24-93 (mg per 100 g fresh weigh

Depebding on the kind, region and season

The maximal content is in December (rupe fruits)

AFFINE ULTRAFILTRATION. METHOD FOR ENZYME PURIFICATION

World market of technical enzymes

12 billions USD (2022) only for technical enzymes

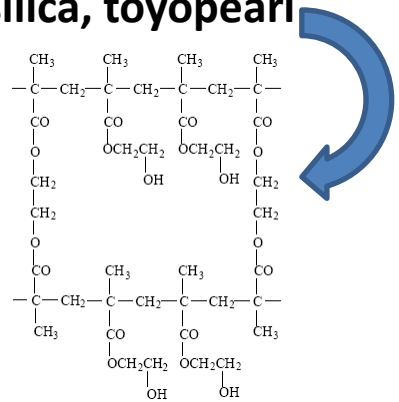
Requirements for enzymes

- **Selective concentrating of the target protein being purified in one phase, additions must be in the second phase,**
- **Mechanical separation of two phases,**
-**Recovery of the target protein from the enriched phase,**
-**Regeneration at least one of the phase for repeated usage.**

Solution of problem

Affinity chromatography- is a separation method based on a specific binding interaction between a immobilized ligand, which is attached to solid (immobile phase), and protein.

Adsorbent matrix – silica, toyopearl



Ligands – The ligands used in affinity chromatography are obtained from both organic and inorganic sources. Examples of biological sources are serum proteins, lectins and antibodies. Inorganic sources are moronic acid, metal chelates and triazine dyes.

AFFINE ULTRAFILTRATION. METHOD FOR ENZYME PURIFICATION

Disadvantage of affine chromatography

Too expensive for industrial application

The adsorbents containing ligands can be unstable

Solution of problem is affine ultrafiltration

Affinity-membrane separation is based on the ability of many biologically active compounds, including enzymes, to selectively and reversibly bind with some substances, which are commonly called ligands or affinity ligands.

Ligands can be high-molecular water-soluble polymers or small solid particles (starch granules, inactivated yeast cells, etc.), which can be easily separated from unbound proteins by ultra- or microfiltration.

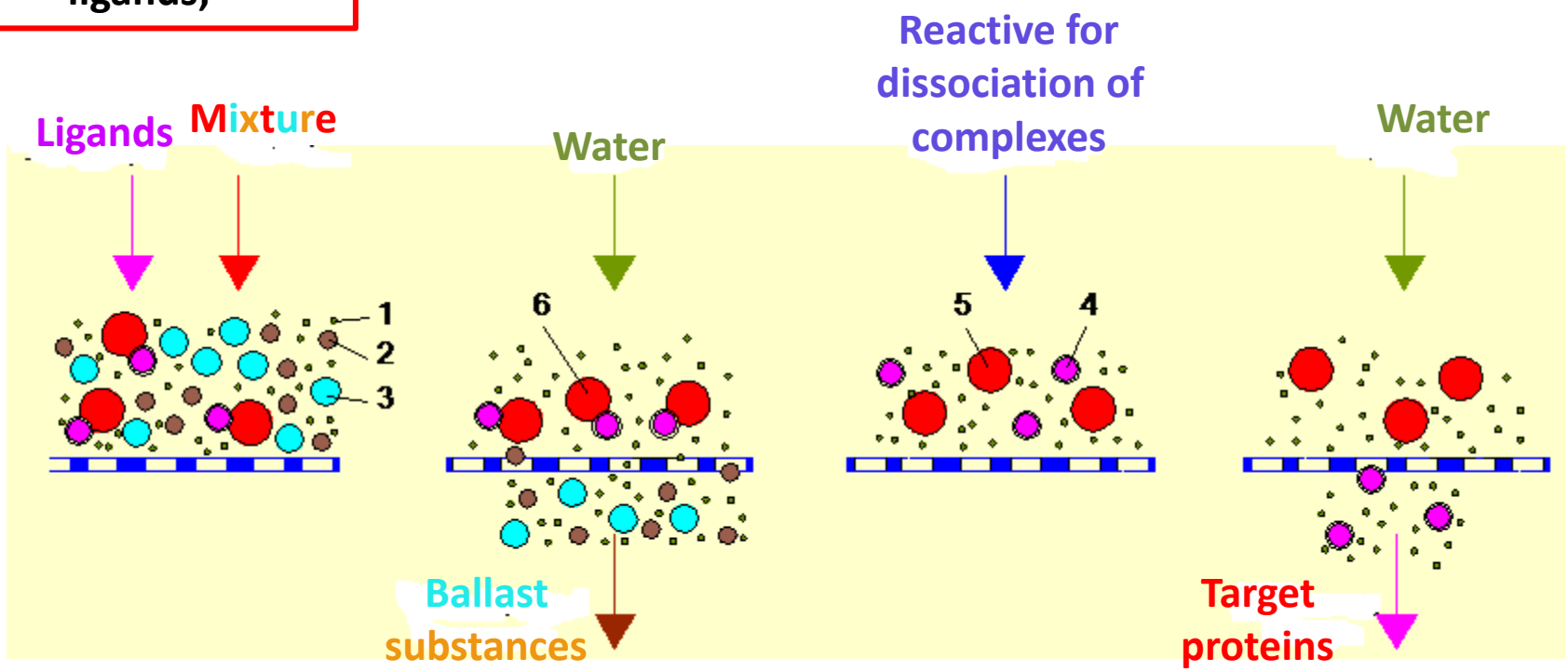
PRINCIPLES OF AFFINE ULTRAFILTRATION.

– Insertion of ligands into the mixture and formation of complexes of target proteins with ligands;

– Diafiltration: Washout of ballast compounds from the mixture with water

– Dissociation of complexes

– Separation of target proteins from ligands



EXAMPLE OF AFFINE ULTRAFILTRATION

Ultrafiltration of urokinase from human urine

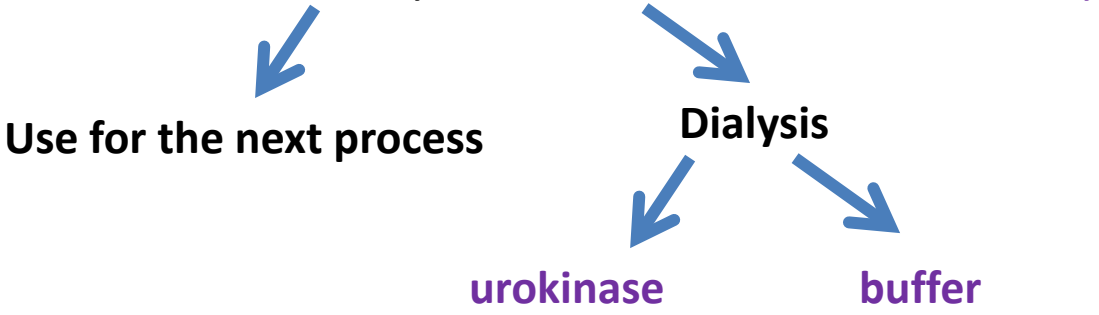
1. Bonding the enzyme with polymerized N-acryloyl-rn-aminobenzamidine.

2. Destroying the complex with a buffer containing 0.1 M NaCl and 0.1 M benzamidine. Ultrafiltration of the mixture simultaneously with washing out of ballast substances. The membrane of 100 kDa cut-off was used;

Permeate – urokinase+ buffer, concentrate – ligand + buffer+ballast

3. Ultrafiltration of the permeate. The membrane of 10 kDa cut-off was used; Per

Permeate – buffer, concentrate – urokinase + buffer;



ADVANTAGES OF AFFINE ULTRAFILTRATION

The possibility of purification of target protein products from all ballast impurities without exception;

Intensification of the process of isolation and purification of protein products;

The possibility of highly efficient continuous purification of protein products in a on an industrial scale;

Shortage of technological stages;

Lower consumption of chemical reagents;

Increase in the yield of target protein products.

DISADVANTAGE OF AFFINE ULTRAFILTRATION

Perhaps the only difficulty in the implementation of affinity ultrafiltration is the need for individual selection of a ligand for a specific protein product and determination of the conditions for complexation and dissociation of complexes.

SEPARATION OF IMMUNOGLOBULIN FROM EGG YOLK BY ULTRAFILTRATION

EGG YOLK IS A GOOD SOURCE OF SPECIFIC ANTIBODIES, which may be used in therapy. For the wide utilization of yolk immunoglobulin (IgY), a large-scale production of IgY with high purity and recovery from egg yolk is necessary. Such separation process should be simple and economical requiring few chemicals for food applications.

Isolation of immunoglobuline

1. **Diluted with water →filtration .**

water soluble fraction

2. **Purification using a freezing-thawing method,**
3. **Alkalization up to pH 9,**
4. **Ultrafiltration.**

These procedures yielded 74-99% pure immunoglobuline with 72-85% recovery.

MEMBRANE TECHNOLOGIES FOR WINE PRODUCTION

Average composition of wine

Components	Concentration, g l^{-1}		
Water		750-900	
Ethanol		69-121	
Glycerol		5-20	
Organic acids		3-20	
Minerals		0.6-2.5	
Nitrogen (amino-acids, proteins)		0.5-5	
	White wine		Red wine
Phenolic compounds	0.1-0.3		1.5-6
Polysaccharides		0.4-0.7	

Wine colloids

Polyphenols, polysaccharides, proteins.

Red wine

Anthocyanins, tannins.

White wine

Hydroxycinnamic acids

Polysaccharides

Grape polysaccharides: pectins, pectin substances,
Yeast polysaccharides,
Fungi polysaccharides: beta-glucan.

Wine proteins

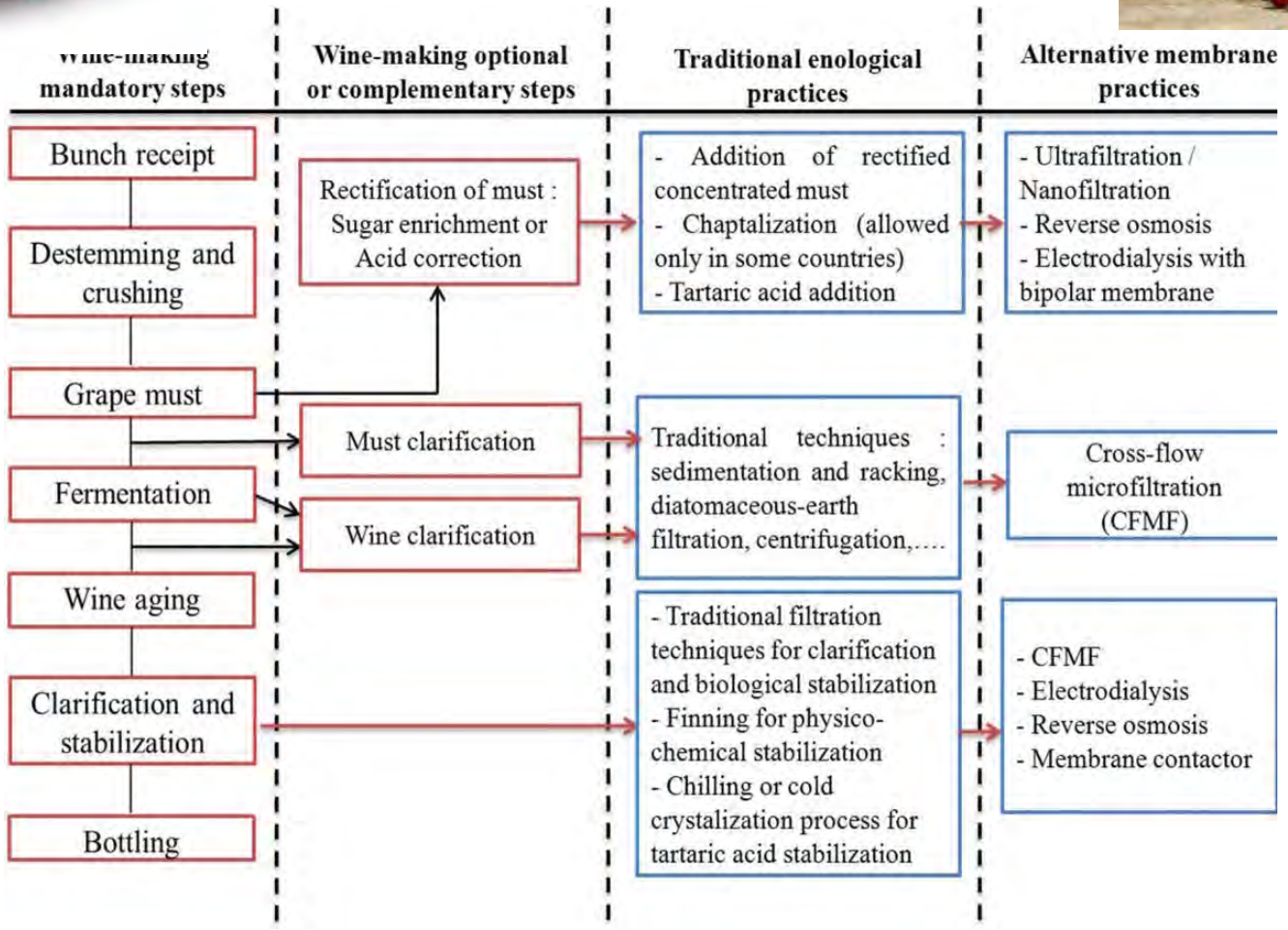
Grape proteins and minor extent proteins from autolyzed yeast 10–500 mg/l).

Tasks of filtration

In the overall production process, wine filtration is used to decrease turbidity and improve microbiological stabilization. Turbidity is due to macromolecules and particles in suspension

MEMBRANE TECHNOLOGIES FOR WINE PRODUCTION

Stages of wine production: with and without membranes



MEMBRANE TECHNOLOGIES FOR WINE PRODUCTION

Grape Must (mosto) Concentration

Must is freshly crushed fruit juice (usually grape juice) that contains the skins, seeds, and stems of the fruit.

Methods

Reverse osmosis, nanofiltration

Pretreatment

Removal of solids

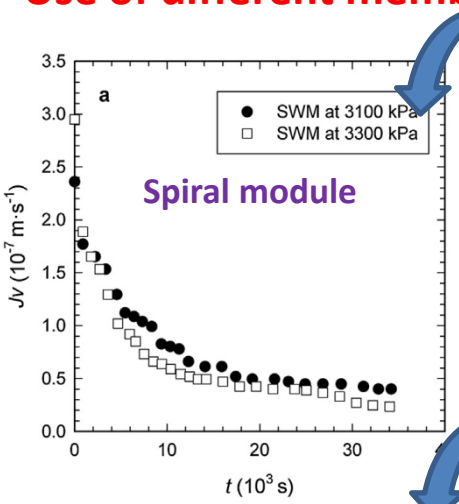
Comparison of two methods

40 bar → NF

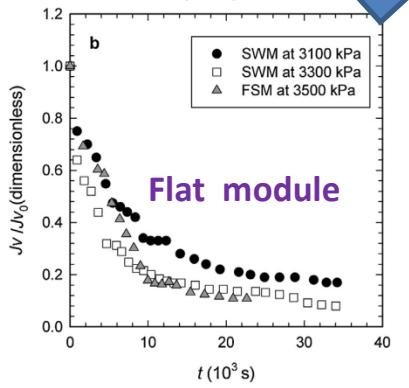
70 bar → RO

Parameter	Unit	Wine enriched by[a] NF	RO
Alcohol	% vol	11.9	11.9
Dry extract	$g\,l^{-1}$	23.2	21.6
Reducing sugars	$g\,l^{-1}$	0.7	0.6
Ashes	$g\,l^{-1}$	2.35	2.20
Alcalinity	$meq\,l^{-1}$	8.5	8.2
pH	—	3.14	3.09
Titrable acidity	$g\,l^{-1}$	6.5	6.2
Tartaric acid	$g\,l^{-1}$	2.15	2.20
Malic acid	$g\,l^{-1}$	4.10	3.90
Total polyphenols	$mg\,l^{-1}$	129	94
DO at 420nm	AU	0.11	0.09
Sulphates	$mg\,l^{-1}$	40	41

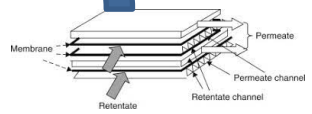
Use of different membrane modules



Spiral module



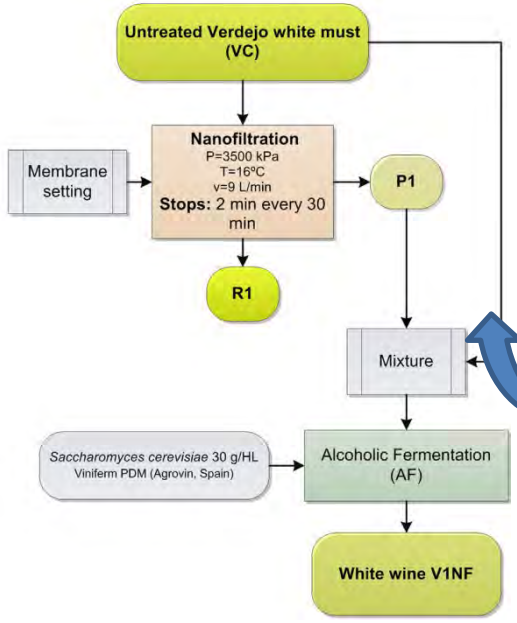
Flat module



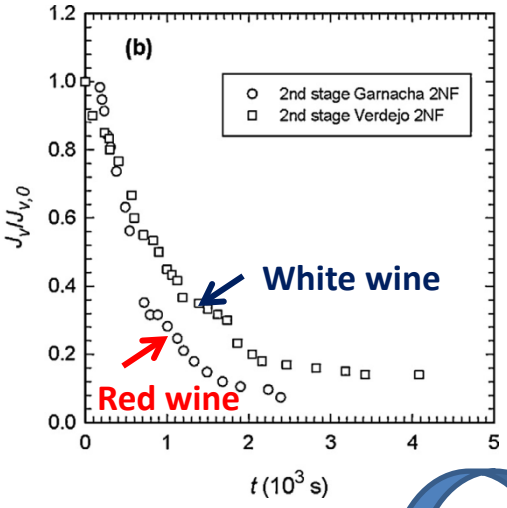
Spiral module is preferable due to optimal hydrodynamic conditions.

REDUCING ALCOHOL CONTENT. REMOVAL OF SUGARS FROM THE MUST

An excess of alcohol must be removed from the must, since it complicates fermentation. Meanwhile, consumers show preference and demand wines with less alcohol content (between 9 and 13%). The way to reduce the content of alcohol is to decrease the sugar content from the must.



Scheme of grape treatment



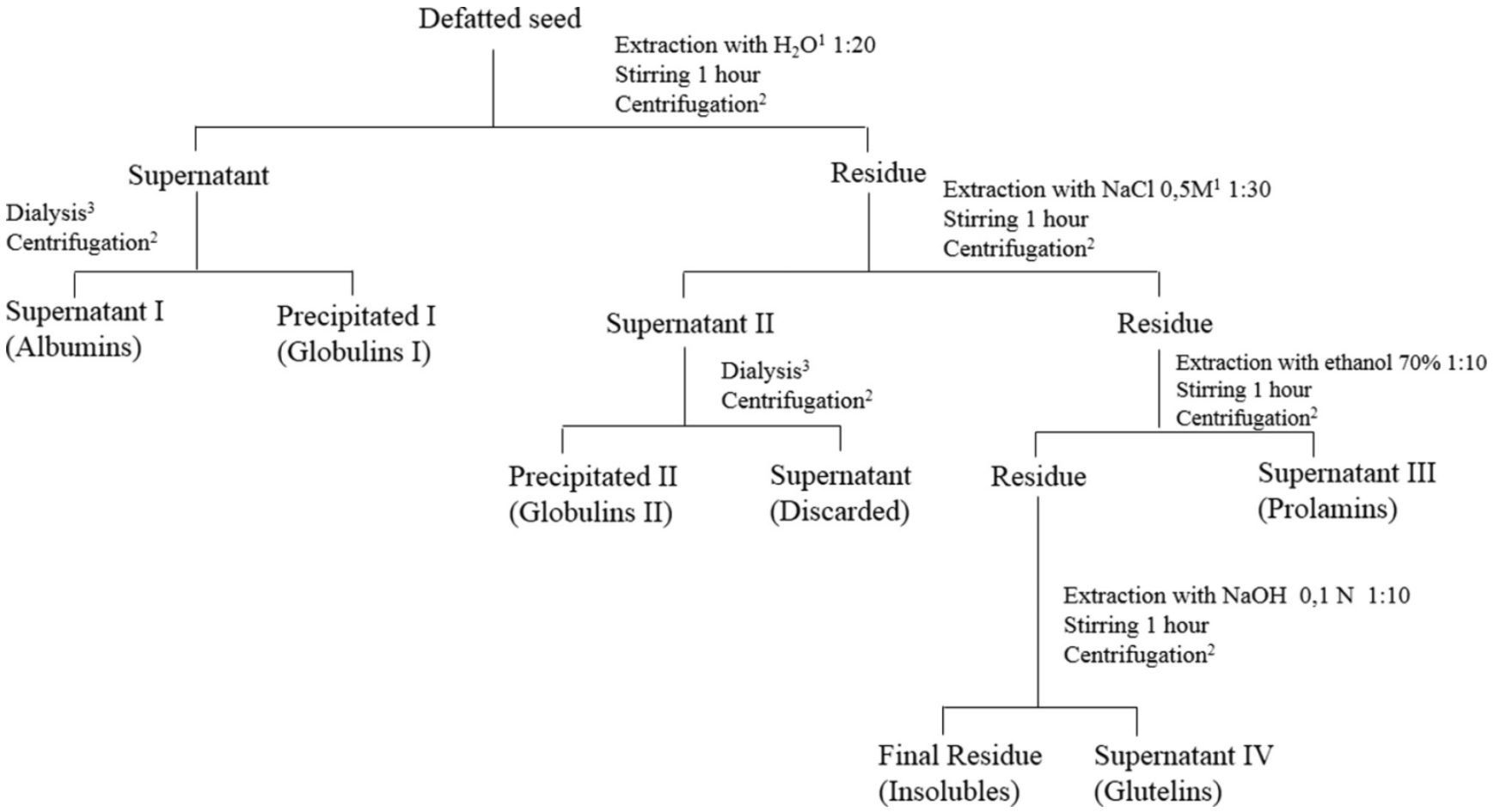
Flux as a function of time

Initial and final content of components in wine

Component	Red grape			White grape		
	Initial must	Must after NF	Wine	Initial must	Must after NF	Wine
Glucose (g/L)	105	90		117	105	
Fructose (g/L)	106	93		120	106	
Alcoholic degree , %	12.5	10.9	11	13.9	12.5	14
Anthocyanins (mg/L)	371		278	4.4		2.2

PROTEIN FRACTIONATION OF SEEDS OF MORINGA OLEIFERA

The extract of the seeds of Moringa oleifera is recommended as a coagulant for water treatment. the concentration 0.2 lg/lL of
Moringa oleifera seed extract recommended to treat water for humans



ULTRAFILTRATION FOR BEER PRODUCTION

MALT

Malt is germinated cereal grain that has been made by soaking in water and dried under elevated temperature or roasted.

Separation of flavor from color by ultrafiltration

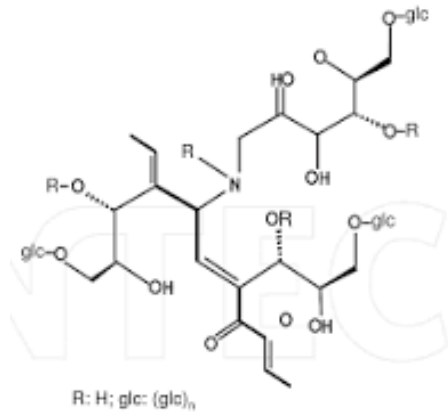
MALT treatment

Speciality Malt
↓
Mill
↓
Aqueous Extraction
↓
Ultrafiltration

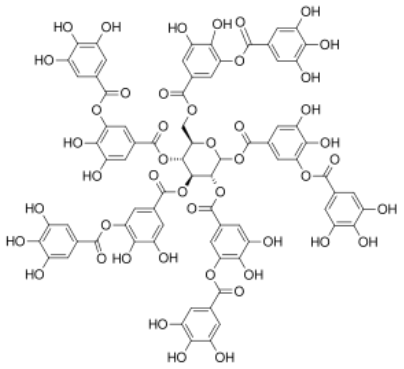
Low MWt Flavor Extract — **1 kDa**

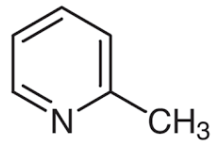
High Mwt Color Extract — **10-100 kDa**

Color is due to polyphenols and melanoidines

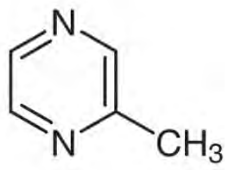


Melanoidine





2-methylpyridine



2-methylpyrazine

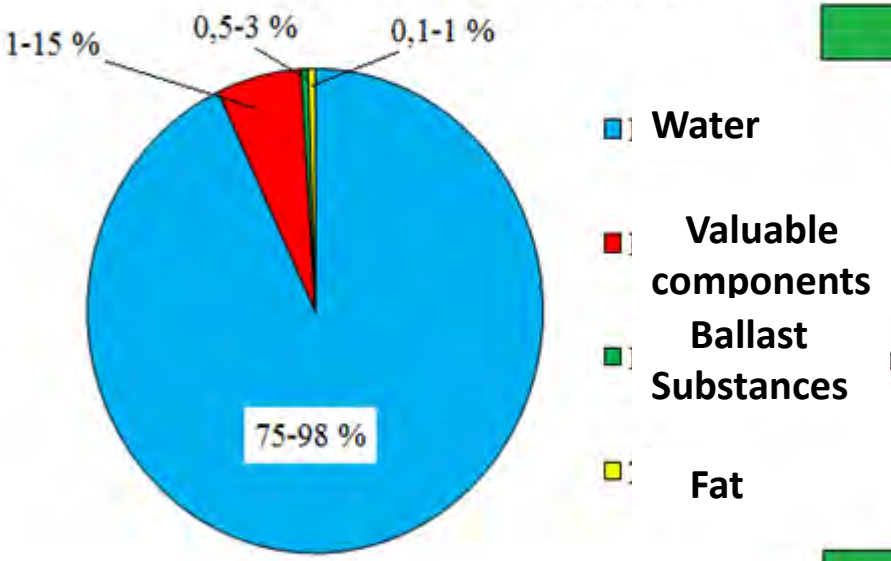
Flavor compounds

Compound	Flavor	Color
2-Methylpyridine	100	0
2-Methylpyrazine	98	2
2,5-Dimethylpyrazine	94	6
2-Ethylpyrazine	80	20
2,3,5-Trimethylpyrazine	98	2
Maltol	98	2

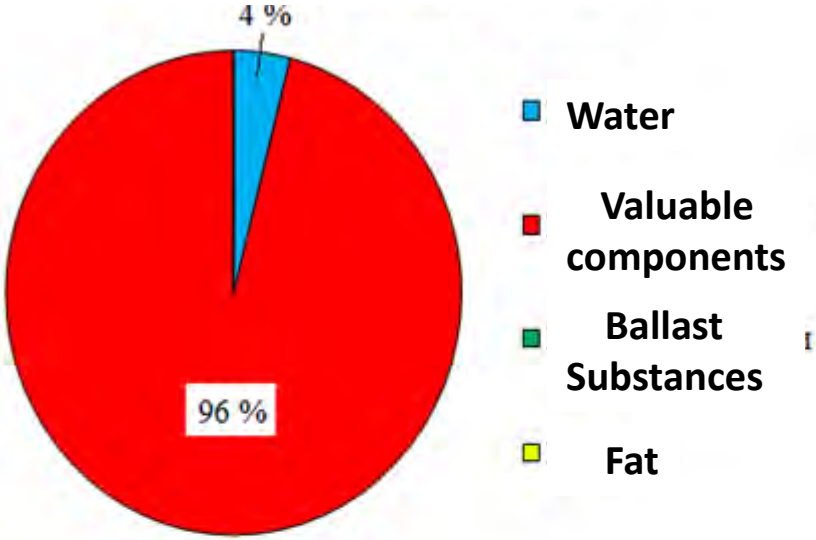
Further the extracts are used for the enhancement of glavor and color.

Solution→Dry product

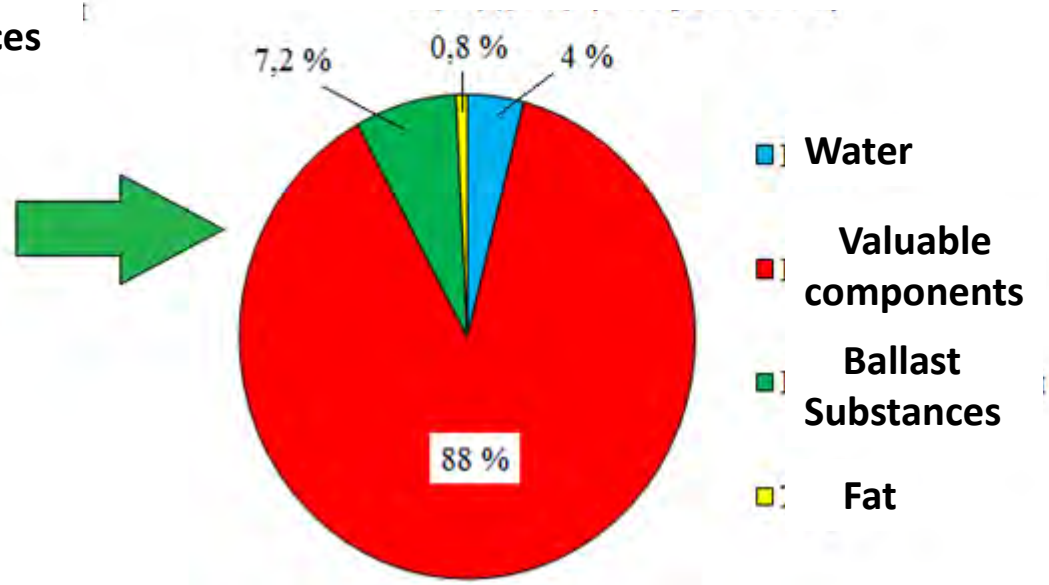
Average values of the composition of solutions In food industry



Ideal composition of the target dried product



Real composition of values of the target dried product



DIAFILTRATION

Liquid of biological origin

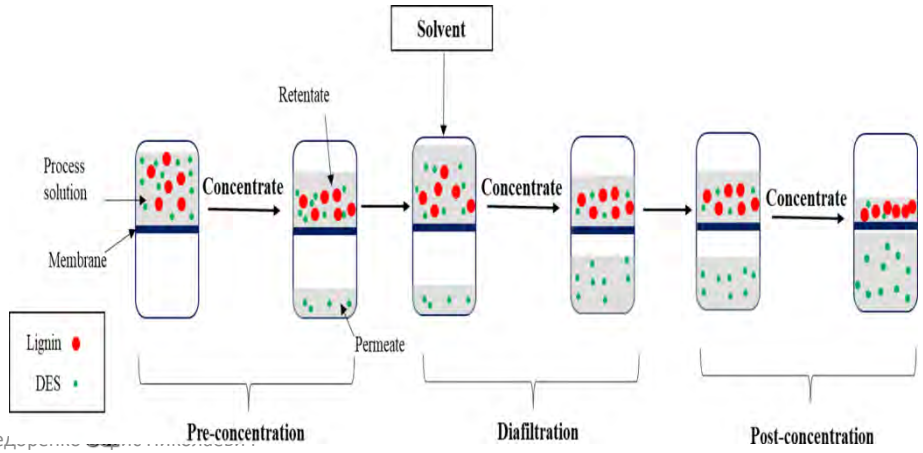
Valuable product
(High-molecular compounds)

Ballast substances
(low-molecular compounds)

Similarly to electrodialysis, DIAFILTRATION allows us to remove ballast (low-molecular) substances.

Diafiltration is the membrane filtration, which involves dilution of concentrate with deionized water. Simultaneously with the removal of permeate from the solution being purified, water is added to the concentrate. Ballast low-molecular compounds are washed from the concentrate by this manner.

Separation over diafiltration is based on different selectivity of membranes to highly- and low-molecular compounds. Membrane rejects highly-molecular compounds, low-molecular compounds are passed through the membrane to the permeate



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EXAMPLE OF DIAFILTRATION

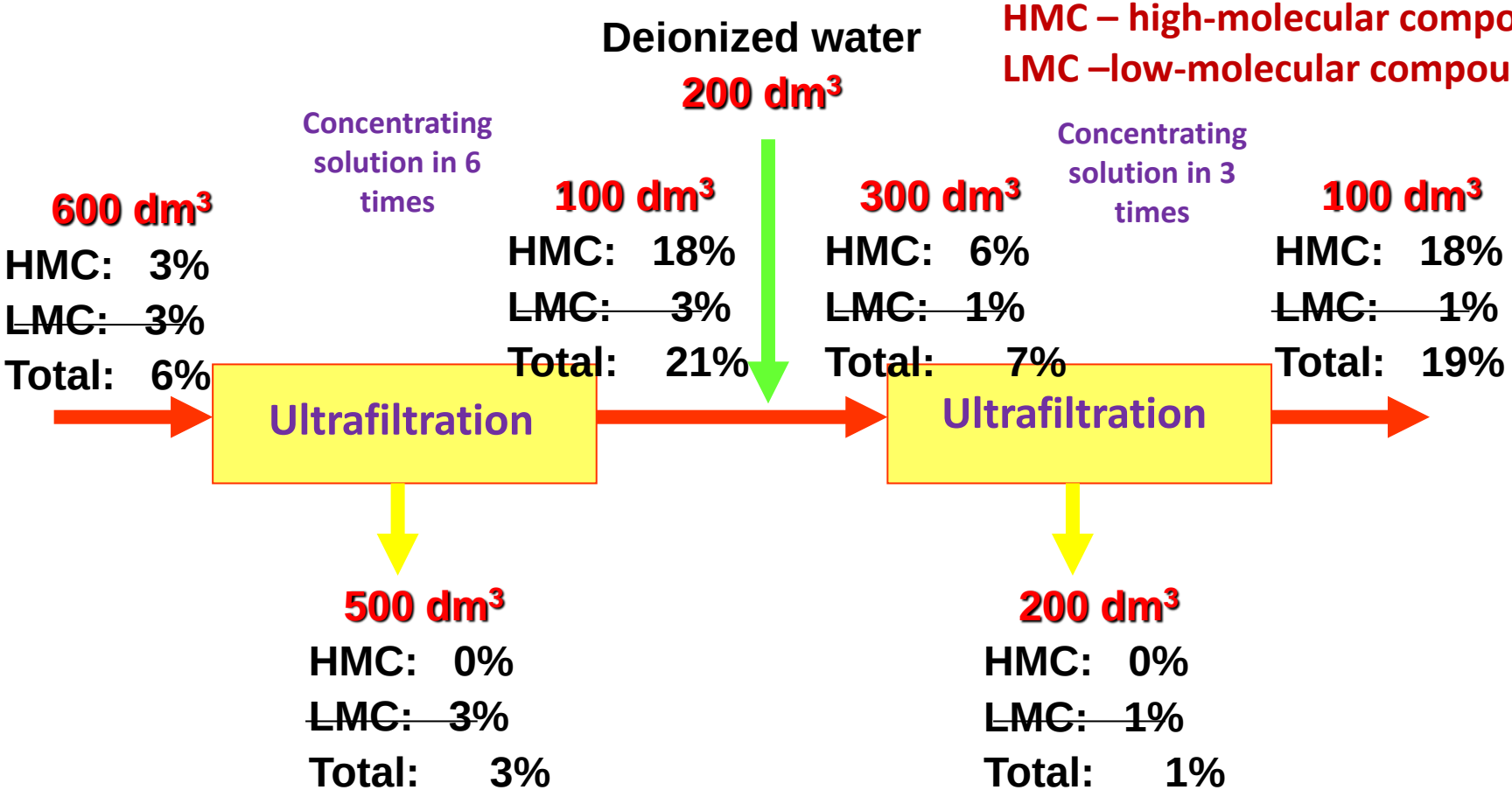
(for ideal membrane system)

Ideal membrane, Ideal apparatus; No fouling

The parameter, which reflects the efficiency of diafiltration Is the ratio of the contents of ballast compounds in the HMC solution before and after the process. This ratio is 3 for the example.

Other parameters are the ratios of concentrations of HMC and LMC before and after the process. These ratios are 3 (before) and 18 (after).

HMC – high-molecular compound, LMC –low-molecular compound.

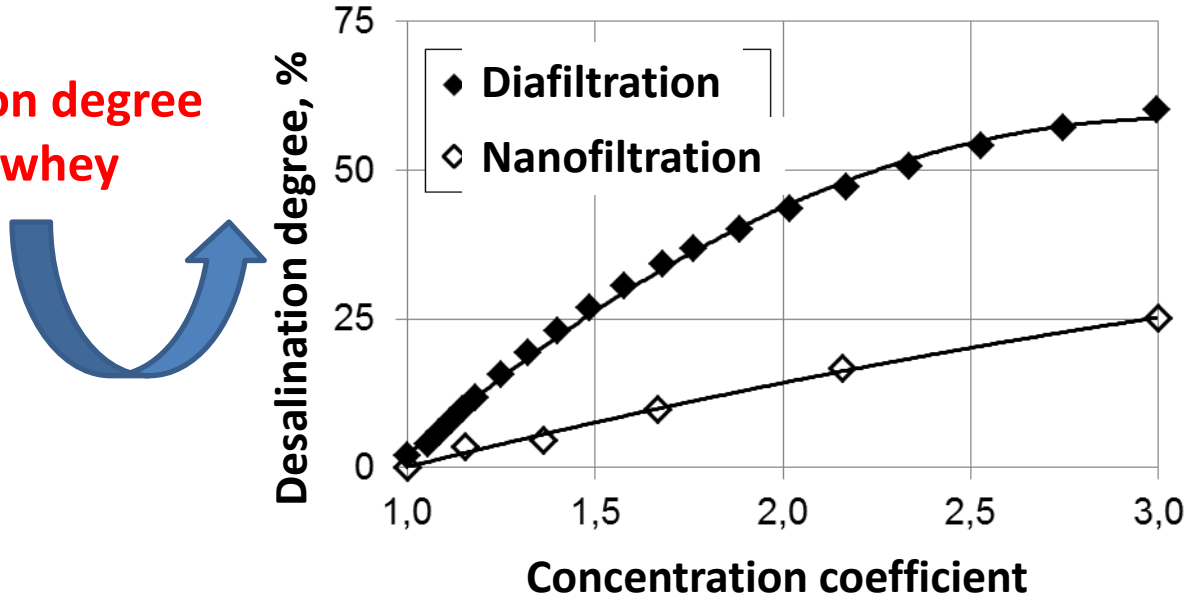


TECHNOLOGICAL POSSIBILITY OF DIAFILTRATION

- **It is possible to purify high-molecular compounds only from low-molecular additions, molecular mass of which is sufficiently different (the order of magnitude) from the molecular mass of high-molecular compounds (target product).**

- **High-molecular ballast additions are also concentrated over diafiltration. In other words, it is impossible to remove them using this method.**

Desalination degree of milky whey



COMPARISON OF DIFFERENT SEPARATION METHODS

Desalination of milky whey

Parameter	Nanofiltration	Diananofiltration	Electrodialysis
Demineralization, %	25-30	50-60	50-60
Energy consumptions, kW m^{-3}	5,2	15,6	3,4-4,2
Water consumptions, m^3 m^{-3}	-	1,5-3	Closer to 0,5
Concentrating dry substances	in 2.5-3.5 times	in 2,5-3,5 times	-
Lactose losses, %	2-4	6-8	3-4
Losses of lactic acid, %	до 10	*20-30*	33-45

Problems of diafiltration. What is unknown?

The efficiency of diafiltration depends on a number of conditions:

- **The composition of the solution being desalinated?**
- **What is a volume of the solution before adding water?**
- **What is a volume of deionized water?**
- **And so on…**

.

MEMBRANE SEPARATION IN DAIRY INDUSTRY

Composition of cow milk

	Concentration in whole milk (g/L)	Size range and average (at weight average
Water	87.1	
Fat globules	4.0	0.1–15 μm, average 3.4 μm
Casein (in micelles)	2.6	20–300 nm, average 110 nm
Serum proteins	0.7	3–6 nm
α-lactalbumin	0.12	14 kDa
β-lactalbumin	0.32	18 kDa
BSA	0.04	66 kDa
Proteose-peptone	0.08	4–40 kDa
Immunoglobulins	0.08	150–900 kDa
Lactoferrin	0.01	86 kDa
Transferrin	0.01	76 kDa
Others		
Lactose	4.6	0.35 kDa
Mineral substances	0.7	
Organic acids	0.17	
Other		

Membrane processes for needs of dairy industry

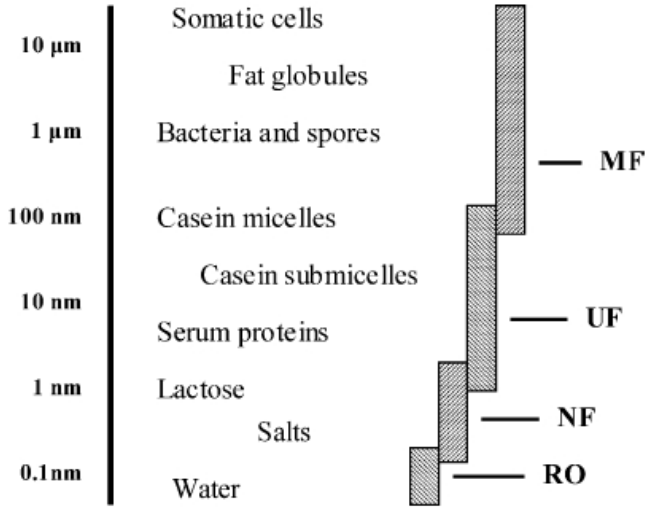
Removal of Bacteria and Spores from Skim Milk (Cold Pasteurization)

Separation of Casein Micelles from Soluble Proteins

Separation and Fractionation of Fat Globules from Whole Milk

Concentration and Demineralization of Whey and Milk Ultrafiltration Permeate

Fractionation of Whey Proteins

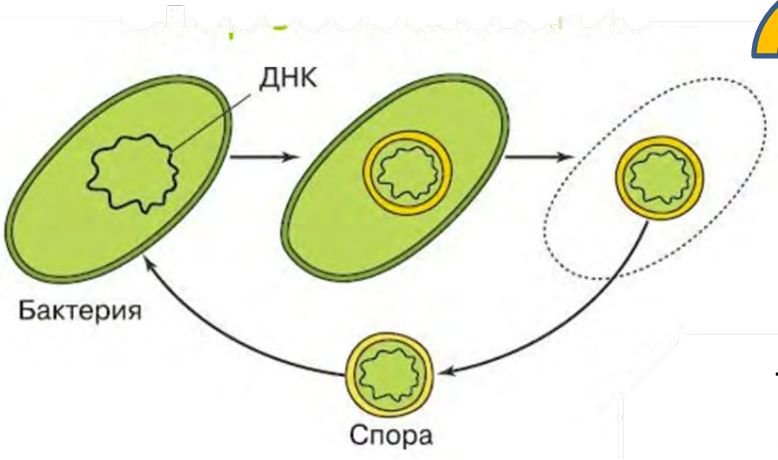


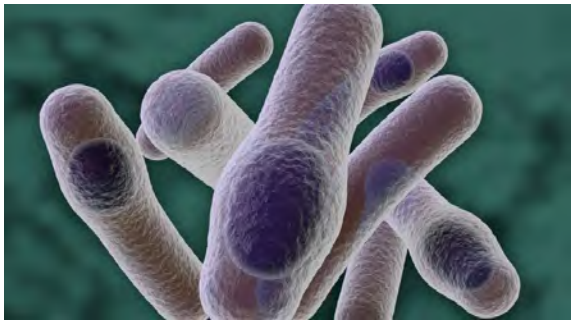
REMOVAL OF BACTERIA AND SPORES FROM SKIM MILK (COLD PASTEURIZATION)

Removal of pathogens from milk

Collected milks by the dairy plant present the risk of containing pathogenic bacteria for human such as *Listeria, Brucella, Mycobacterium, or Salmonella.* Therefore, the reduction of bacteria and spores has to be achieved, without changing the functionality of the milk proteins, especially when the milk has to be used for cheese production. The growth of unwanted bacteria and spores can spoil the cheese by a late blowing during ripening.

Spore formation





A **spore** is a dormant stage in which the **bacterium** can survive despite unfavourable external conditions.

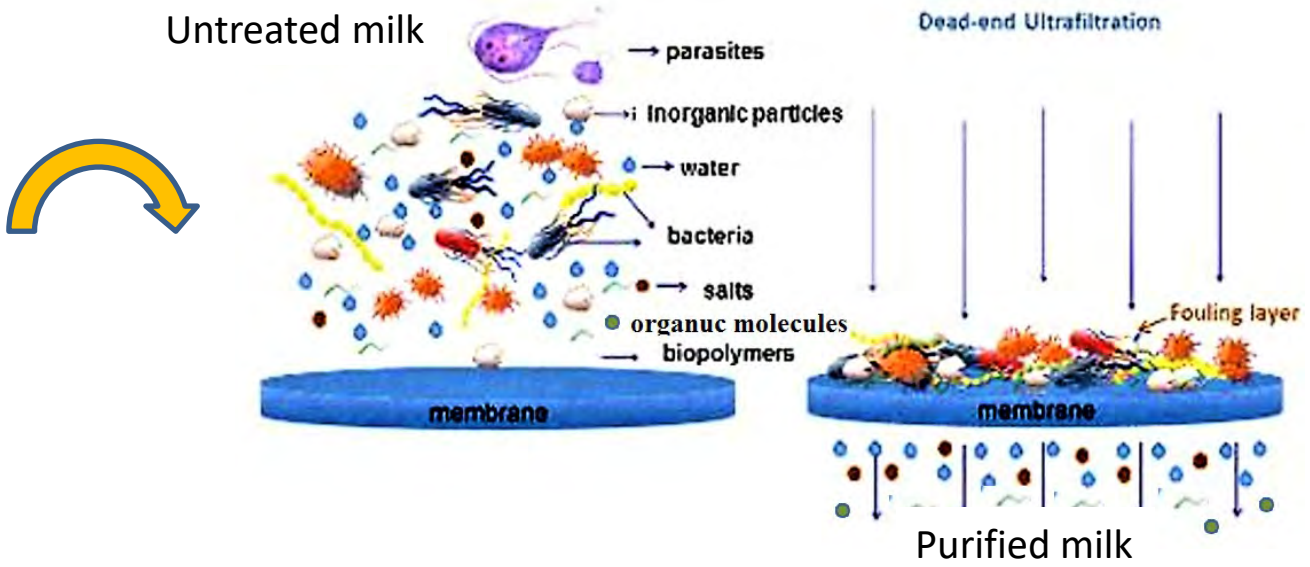
As opposed to plant or fungi, bacteria **spores are only for survival,** not for reproduction.

REMOVAL OF BACTERIA AND SPORES FROM SKIM MILK (COLD PASTEURIZATION)

Typical pathogens in skim milk

Species	Size, nm	Method	Pressure, bar
Helminth eggs	25000-55000	Macro-, microfiltration	0, 0.5-5
Eukaryotes, (protozoa)	10000-100000	Macro-, microfiltration	0, 0.5-5
Procaryotes (bacteria)	300-10000	Macro-, micro-, ultrafiltration	0, 0.5-10
Bacteria spores	800-1200	Micro-, ultrafiltration	0.5-10

Rejection of pathogens with a membrane



REMOVAL OF BACTERIA AND SPORES FROM SKIM MILK

A commercial MF process for the reduction of bacteria and spores from milk is available under the name Bactocatch (Tetra Laval Co.)

The pressure is about 0.5 bar.

Pore size of 1.2 µm is preferable. Smaller pore size causes casein rejection.

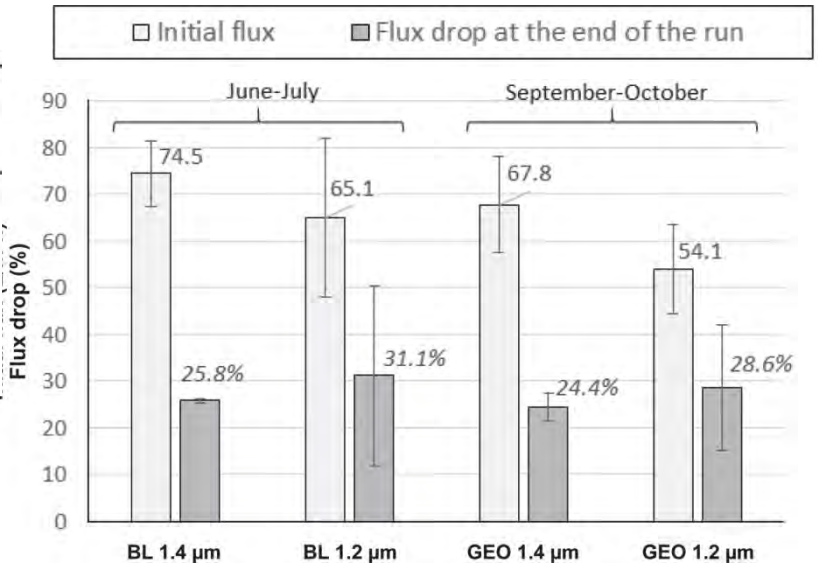
Strategy of fouling control:

To minimize the formation of the fouling layer, high cross-flow velocities (4–8 m/s) or backflushing techniques have to be used.

Removal of bacteria spores

Challenge study	Initial load (log cfu/mL)	After MF (log cfu/mL)
Bacillus licheniformis		
1.4-µm MF membrane	6.11 ± 0.53	3.94 ± 0.13
1.2-µm MF membrane	6.98 ± 0.08	2.41 ± 0.15
Geobacillus sp.		
1.4-µm MF membrane	6.56 ± 0.29	ND[1]
1.2-µm MF membrane	6.38 ± 0.24	ND

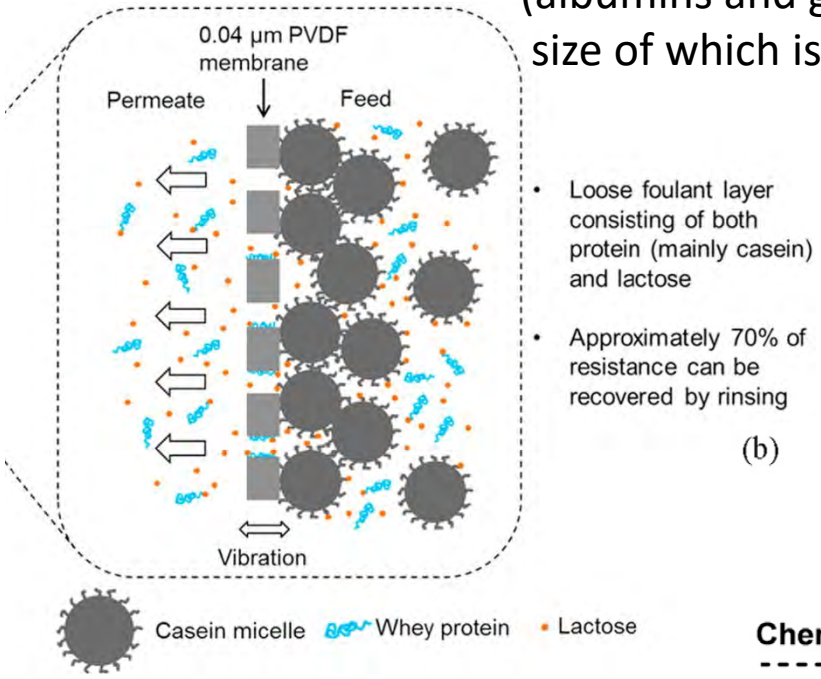
Removal of bacteria spores



Bacillus licheniformis ***Geobacillus sp.***

SEPARATION OF CASEIN MICELLES FROM SOLUBLE PROTEINS

Casein micelles (30-400 kDa) are not in the concentrate, they are deposited on the membrane. Lactose is partially associated with casein. Soluble whey proteins (albumins and globulins) pass through the membrane, the pore size of which is 40 nm.



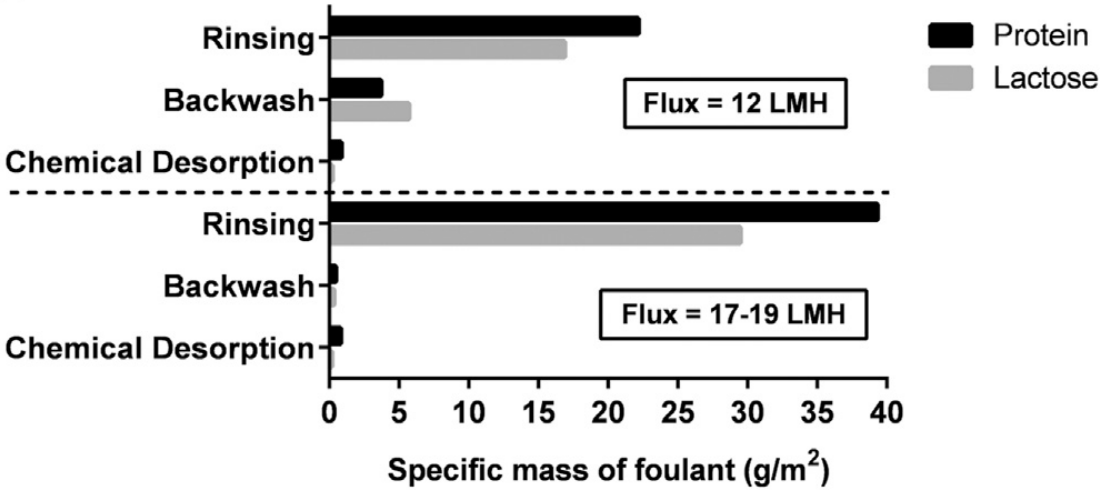
- Loose foulant layer consisting of both protein (mainly casein) and lactose
- Approximately 70% of resistance can be recovered by rinsing

(b)

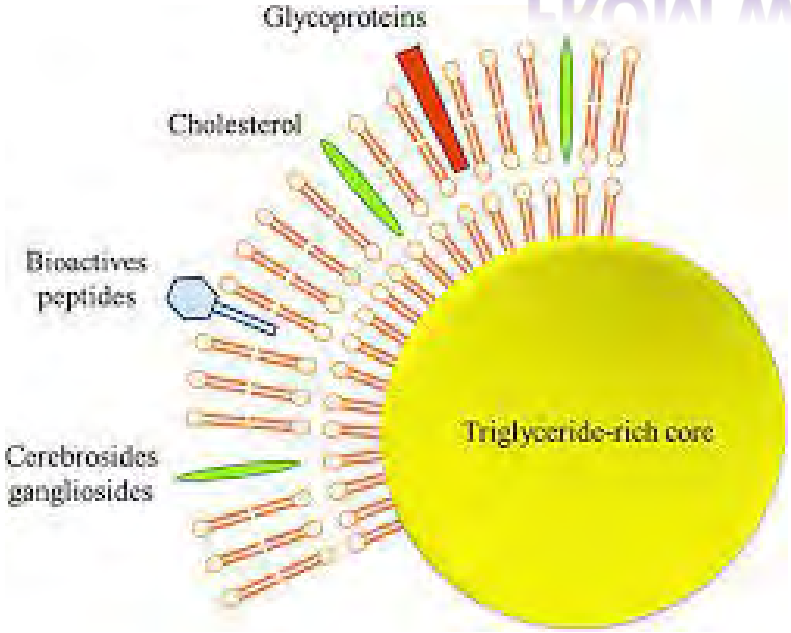
Casein is removed by washing (about 70 %).

Fouling control – vibration of membrane module.

Removal of deposit

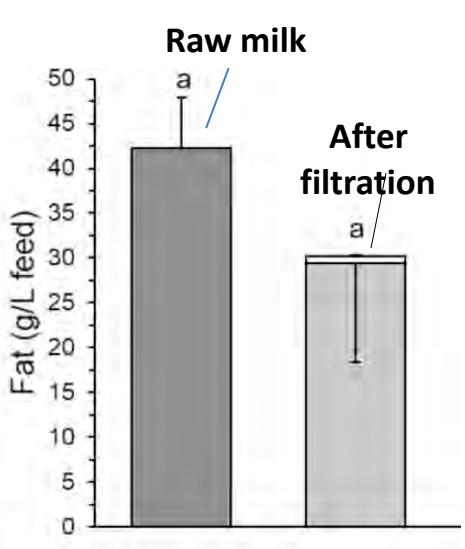


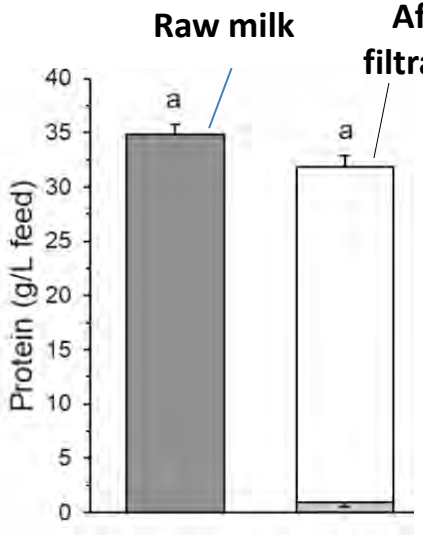
SEPARATION AND FRACTIONATION OF FAT GLOBULES FROM WHOLE MILK



Milk fat mainly consists of dispersed fat globules, with diameter between 0.1 and 15 µm. Their integrity is maintained by a thin membrane surrounding their internal core. The number of fat globules per milliliter is between 10^{10} and 10^{11}.

MF is known for not damaging the fat globules membranes.





Ceramic membranes with pore size of 0.8-1.4 µm were used. Pressure is 0.5 bar.

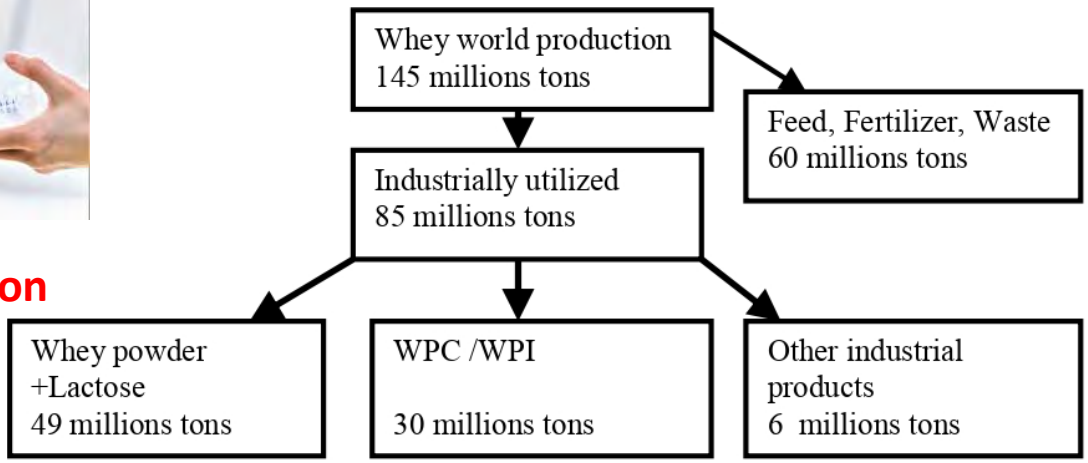
Disadvantage – casein particles are also rejected.

Final product is skimmed milk.

MEMBRANE TREATMENT OF MILKY WHEY

Milky whey in a global scale

Infant nutrition



Sport nutrition

Composition of milky whey

S.No	Constituent	Unit	Sweet whey	Acid whey
1	Water	%	93-94	94-95
2	Dry matter	%	6-6.5	5-6
3	Lactose	%	4.5-5	3.8-4.3
4	Lactic acid	%	traces	up to 0.8
5	Total protein	%	0.8-1.0	0.8-1.0
6	Whey protein	%	0.6-0.65	0.6-0.65
7	Citric acid	%	0.1	0.1
8	Minerals	%	0.5-0.7	0.5-0.7
9	pH		6.4-6.2	5.0-4.6
10	SH Value		about 4	20-25

Source : *www.dairyforall.com*

Mineral composition of milky whey

K – 36 mmol dm^{-3}

Na– 16 mmol dm^{-3}

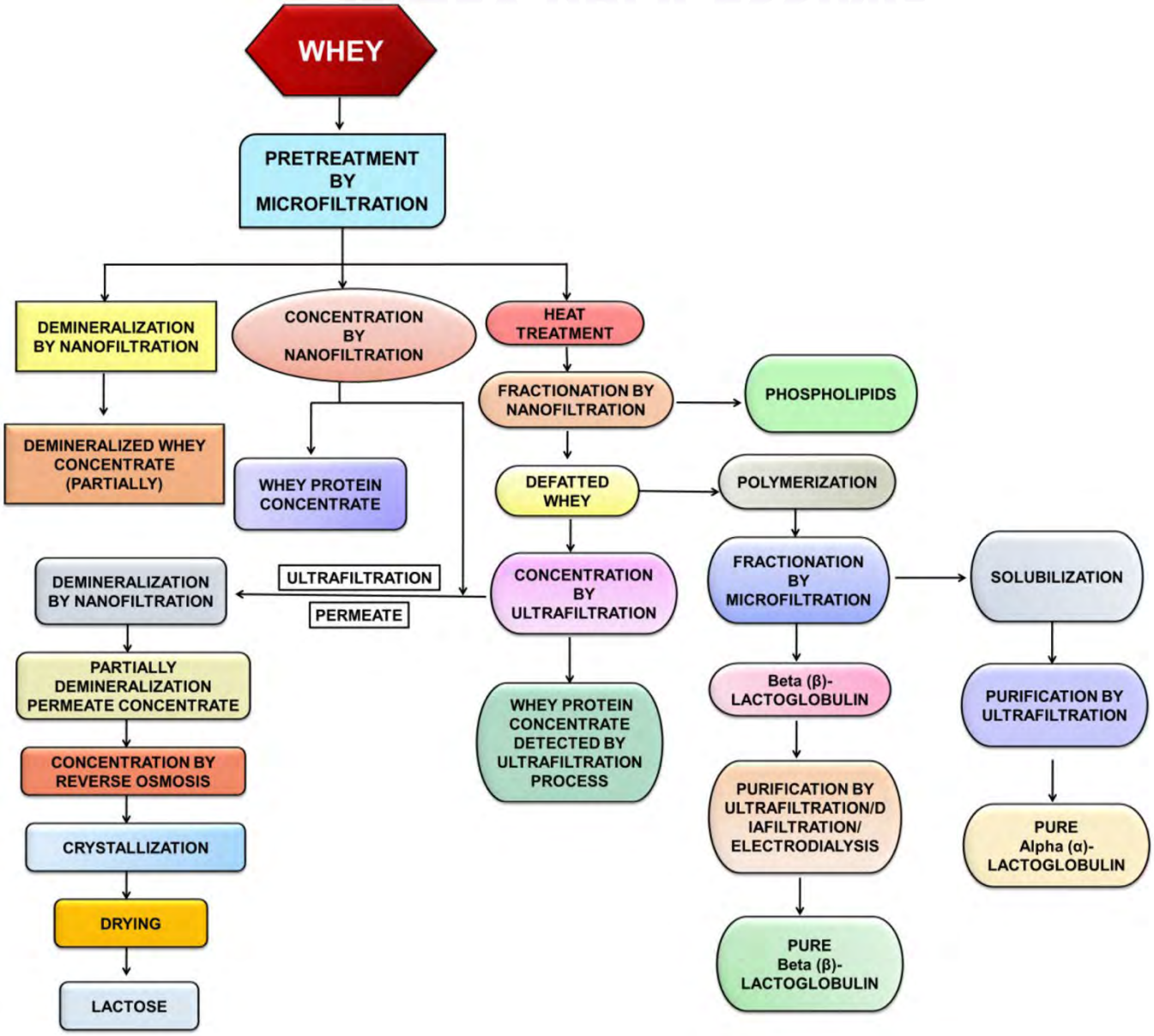
Ca – 24 mmol dm^{-3}

Mg – 4.3 mmol dm^{-3}

P – 30 mmol dm^{-3}

Cl – 51 mmol dm^{-3}

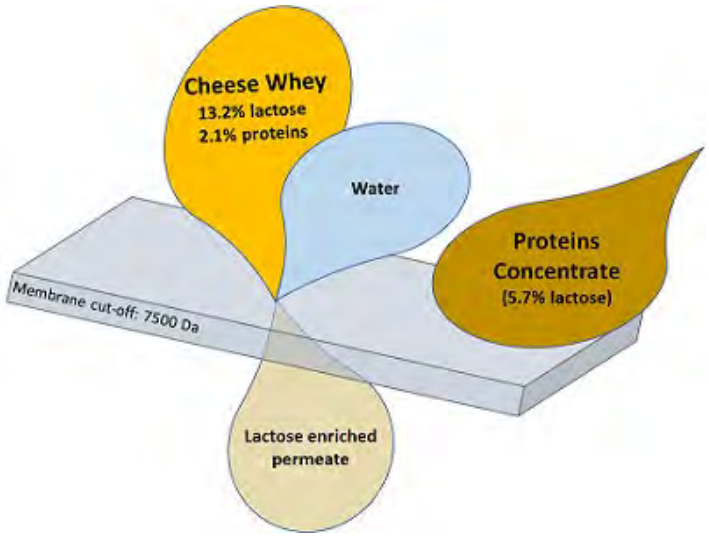
WHEY PROCESSING



WHEY PROCESSING

Ultra- or nanofiltration

Target product is mineralized protein concentrate



Key field of investigations is the development of membranes with antifouling properties.

Modifying microfiltration membranes

- transformation of microfiltration membranes to ultrafiltration separators.

Advantages over microfiltration membranes

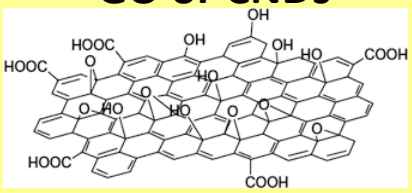
Rejection of colloidal particles.

Advantages over ultrafiltration membranes

Higher mechanical stability.

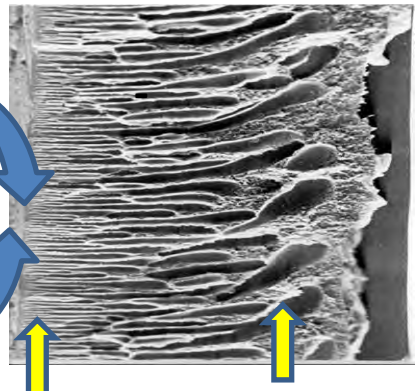
MODIFIER

GO or CNDs

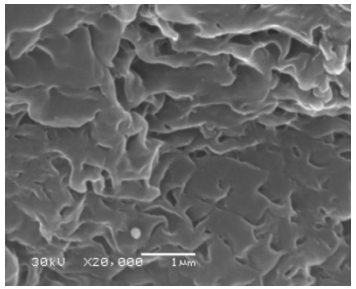


Inorganic ion-exchanger (binder)

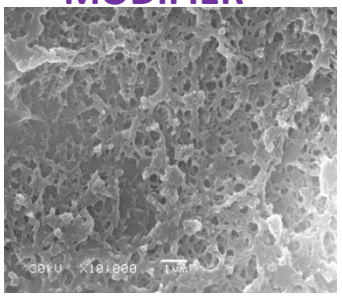
POLYMER FILTRATION MEMBRANE



Active layer



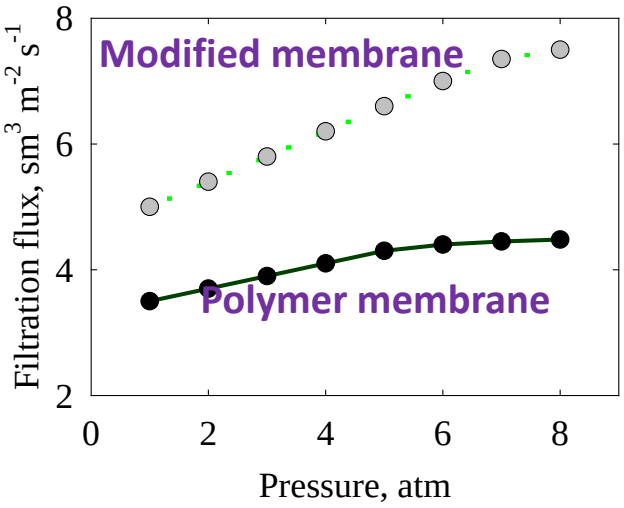
Active layer + MODIFIER



Active layer

WHEY PROCESSING

FILTRATION OF MILKY WHEY



Typical vitamin content

Vitamin	Whey mg/kg	WPC[b] mg/kg
Thiamine	.31	.32
Folic acid	.07	.11
Niacin	1.18	1.28
Riboflavin	.16	.20
Choline	108.00	136.00
Pantothenic acid	3.94	4.43

Initial whey

Concentrate

Typical whey composition before and after concentrating

Fraction	% Water removed (volume reduction) 0	80	90	95
Total solids	6.60	9.50	13.00	18.00
Lactose	4.80	5.50	5.60	5.80
Protein	.67	2.85	5.50	9.54
Ash	.74	.79	.77	.75

The problem of concentrate is high salt content

TREATMENT OF ULTRAFILTRATION PERMEATE

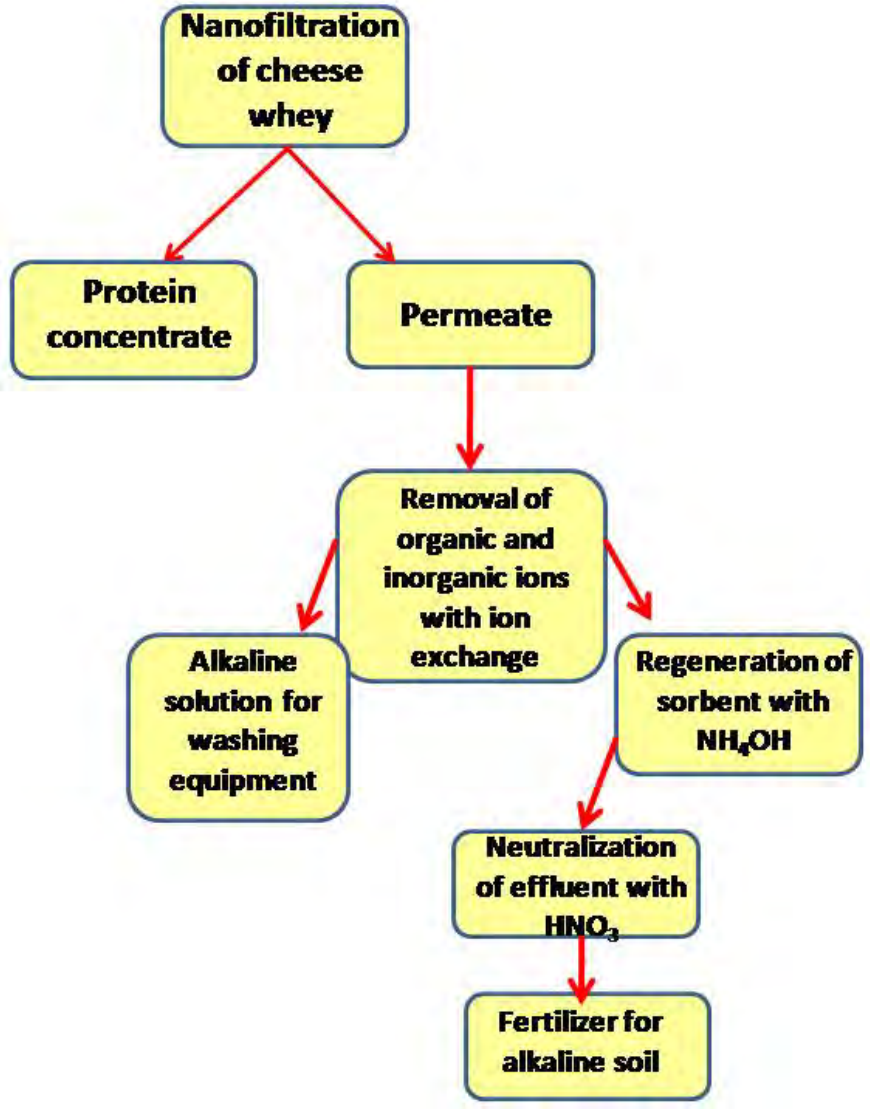
Ion exchange method

$$RNH_3^+OH^- + An^- \rightarrow RNH_3^+ An^- + OH^-$$

Where An^- is Cl-, $H_2PO_4^-$, HPO_4^{2-}, Tartrates, citrates, lactaites, lactic acid, aminoacids .

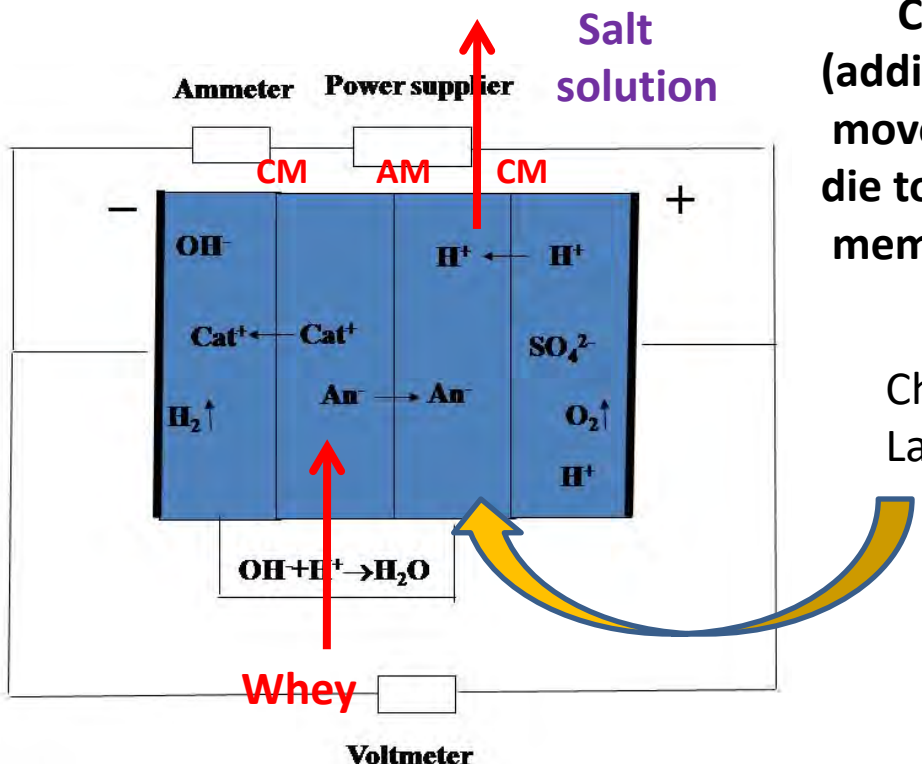
Alkaline solution is formed at the outlet of the column. It could be used for washing equipment. Amino acids substances are removed during the treatment with ion-exchanger, therefore the alkaline soluble has no an unpleasant smell. The spent regenerating NH_4OH solution is used to obtain nitrogen fertilizer.

Scheme of the permeate treatment



Electrodialysis of milky whey

Experimental set-up



Complication of electrodialysis module (additional camera, to which anions are moved) is to prevent whey acidification die to the acid leakage through the membrane from the anodic side.

Chlorides, (di)hydrophosphates, sulfates, Lactates, tartrates, citrates, aminoacids.

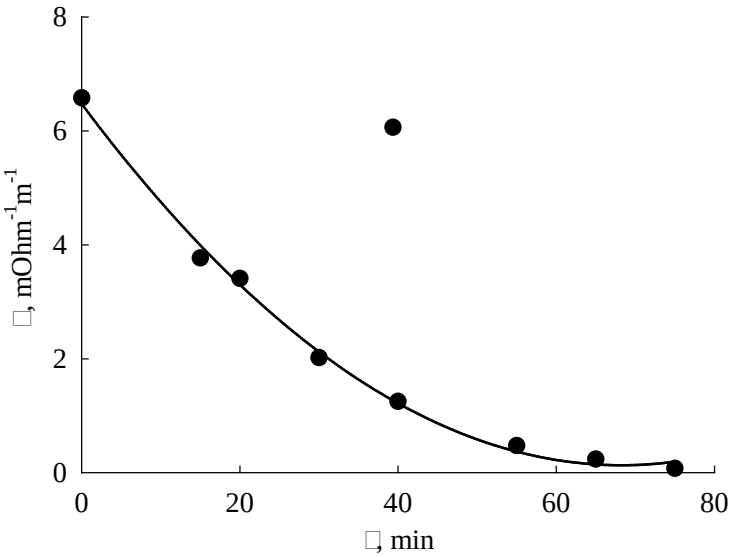
Decrease of salt content

Decrease ofsalt content

The energy consumptions of 2.4 kWh per 1 kg of salts,. For water treatment, it is typically 1 kWh per 1 kg.

Possible directions to decrease energy consumptions

Change of module configuration and geometrical parameters → difficult passage of liquids,



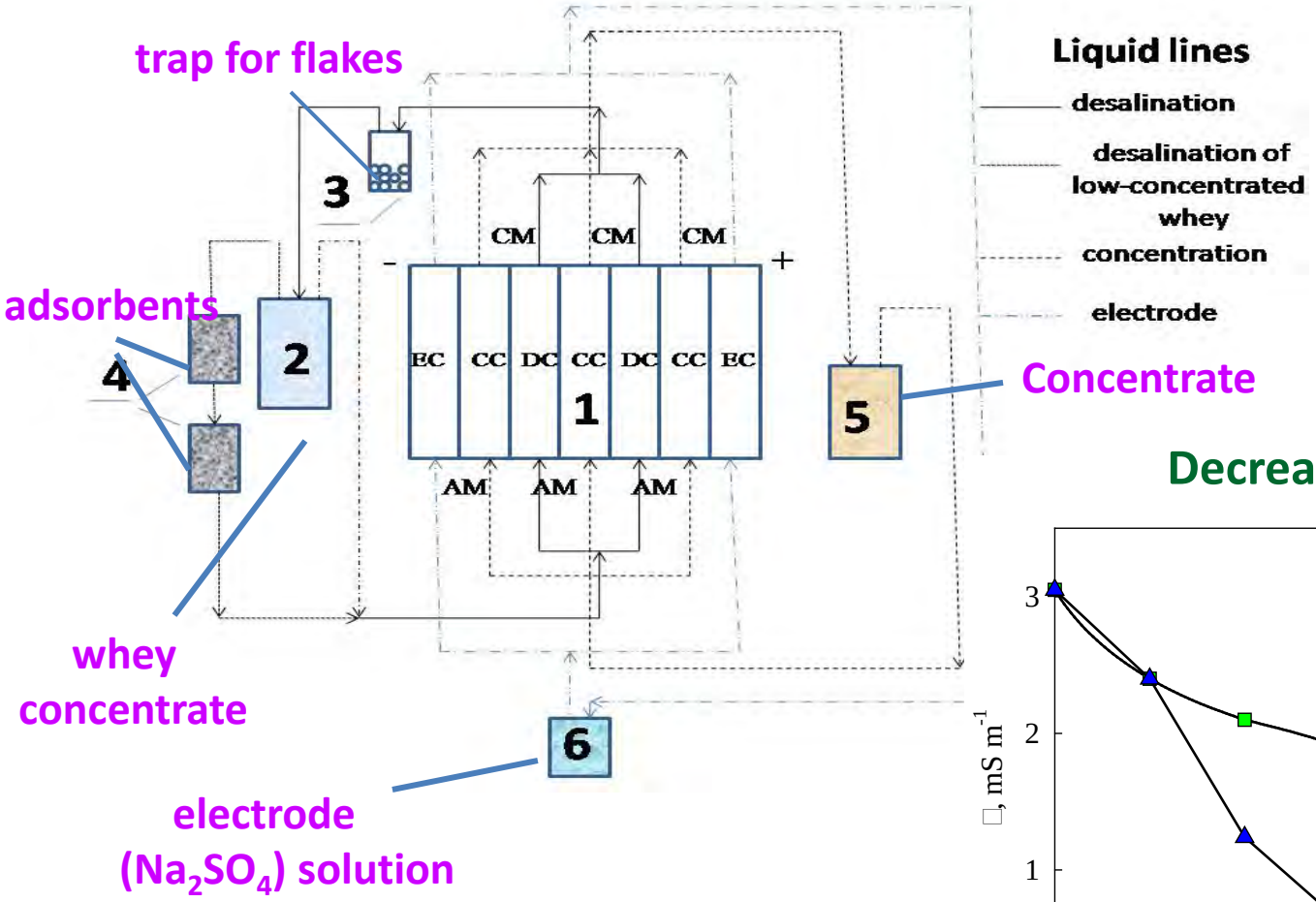
Electrodialysis of whey concentrate

Experimental set-up

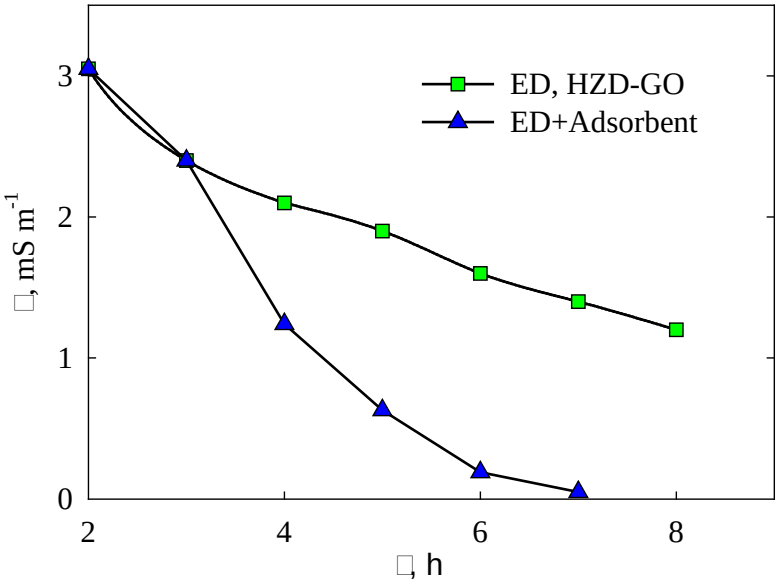
Adsorbents are integrated into the membrane set-up.

Why is it necessary?

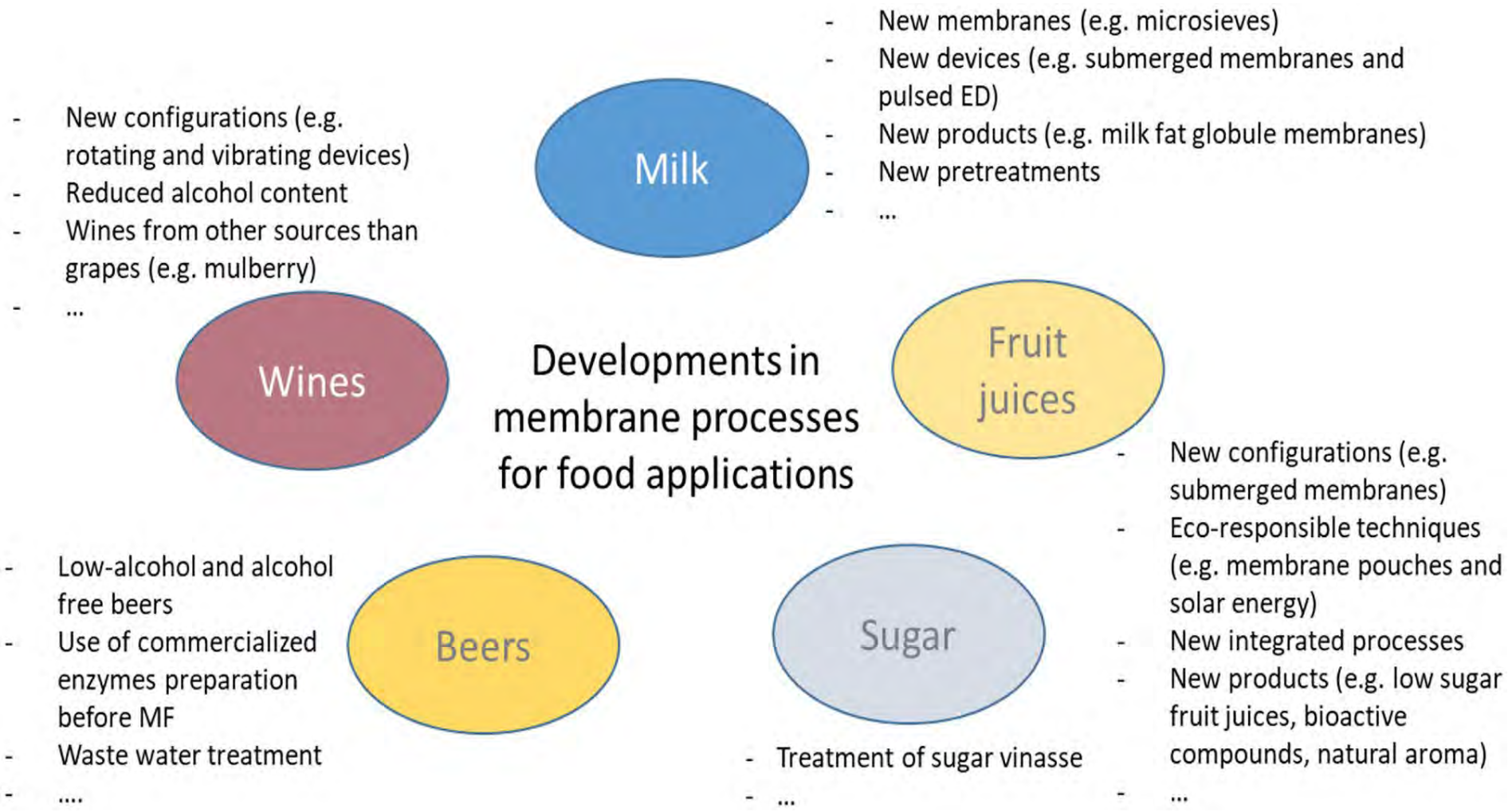
Too high salt content



Decrease of salt content



DEVELOPMENT IN MEMBRANE PROCESSES FOR FOOD APPLICATIONS



Conclusions