Wisconsin Center for Dairy Research

DAIRY PIPELINE

A Technical Resource for Dairy Manufacturers

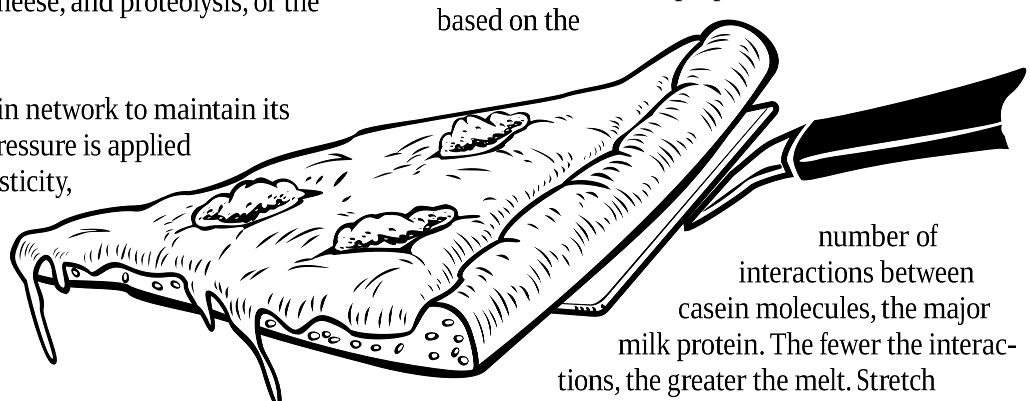
Winter 2000, Volume 12 Number 1

The Melt and Stretch of Cheese

by Mark Johnson, CDR

Melted cheese—it's the essential ingredient in nachos and pizza and the soul of a grilled cheese sandwich. But what do we really mean when we say that cheese melts? A chemist will tell you that a substance melts when it changes from a solid or crystalline state to a liquid. A food scientist will describe melt as the ability to flow or spread. Generally, we think of cheese melting from high heat, perhaps during baking or grilling. However, some cheeses, like ripened Camembert or Limburger, actually melt or flow at refrigeration temperature. Whether or not a cheese melts or stretches, and how well it melts and stretches, depends on the chemistry and thermodynamic properties of its casein network. Sound complicated? Well, it is! But most cheesemakers are already influencing the chemistry and physics of cheese melt and stretch when they adjust the following factors: milk heat–treatment, pH during cheese manufacture, cheese composition, the lowest pH obtained in the cheese, and proteolysis, or the breakdown of intact casein.

Stretch is the ability of the casein network to maintain its integrity and not break when pressure is applied to the cheese. Observing the elasticity, or stringy behavior, of Mozzarella baked on a pizza is a simple way to see stretch. Stretch is also responsible for the blisters that form when cheese is baked. Stretch is most often associated with high temperatures but, like melt, it can occur at much cooler temperatures.



Stretch is necessary for developing round eyes in Swiss cheese. Whether you produce a Swiss cheese with round eyes or slits will depend on the stretch or pliability of the casein network, the rate of gas formation during the warm room treatment, and the temperature of the cheese. Similarly, the temperature of the cheese and the rate at which the cheese is stretched determines the elongation of cheese on a baked pizza.

Casein interactions

The melt and stretch properties of cheese are based on the number of interactions between casein molecules, the major milk protein. The fewer the interactions, the greater the melt. Stretch requires an intact, interconnected casein network and is lost as the interactions between casein molecules (or aggregates) decrease. Stretch is the result of casein–casein interactions that are broken easily but also readily reform at different locations in the casein network. Think of holding a piece of warm Mozzarella, take one end in each hand and gently pull it apart. The casein molecules are grabbing and releasing each other while sliding past as you pull the cheese.

There are several factors we need to review to understand the casein to casein interactions. Each

next page

What's Inside:

The Melt and Stretch of Cheese 1
Mechanics of Membrane Processes 6
News from CDR 8
Curd Clinic 10
Calendar .... Back page

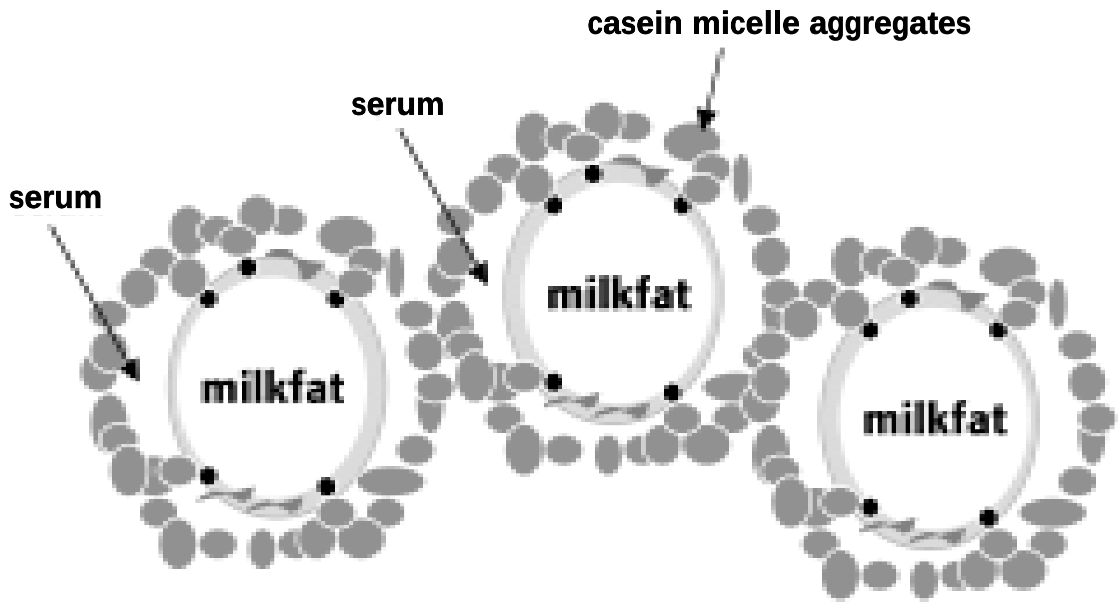


Figure 1. Casein micelles as an aggregate

has an influence on melt and stretch, and there is a great deal of interplay. First, we need to consider the cheese composition, or casein density. Then, there is the amount of interplay between casein molecules. These interactions are strongly influenced by pH and temperature. Finally, there is dissolution or breakdown of the casein molecule—proteolysis.

Cheese composition and chemistry how they affect melt and stretch

As you can see in Figure 1, most of the casein in milk exists in micelles— or "bundles" of many casein molecules. During the clotting process the micelles form aggregates. The clot, or coagulum, is an interconnected network of aggregates. Considerable space exists between the aggregates and these spaces, or pores, are filled with serum and milkfat. After the coagulum is cut, individual curd particles begin to shrink, losing serum in response to stirring, heating and acid development. The aggregates come closer together but do not necessarily fuse. Micelles within the aggregates and micelles of adjacent aggregates begin to fuse only if the casein molecules are able to rearrange and form new associations with other casein molecules. This occurs as the pH of the curd decreases. Concomitantly, there is a loss in calcium phosphate from the casein and an increase in the hydration of the casein. The presence of bound calcium phosphate prevents the necessary rearrangement of the casein molecules. The same thing happens between curd particles. Individual curd particles also begin to fuse. With fusion, the casein molecules have formed a continuous network of casein, a condition necessary for stretch. Heating the cheese, for example during baking also encourages curd fusion, but the chemistry of the cheese must be right for this to happen. If the pH drops too far, the casein molecules begin to "disconnect" and reorganize into aggregates again. There is less contact between the aggregates and therefore a loss in stretch. Similarly, melt increases as the pH decreases, though the flow of cheese at very low pH (4.6) is inhibited.

Milkfat globules are surrounded by these aggregates but do not interact with them. Think of fat as an inert material between aggregates of casein micelles. It does not form any part of the casein network but it does influence cheese melt in a big way. Individual casein aggregates are small compared to the average sized fat globule. These "giant" fat globules break up the continuity of the casein network. The more fat globules in the cheese, the less dense and further apart the casein aggregates are from each other. Thus, there are fewer interactions between aggregates. This weakens the network and results in a cheese that melts and stretches more readily and at a cooler temperature than a lower fat cheese. Increasing the moisture level of cheese will also increase melt and stretch, but the mechanism is different.

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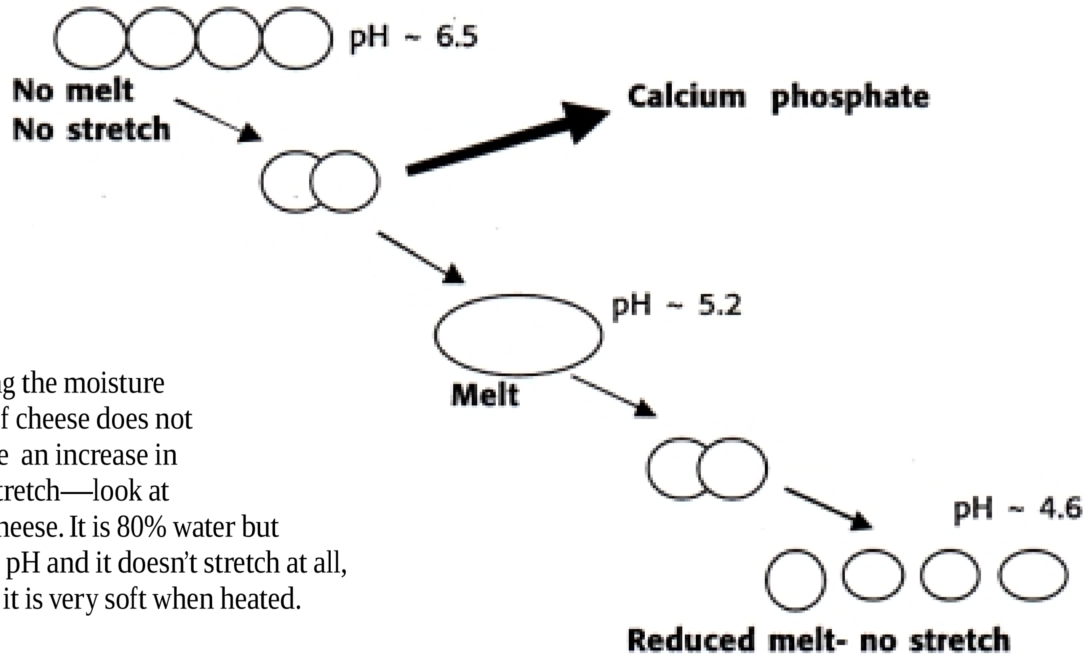
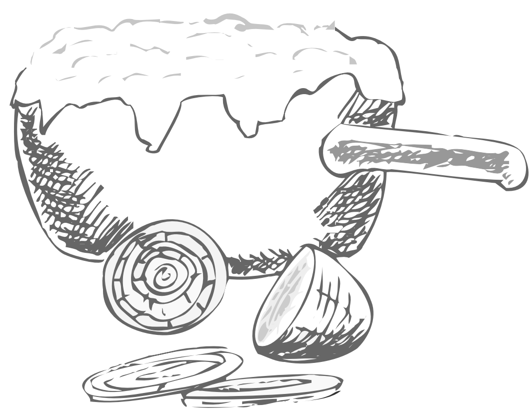


Figure 2. Melt and stretch increases as pH decreases—until you each pH 4.6

Increasing the moisture content of cheese does not guarantee an increase in melt or stretch—look at cottage cheese. It is 80% water but has a low pH and it doesn't stretch at all, although it is very soft when heated.

At higher pH (6.6 - 6.7) the main interactions between casein molecules involve calcium phosphate. As the pH decreases, the calcium phosphate dissolves from the casein and is replaced by hydrogen, H+. There is an increase in melt and stretch as the pH decreases. (See Figure 2) However, if the pH falls too low, the stretch characteristic can be lost. At a low pH, the caseins aggregate into large masses but there are too few contacts or interactions between the masses to allow stretch. The actual pH at which cheese will begin to melt or stretch, or lose stretch, depends on casein content and bound calcium phosphate. Cheeses higher in fat content may require a higher bound calcium content (higher pH) to maintain stretch and desired melt and vice-versa for lower fat cheeses. Bound calcium phosphate content of cheese is affected by many factors, including casein content of the milk and pH of the milk and cheese during cheese manufacture. Factors influencing calcium content of the milk include feeding practices (more grain = higher calcium), stage of lactation (late lactation = less calcium), and animal health (mastitis = less calcium).

"Factors influencing calcium content of the milk include feeding practices, stage of lactation, and animal health."



Melt releases milkfat

Melt is important in the release of milkfat from cheese during baking. If the flow or melt of the cheese is restricted, the release of the fat is also restricted. The faster and greater the rate of flow of a cheese, the greater the release of milkfat, which you can see as oiling-off. When cheese is warmed, the casein network constricts. This is due to an increase in hydrophobic interactions between the casein molecules. Water is pushed out of the casein network and there are

continued on page 5

larger gaps between the casein aggregates. It is much easier for the fat to "leak" out. If cheese is heated in a beaker, some fat will appear on the surface. This is due to the constriction of the casein, which allows the milkfat to pool at the surface. If the cheese is stirred as it is heated, more and more of the milkfat will be released and pool. The casein network actually becomes more or less "fat free." This is exacerbated in the manufacture of pasta filata cheeses (Mozzarella) and in the manufacture of process cheese. In the case of Mozzarella, the pools of fat are not redistributed. When baked, the cheese melts, and the pooled fat is readily released. In the manufacture of process cheese, phosphates, or other "melting salts" and water are added during heating and stirring to make sure that the fat is emulsified and does not pool. In non-pasta filata cheeses the milkfat is more evenly distributed, it doesn't pool and there is less milkfat released. To increase the release of milkfat in these cheeses, there must also be an increase in the rate and extent of melt compared to a pasta filata cheese.

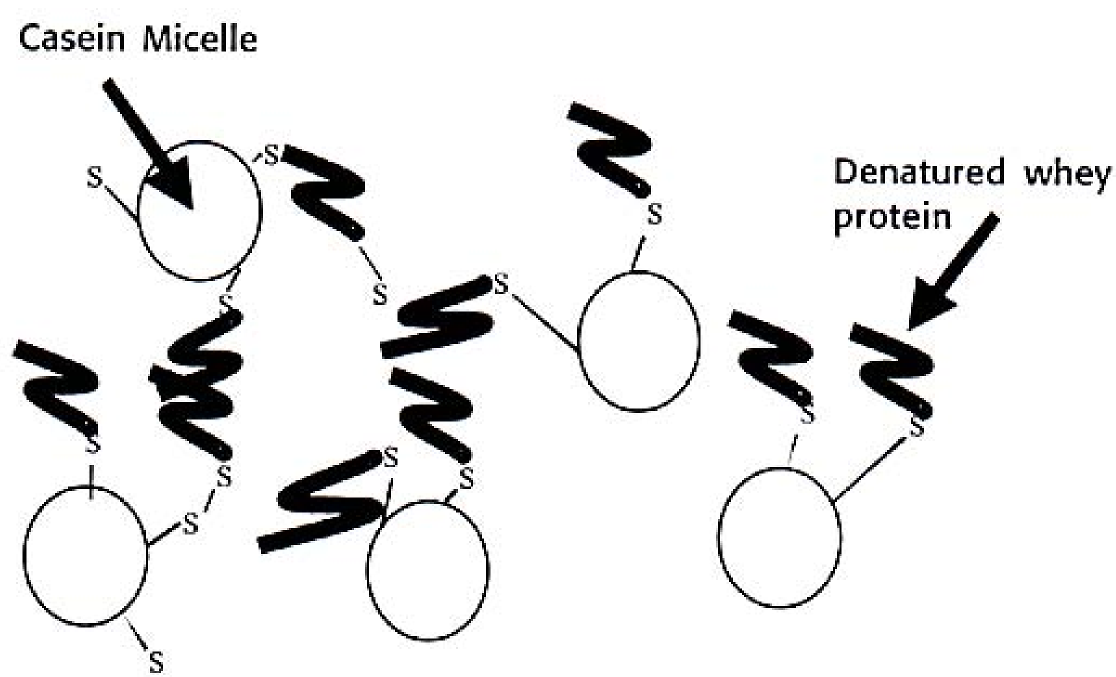
Heat treating milk—effect on melt and stretch

When you heat milk, you increase the possibility of an interaction between casein and whey proteins. (See Figure 3.) When heated, the serum proteins open up, or denature, exposing sulfhydril (SH) groups. These groups are very reactive with similar groups on K-casein molecules near the surface of the casein micelle. They form covalent S-S bonds with each other. Serum proteins may also react with each other and this aggregate may react with K-casein. The net result is a complex of protein that does not react with other casein micelles to form a clot. The clot that does form is weak. This cheese may not melt or stretch when baked because the S-S bonds do not break. If the serum proteins are heated in the absence of casein, they also form aggregates with themselves. When added to the milk there is no effect on melt or stretch other than the effect similar to fat. The added protein aggregates acts as a filler, like fat, and separate the casein aggregates but they don't react with the casein network. Thus, melt and stretch are not adversely affected.

Proteolysis—effect on melt and stretch

Since cheese is a network of interconnecting molecules of casein, the hydrolysis or breaking of bonds within the casein molecule will increase melt but decrease stretch (recall that intact interconnecting casein is required for stretch). Proteolysis of intact casein molecules by residual rennet or by naturally occurring proteolytic enzymes in the milk (plasmin) increases melt or decreases stretch. Proteolysis can be slowed by using less coagulant, or in the case of Swiss, Parmesan, Romano and Mozzarella, higher cook temperatures or mixer molder temperatures can inactivate some of the coagulant. Some coagulants are more sensitive to heat than others. Breakdown of the peptides formed by

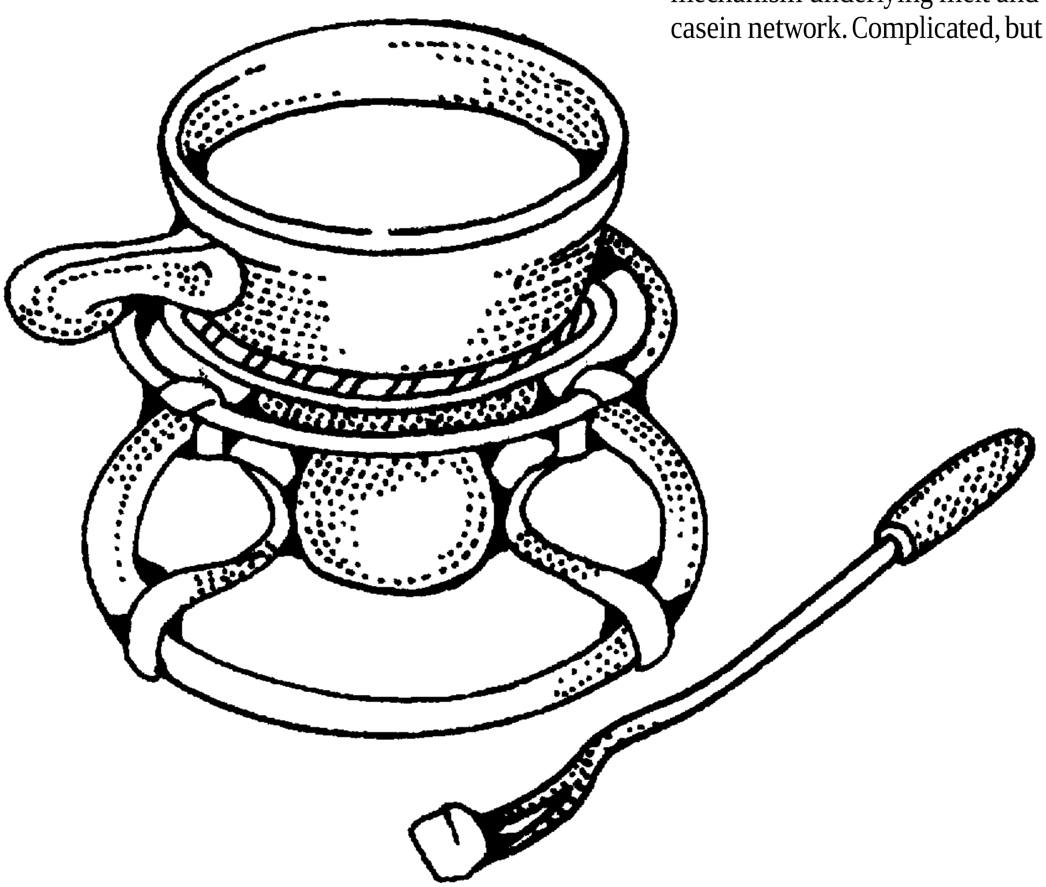
Figure 3. Heat treating milk



the activity of these proteinases has little effect on melt or stretch. Therefore, since bacterial proteinases act on these peptides and not on intact casein, the starter proteinases have very little effect on the melt or stretch of cheese. Wild strains of yeast or bacteria may be active against intact casein, however.

Proteolysis may actually have a more complicated effect on stretch than melt. Proteolysis leads to an increase in casein solubility and fewer bonds form within the casein network. The remaining casein molecule may rearrange, forming associations, or non-interconnecting aggregates of casein, that may result in a loss of stretch (Harry Farrell, personal communication).

Proteolysis is extensive at the surface of mold or surface ripened cheeses, although the proteinases of the microorganisms can only penetrate a few millimeters. Ammonia is released and migrates into the cheese, which increases the pH of the cheese. There is a concomitant increase in the hydration and solubilization of the casein; this increases the melt of the cheese. In addition, you may see proteolysis of casein by residual rennet and plasmin—the native milk proteinase. In Camembert and Blue cheese, due to a low initial pH of 4.8, there is no stretch.



What about the effects of aging?

Aging can be thought of as two distinct but often related events. First, the "buffering" phase which involves displacing bound calcium with H+ and the hydration of the casein. The second phase is proteolysis. The first step may take several days to complete and it is the dominant reason for the increase in melt and stretch in very young cheese. The loss of calcium phosphate is pH dependent. The lower the pH of the cheese, the faster the hydration and the faster you'll see changes in the melt. Calcium phosphate loss also depends on the pH of the milk at set and the pH of the cheese at drain. The lower the pH at each of these steps, the less bound calcium.

Proteolysis is slow in some cheese, especially pasta filata types, and may not have an effect on melt or stretch for several weeks. However, proteolysis increases at a lower pH—perhaps because of the increased activity of residual coagulant and the rearrangement or structural changes to the casein aggregates. This increase in the loss of calcium phosphate and hydration of casein make the casein more accessible to the coagulant.

During this discussion of melt and stretch, we've considered cheese composition, chemistry and temperature. The structure that is both influenced by all these factors and the mechanism underlying melt and stretch is, of course, the casein network. Complicated, but worth the contemplation.

Mechanics of Membrane Processes

A focus on the dairy industry

by Karen Smith, Ph.D.
CDR's Whey Applications program

From filtering milk to sorting whey proteins, membrane separation processes have increased throughout the dairy industry during the last 20 years. Reverse osmosis (RO), nanofiltration (NF), ultrafiltration (UF) and microfiltration (MF) are all processes that can separate dairy products into two streams, retentate and permeate. The retentate stream does not cross the membrane—it is retained. The permeate stream is the one that moves, or permeates, across. You can control the composition of the streams by using different types of filtration.

Although membrane separation processes may sound like discrete entities, the distinctions between them are somewhat arbitrary. In many cases, they evolved with experience and time. All of these separation processes use cross flow membrane filtration, that is, the feed stream flows parallel to the membrane under pressure. A number of factors determine potential to cross the membrane, but the size of the molecule and size of pores in the membrane are two of the more important factors to consider.

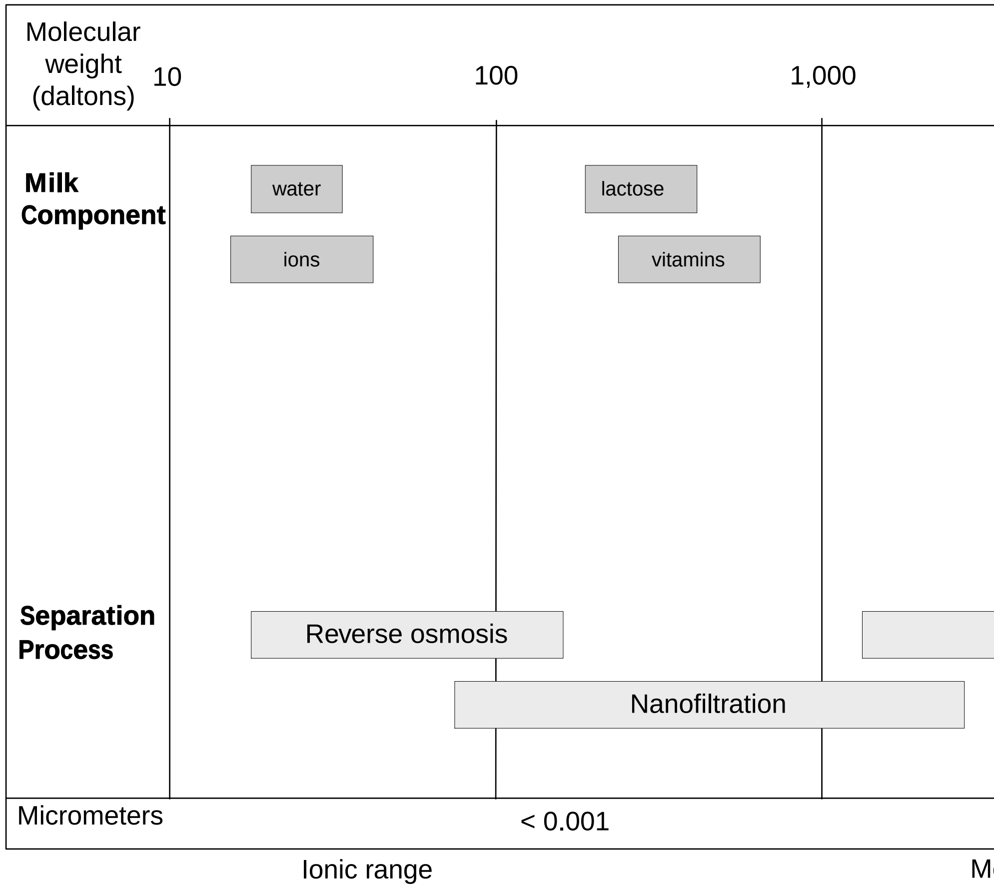
Separation processes

RO membranes generally remove water. In the dairy industry, they are used to concentrate milk or whey, like an evaporator. These membranes are often rated according to their ability to reject sodium chloride.

NF membranes usually remove simple, monovalent ions like sodium and chloride. They may be described by the percentage of sodium chloride they reject. If you wanted to reduce the mineral content of whey, you could use NF membranes to remove sodium and chloride.

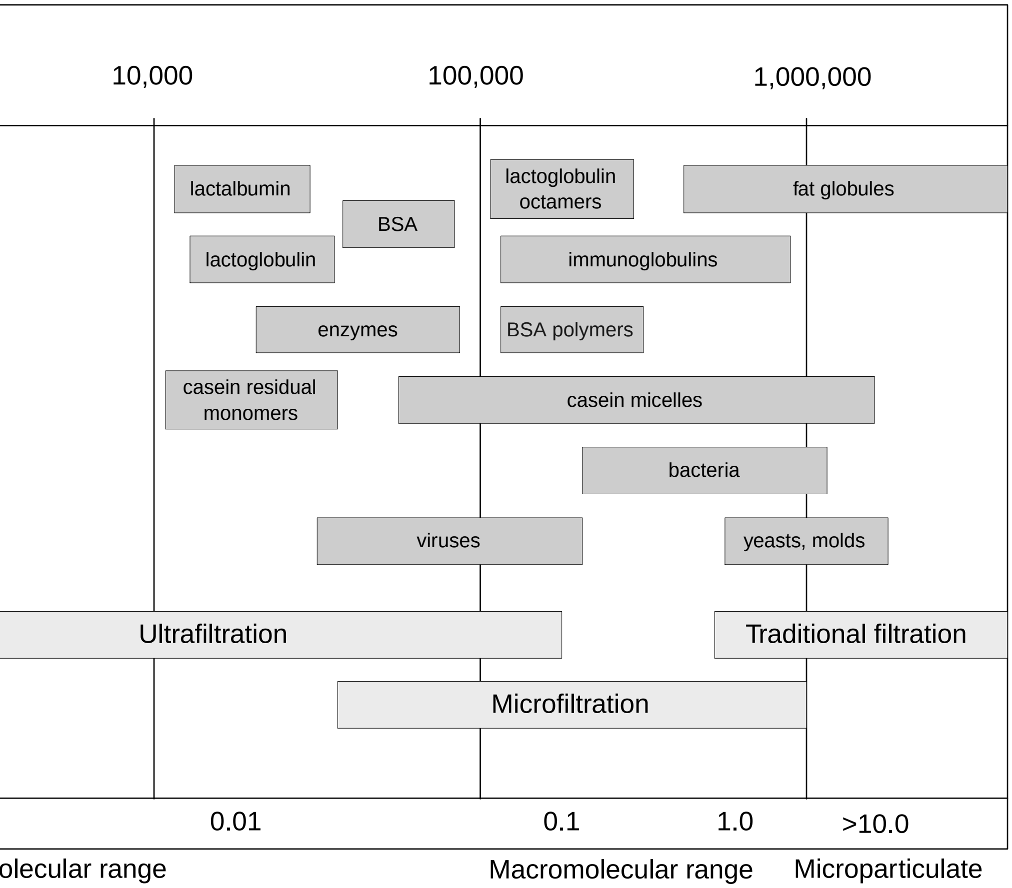
UF membranes often are classified according to their molecular weight cutoff. This term refers to the smallest molecular weight compound that can cross the membrane into the permeate. In practice, this is a rather loose definition. Shape, charge, and flexibility of a molecule influence whether a molecule will cross the membrane. Imperfections in the membrane also make a difference. UF membranes remove both lactose and ash from milk for cheese manufacture.

MF membranes typically are referred to by pore size. The same provisions given for UF membranes and molecular weight cutoff apply to MF mem-



Process	Reverse Osmosis (RO)	Nanofiltration (N
Operating pressure	200 - 1,200 psig	150 - 400 psig
Retentate	All total solids of stream	Total solids of stream monovalent ions
Permeate	Water only	Monovalent ions
Separation method	Ability of compound to mimic tetrahedral structure of water determines ability to permeate	Diffusion and flow thr controlled by mass tra characteristics and ch

s, Part 2



IF)	Ultrafiltration (UF)	Microfiltration (MF)
	30 - 150 psig	20 - 100 psig
except for	Proteins and fats	Fat, very large proteins and particles
	Minerals, NPN and lactose	Lactose, minerals and small proteins
ough pores ansfer, diffusion harge	Shape, charge, flexibility, molecular weight determine ability to cross membrane	Size determines ability to cross membrane

branes. You can use microfiltration to remove the residual lipids from cheese whey.

Important considerations

Please take a look at the chart and note the overlap in the separation processes. It is possible for one manufacturer to refer to a membrane with a given molecular weight cutoff as an UF membrane while another manufacturer could say a membrane with the same characteristics is a MF membrane.

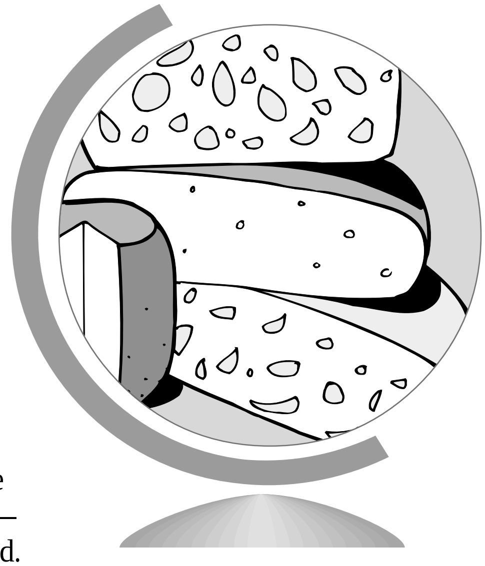
The separating cutoffs also are not absolute for membranes. Membranes have a range of pore sizes and the rating they are given often reflects a separation under very specific conditions with certain molecules. However, these separation characteristics may not apply to your application. Also, it may be possible to have compounds with higher molecular weights pass through the membrane or, conversely, compounds with lower molecular weights may be retained.

Many of the components in milk overlap, or are very close, in molecular weight. This can make certain separations difficult, if not impossible. For example, you can see on the chart that a-lactalbumin and b-lactoglobulin have similar molecular weights—which complicate separation. They cannot be separated by membrane systems unless you first use a method to alter the apparent size of one of the proteins.

You will get the most efficient separations when there is a large difference in molecular weight between compounds. The successful application of UF to dairy fluids illustrates this. There is a large difference between the molecular weight of lactose and salts (ions) and the proteins found in milk or whey. This permits a very clean separation and high rates of permeate production. This also illustrates the problem with using membrane systems to separate specific proteins in milk or whey.

This chart is only a starting point for developing membrane processes for dairy based applications. Because of the complicated nature of membrane processing, the hands on approach to evaluating membranes for your particular application is still the best whey to go.

News from CDR



Jim Path launches the Cheese Exchange

Have you ever tried to look up Adelost, a Swedish cheese? Or wondered what the Turkish cheese, Mihalic looks like? We've all been told that there are hundreds, perhaps thousands, of different cheeses—now you can sit down and look them up in one convenient place. Jim Path, coordinator of the specialty cheese program has been compiling a cheese database for several years and the results are available. Dubbed the World Cheese Exchange, look for Jim's efforts on CDR's website: www.cdr.wisc.edu.

Jim cautions that he is still working on the Exchange, but that is one reason why it's up for viewing now. He's still seeking contributions—photos plus information about any cheese that he might have missed. Jim happily credits donations, so go ahead and contribute. His e-mail address is jpath@cdr.wisc.edu

Open House

Open House
April 25, 2000
4:00 - 6:00 PM
Babcock Hall
1605 Linden Drive

CDR Spotlights Technologies Affecting the Cheese Business

CDR staff will demonstrate equipment, show off the applications laboratory, and answer your questions. There is no set schedule, you will have the opportunity to browse as you like.

RSVP by April 18. Use your phone, fax or e-mail.
Phone: 608.262.5970
Fax: 608.262.1578
E-mail: utter@cdr.wisc.edu

Events—Near and Far

International Cheese Technology Exposition

April 25-27, 2000
Dane County Expo Center
Madison, Wisconsin

Sponsored by
Wisconsin Cheese Makers Association and Wisconsin Center for Dairy Research

Seminars and Events

4-25-00
CDR Open House, 4-6 pm
Expo Welcome Reception, 6-8 pm

4-26-00
Global Perspectives on Cheese Technology
Mark Johnson, Moderator

8:30 a.m. "Dairy Ingredients in Cheesemaking: Growing Possibilities and Possible Problems" John Lucey, professor, Department of Food Science, University of Wisconsin—Madison

9:05 a.m. "Present and Future Technology for Controlling Flavors During Accelerated Ripening" Robert Lindsay, professor, Department of Food Science, University of Wisconsin—Madison

9:40 a.m. "GMO's (Genetically Modified Organisms) and Dairy Products" David Carpenter, VP Dairy Systems, North America, Chr Hansen, Inc.

10:45 a.m. " Extended Shelf-life of Shredded Cheese" Joe Marcy, professor, Virginia Polytechnic Institute & State University

11:20 a.m. "Dairy Product Safety" Rob Byrne, VP Regulatory Affairs, National Milk Producers Federation

4-27-00, Concurrent Morning Seminars
OSHA's Safety Programs and Ergonomics Update
Preferred Suppliers—New Buyer and Seller Relationships

Dairy Ingredient Science 2000

June 28-30, 2000. Dairy Ingredient Science 2000, Exhibition and Convention Centre, Melbourne, Australia. For more information, tel: +61 7 3854 1611 fax: +61 7 3854 1507 email: ozaccom@ozaccom.com.au or register online at http://www.diaa.asn.au/seminar/index.html.

Curd Clinic

Curd clinic doctor for this issue is Jeff Pfaff, BK Ladenburg Corporation

Questions for the Curd Clinic?
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Calcium diphosphate crystal Photo from Processed Cheese Manufacture, A JOHA® Guide BK Ladenburg

Q. As part of our new product development, we have started experimenting with some creative varieties of process cheese. We like some of our prototypes, but we are have problems with a basic, but common, cheesemaking issue—crystal formation. Do you have any tips?

A. The formation of crystals in process cheese is a defect, which can be caused by a variety of factors. The following factors influence crystal development, and even though I've listed them separately it is important to remember that they and also influence each other.

Level of emulsifying salts

Sodium phosphates and sodium citrates can form crystals due to an over dosage of emulsifying salts. Lower moisture products can be especially sensitive to crystal formation due to the increased possibility of exceeding the saturation point of some of the emulsifying salts in the cheese matrix. They appear as small white specks on the surface of the cheese. The pH of the finished product can also influence the formation of these types of crystals. In general, process cheese with a higher pH is more likely to develop crystals. A good quick test of reformulated product is to expose slices to the air in a cooler. As the air dries out the surface of the slices it will force out possible crystal formation.

Although not as common, low levels of emulsifying salts can also cause crystal development. This can be related to the types and combinations of emulsifying salts used.

Final pH

The finished product pH can also influence the formation of these crystals. In general, process cheese with a higher pH is more likely to develop crystals.

High lactose levels

Another type of crystal formation can be caused by lactose levels that are too high. These crystals are normally larger than phosphate or citrate crystals and are sometimes mistaken for pieces of glass. Sources of lactose in process cheese formulations include young cheese, whey and milk powders. Storage temperature, cook temperature and types of other ingredients present can all influence the formation of lactose crystals. A good rule of thumb is not to exceed 14 % lactose in the water phase.

> "If you want a good quick test, expose slices of reformulated product to the air in a cooler. As the air dries out the surface of the slices, it will force possible crystal formation."

Aged cheese

A third type of crystal in process cheese is caused by the use of very aged cheese in the blend that already has a precipitation of tyrosine. Tyrosine is released from proteins and peptides during proteolysis by lactobacilli.

If you want a good quick test expose slices of reformulated product to the air in a cooler. As the air dries out the surface of the slices, it will force possible crystal formation. Most crystal problems can be identified under a microscope and confirmed by analytical testing. Checking levels and, often, recalculating the emulsifier and lactose levels in your formulation will help you solve the problem.

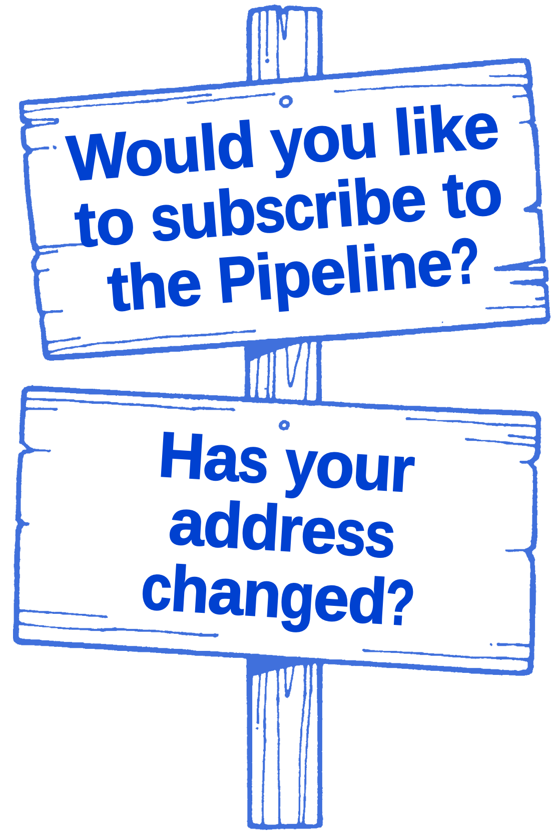
Solving the problem

Most crystal problems can be identified under a microscope and confirmed by analytical testing. Recalculation of the emulsifier and lactose levels in the formulation will normally point to the solution to the problem.

Calendar, continued from back page

Sept. 27-28 Dairy, Food and Environmental Health Symposium. cosponsored by Wisconsin Association of Milk and Food Sanitarians, WI Association of Dairy Plant Field Reps, and WI Environmental Health Assn., Green Bay, WI. For more information, call George Nelson at (715) 232-0404.

Oct. 16-20 Wisconsin Cheese Technology Short Course. Madison, WI. Call Bill Wendorff at (608) 263-2015.



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Calendar

April 11-14, 2000. Basic Cheesemaker's License Short Course, UW-River Falls. For info, call (715) 425-3702.

May 2-3 Whey and Whey Utilization Short Course, Madison, WI. Call Bill Wendorff at (608) 263-2015 or K.J. Burrington at (608) 265-9297.

May 17-18 Applied Dairy Chemistry Short Course, Madison, WI. Call Bill Wendorff at (608) 263-2015.

June 6-7 Wisconsin Cheese Grading Short Course. Madison, WI. Call Bill Wendorff at (608) 263-2015.

June 10-14 IFT Annual Meeting, Dallas, TX. For information call IFT, (708) 786-4120.

June 21 Food Safety Workshop for Manufacturers of Ready-to-Eat Products. Madison, WI. Sponsored by WI Assn. of Milk & Food Sanitarians. For further information, call Neil Vassau at (608) 833-6181.

July 24-28 American Dairy Science Association Annual Meeting, sponsored by American Dairy Science Assn. Baltimore, MD. For more information call ADSA, (217) 356-3182.

Aug. 10-13 American Cheese Society Annual Meeting. Rohnert Park, CA. For info, call (262) 728-4458.

Aug. 21-24 Milk Pasteurization and Process Control School. Madison, WI. Call Bob Bradley at (608) 263-2007 for information, or the CALS Outreach Services (608) 263-1672 to register.

Calendar continued on page 11

DAIRY PIPELINE

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