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Rapid Sheep Milk Freezing

The Rapid Freezing team: Richard Archer, Jolin Morel, Lindsay Robertson (of Massey) and Ian Macdonald of Sheep Milk Supply Group

Introduction

The rapid freezing project is now in commercialisation phase. We started nearly six years ago in response to the growing sheep and goat milk industries. Farmers wanted to develop farms remote from the few milk processors available. Farms producing say 500 L of sheep milk daily needed to amass perhaps 2,000 L for a cheese run or 50,000 L for a dryer run. Or farms needed to club together.

Farmers in this situation traditionally freeze milk in 5-10L bladders or pails. Such freezing is very slow and thawing is so slow that high bacterial growth can occur. The slow freezing causes pure ice to separate out and concentrates all the proteins together in little pockets. Over time the caseins knit together. The milk will not be the same on thawing, and can be flaky or gel together.

We set out to understand the physics of the processes by which ice and milk solids separate in order to avoid this happening. We hoped to build a prototype sheep milk freezer that would get milk frozen in less than 3 or 4 minutes and allow milk to thaw just as fast. We wanted to keep the milk proteins soluble during storage. We wanted a system simple enough, small enough and strong enough to sit on farm. We needed it to be built and maintained in New Zealand and to be affordable to farmers setting up.

The effect of speed of freezing on ice's structure

Before we started it was well known that ice forming in a solution on a cooled surface starts freezing as parallel needles growing outwards from the surface. A very cold surface grows needles faster and closer together. Over time the needles thicken up and grow together squashing any still liquid solution out of that zone entirely or possible entrapping some between the nearly-touching columns. This is called columnar ice and it can have quite big ice crystals. The solutes get concentrated in the small volume of liquid that gathers between ice crystals.

Early on, heat transfer is easy. The heat has only a thin layer of young ice to get through to travel from the freezing front to the cooled surface. In this stage, ice-growth is really fast and the needles of ice are fluffy - they develop hundreds of small offshoots called dendrites (see Figure 1). This gives a tangled mix of fluffy ice dendrites and unfrozen liquid. That is exactly what we want when we freeze sheep milk – to keep the solid and the solid water tangled up together. And if casein micelles are crushed together, we want this to be in tiny zones which would make micron size aggregates should they be stored frozen long enough and warm enough to lose solubility.

We wanted to develop a freezer format where the speed of freezing, from beginning to end, is up in the dendritic range. First, we needed

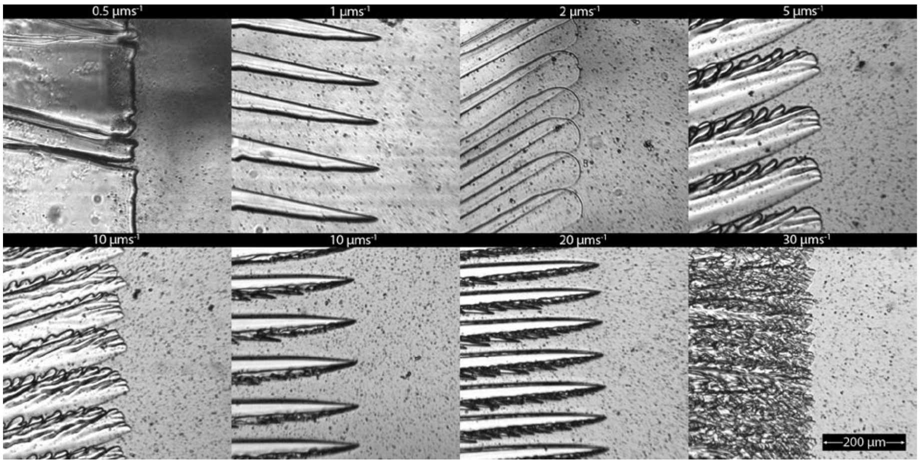


Figure 1: Ice morphologies in freezing skim sheep milk. Fully dendritic growth is seen at 30 µms-1

Figure 2: A range of liquid food products frozen with our laboratory-scale freezer

to know what the critical freezing rate is when our milk of interest starts/stops growing as dendrites. That depends on the composition of that milk. We needed to work out what happened with various milks, whose compositions are:

Compositions of various milks

Component	Goat	Sheep	Cow
Fat (%)	3.80	7.62	3.67
Solid-not-fat (%)	8.68	10.33	9.02
Lactose (%)	4.08	3.7	4.78
Protein (%)	2.90	6.21	3.23
Casein (%)	2.47	5.16	2.63
Whey Protein (%)	0.43	0.81	0.60
Ash (%)	0.79	0.90	0.73

We froze whole sheep milk, skimmed sheep milk, sheep milk ultrafiltrate and water. We determined the impact of each of the major solutes present and measured the critical freezing speeds, which increased in the order: whole sheep milk< skimmed sheep milk< sheep milk ultrafiltrate< water.

Laterial ideas trialled

The next step was to come up with a freezer that could perform this function. Clearly, we needed to freeze milk in small amounts at a time – if the distance for heat transfer gets too great for the cooling temperature we have available, the system will fall off its foils. We came up with three formats to try:

1. Rolling droplets – we drop ~3 mm spheres of chilled milk on to a corrugated stainless steel slope against a very cold breeze. They roll and freeze and the rolling motion helps mix the interior. We hoped the droplet-forming jets wouldn't freeze up and the stainless steel would not build up frost.

2. Falling film – we arrange chilled milk to flow down the outside of a cold vertical stainless steel tube. The milk ice builds up until it reaches a critical thickness. Then we stop cooling, heat the metal pipe quickly and let the tube of frozen milk slide off, maybe with some mechanical assistance. We hoped the energy, lost in heating would not be too great: that the ice would come away cleanly and that this system, although exposed to the air, could be run cleanly.

3. Cooled tube. We pump milk under pressure through a cooled pipe. We hoped it wouldn't just form a frozen shell and squirt through the middle and that it wouldn't burst the pipe when it froze right to the centre. We hoped that the frozen plug would slide along the wall and emerge intact from the far end of the tube as a solid rod ready to break into pellets.

Figure 3: Sheep milk frozen during an initial trial with an early larger-scale tube freezer prototype

We tested all of three formats and had greatest success, unexpectedly, with the cooled tube. It is a very simple device and not too hard to fabricate. Yes, the risk factors exist and it does not work with all fluids or under all circumstances. We have looked carefully at why it might work and have our theories. We have looked carefully at situations where it does not work and have more theories.

With our very small laboratory scale tube freezer (4.4mm internal diameter) we have successfully frozen sheep milk, goat milk, orange juice, other dairy liquids, coffee, kiwifruit pulp and other (secret) liquid food products. With a larger unit (10.2 mm ID) we have frozen sheep milk, and other liquid dairy products so far.

Answering the new questions

How fat a tube can we use? How long must it be? We think we know all this and the answer is 900. A single unit can freeze about 900 L of sheep milk in a day. Beyond that we can easily parallelise units.

We have a patent under examination on this technology and Cuddon Ltd of Blenheim are building the first commercial prototype. We anticipate such a unit, sensibly designed and operated, will be well received by MPI. It is simple, enclosed, easily cleaned and freezes milk quickly into a format that will store well and thaw very quickly. It is a distinct step forward in milk quality over bladders and pails.

These units could well be in a rural supply store near you in the near future.

Atmospheric Freeze Drying - no vacuum required

The project team, (from right to left), Prof. Richard Archer, Prof. Jim Jones, Dr. Qun Chen

Introduction

New Zealand is big in freeze drying. In Cuddon Freeze Dry of Blenheim we have a successful manufacturer (and exporter) of batch freeze drying equipment. In our mussel, kiwifruit, pet food, and dehydrated vegetable industries we have some large scale freeze drying companies. And in our military and tramping rations companies, a range of expert users of freeze drying.

All of this is classic vacuum freeze drying (VFD), an excellent process capable of preserving structure, flavour and bioactivity in many materials. But the equipment is expensive, being based on a large-diameter pressure vessel, vacuum pumps and complex heating manifolds. And it is very hungry on energy. VDF is expensive.

Drying from frozen in a full atmosphere of pressure

Within FIET we have been developing atmospheric freeze drying (AFD) for five years now and it is looking promising. The principle is simple. Put product in a freezer store at (say) -10°C and blow very dry (dew point < -35°C) over it. Water will sublime from the food and diffuse out into the cold dry air. If that air contacts a pile of frozen food at (say) -8 °C, then it will do some drying work and leave at about -10 °C. The job of the equipment is to dry out that air, warm it back up to -8 °C and send it round through the product again.

AFD is not a new concept. A few engineers have seen the promise and have tried heat pump and other solid desiccant approaches. None has quite cracked it yet. What has changed is the ready availability nowadays of very good desiccant wheels with very low thermal mass. We have found that two such wheels, carefully sized and set in cascade, is the secret. One large wheel is placed in an air handler unit beside the freezer tunnel down which the cold dry air is blown. A second wheel makes warm dry air with which to regenerate the large wheel. And the second wheel is itself regenerated using either a small flow of hot air like a normal dryer, or by a heat pump operating over a comfortable temperature range.

Considerations

1. Drying time.

AFD is hideously slow. Water vapour must diffuse out through the food and navigate all the air molecules inhabiting the pores. Where VFD may take two days, AFD may take more than two weeks. That means the drying chamber is 10 times larger. But that chamber is just a light poly-panel tunnel, it is cheap to build. And if the product is sitting waiting in a freezer store anyway, there is no penalty.

2. Not suitable for batch processes

AFD does not suit all situations. It is best operating semi-continuously at large scale, where every day dried product is withdrawn from one end of the tunnel and fresh frozen feed put in the other end. The air flow hits the driest product first, and wettest last. It does not work well under -10 °C because air carries so very little water vapour down there – you have to recirculate air too often to be economic. This restricts AFD to low salt, low sugar foods which don't build too much freezing point depression as they dry.

3. Best for complex shapes requiring a gentle process

AFD suits some products far better than VFD does. Complex shapes and delicate materials such as cut flowers, hop cones, leafy green herbs do not like sitting with one petal or leaf resting on a very hot plate. That one part gets scorched and over-dried while the rest stays moist. AFD provides even heating over the whole surface.

In VFD it is common for the heating plates to get up to high temperatures – 40, 50, even 60 °C. Product can rise to these temperatures late in the drying cycle. But with AFD, not one molecule of product can get above the inlet air temperature (perhaps -8 °C) at any point in the cycle. It is really very gentle.

VFD usually suffers from some point to point variability in a dryer. Vapour paths differ between locations. Building the perfect heating manifold to make each tray identical is very difficult. Here the slowness of AFD becomes a virtue. No part of the product can race away from another. The whole load evens out in moisture content very well.

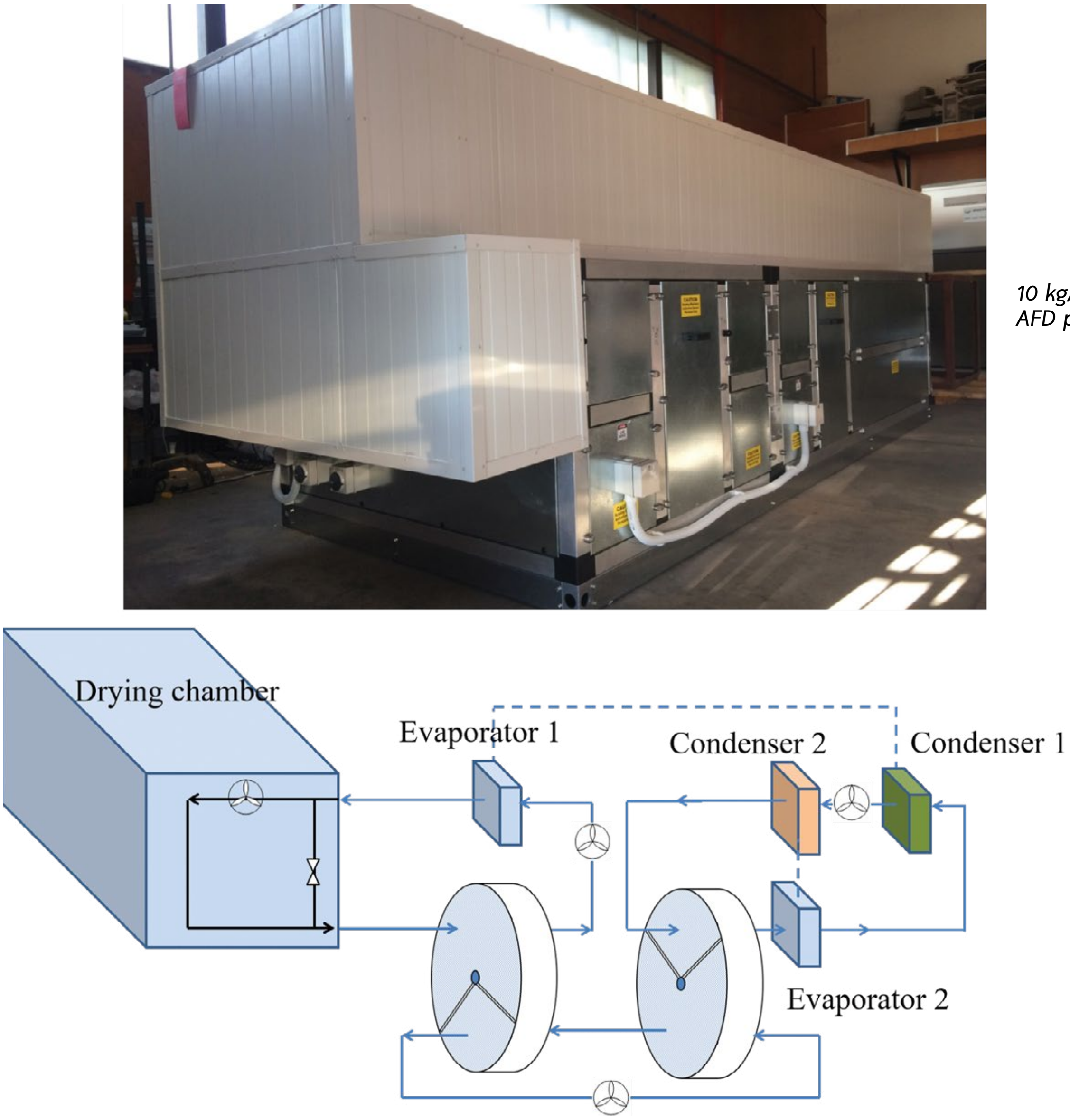
Trial results

We have performed successful AFD trials on a number of products now, including snap frozen peas, corn kernel, cabbage leaves, frozen smoothie drops, hop cones, mussels, insect larvae and quite a few whose owners would like to stay quiet.

We have built trial devices at three scales:

1. Several airtight mini-scale boxes with a drying capacity of ~1g water/

AFD small scale trial units and examples of dried product



10 kg/day prototype and AFD process diagram

day, which allow us to measure the drying rate of small samples under different relative humidities and temperatures;

2. A bench scale medium-size testing box with a maximum AFD drying rate of 100g water/day for characterising drying behaviour in a semi-continuous process;

3. A proof-of-concept prototype of the desiccant wheel-driven AFD process with a drying capacity of 10kg water/day consisting of an insulated tunnel for semi-continuous drying and an air handling unit holding the cascading desiccant wheel dehumidification system. [The AHU was designed, built and donated by Cooke Industries of Auckland].

Our calculations indicate that, at scales over 2 MT of water removal per day, AFD looks to be about half the capital cost, and half the operating cost of VFD.

Our conclusion

But... the best application looks to be as a finisher to a VFD operation. In vacuum freeze drying, the first 2/3 of the water dries off in well under the first 1/3 of the cycle. If you can keep the product cold and break vacuum after say 30% of the normal cycle time, then transfer the load to an AFD for finishing, you might treble your throughput at the cost of a very simple AFD. Product may need to stay a week or more in the AFD but it will stay very cold and come out very evenly dried. It may not much matter if you leave it over the weekend and pack out on Monday – the final part is the slowest.

FIET
Food Industry Enabling Technologies

Food Industry Enabling Technologies (FIET) is funded by the Ministry for Business, Innovation and Employment and its purpose is to support new process developments that have the potential to add significant value to our national economy. The programme has six research partner organisations, Massey University (the host), Riddet Institute, University of Auckland, University of Otago, Plant and Food and AgResearch. Funding is $16.65m over six years (2015-2021) and targets pre-commercialisation activities. If you are interested in more information, then please contact either Dr Ross Holland (R.Holland1@massey.ac.nz) or Professor Richard Archer, Chief Technologist, (R.H.Archer@massey.ac.nz).