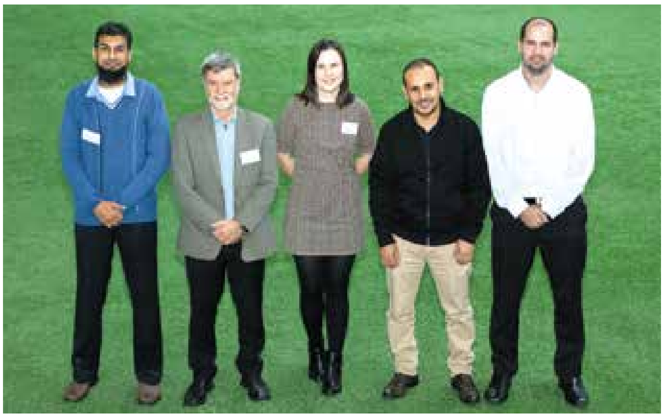
Milk chilling and farm milk vats

Richard Archer, Massey University



Mohammad Harris, Richard Archer, Rachel Waite, Refat Al-Shannaq, Kevin Silver

The challenge

In New Zealand, we produce some of the best milk in the world at the udder but it is not necessarily the best by the time it hits the first process in the factory.

By then we have cooled it slowly in an agitated vat, stored it without insulation, pumped it rapidly into an uninsulated tanker and sloshed it around. Air can become incorporated at numerous points. Biofilms can develop on warm roof surfaces in vats and tankers, and secrete heat stable protease and lipase enzymes into the milk. The milk is perfectly safe but these enzymes limit the range of products we can make.

Add to this the new challenges in front of us: MPI's rules for cooling have just changed (a 2017 update to NZCP1 just came into effect at July 2018) rendering some of the current farm set-ups marginal; The refrigerants that suit our dimple-pad cooling systems are likely to be outlawed for their high Global Warming Potential. Our largest company owns the vats but not the refrigeration plant, leaving responsibility for performance uncertain. Our systems are good but less than perfect.

Current best practice is used in Europe but seldom here. That does not matter greatly if we stabilise milk rapidly as powder. But some newer specialty and value-add products are more sensitive to heat-stable enzymes and to milk fat globule membrane damage.

The European system may well suit small farms and subsidised milk, but may not fit the New Zealand context. It is time for New Zealand to decide what our best practice might look like.

FIET is rising to the challenge

The FIET project "Milk Chilling and Farm Vat" gives us options and advances the thinking. The project has three components:

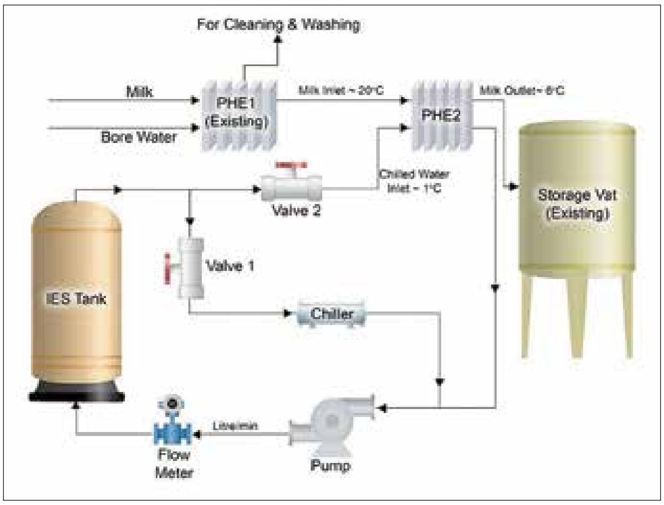
1. Best practice ice banks employing phase change materials – University of Auckland
2. 3D printed insulation for simultaneous strength plus insulating performance – Massey University
3. Industry-based development toward hybrid tanks – Fonterra, Longveld, RX Plastics and Massey University

Best practice looks to lie in the direction of snap chilling, probably using chilled water cooled by ice-banks. Compact refrigeration plant using ammonia or CO_2 will chill water or glycol. We anticipate stainless-lined, polymer-insulated tanks. Ultimately, we will also have deaeration and pumpless transfer from vat to tanker - dispersed air is an evil to avoid. And perhaps we will also have a heat exchanger that is as good as the plate heat exchanger but is much gentler on warm, raw milk.

Next-generation ice banks

If you wish to snap chill milk into a vat, then either you need a large refrigeration plant drawing heavy electrical currents or you need to store "cold". If you use chilled water you will need nearly three times as much water as you have milk. Ice is much more compact. Ice banks are not new, and they are effective. However, most current systems store ice on copper refrigerant coils. Ice-on-coil is neither fast (thick ice is insulating) nor compact. The new FIET system is both and now looks to be best available practice for snap chilling milk.

As shown in the schematic, milk is first cooled against water in plate heat exchanger PHE1, and then further cooled against recirculated



Schematic of chilling system based round an IES ice-bank

chilled water (doped with a little glycol) in PHE2. This chilled water is itself circulated through the IES (ice storage) tank, being cooled by the ice melting there. Milk will enter the vat at ~4°C. Assuming the vat is well insulated, and is agitated lightly, the milk should stay below 6°C for two or three days. At each subsequent milking, the vat contents will drop in temperature, not rise. A tanker arriving at almost any time during milking or storage can be assured of picking up cold milk.

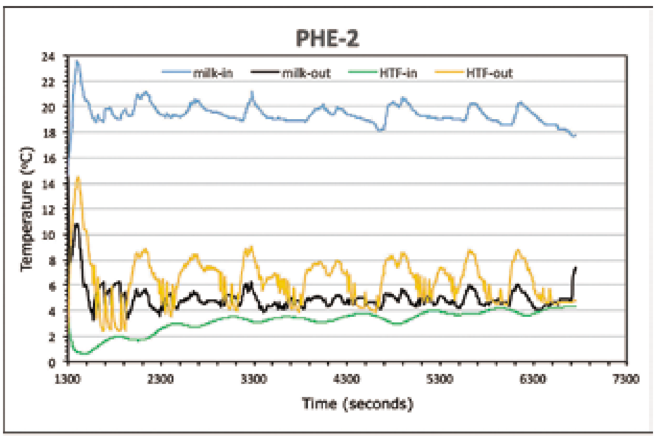
The IES system can make ice whenever the shed is not milking – overnight may access low cost, off-peak electricity. For ice-making, the chilled water-glycol, rather than passing through PHE2 to chill milk, is instead drawn through the chiller unit to be chilled to about -5°C, and then pumped back through the ice storage tank.

Refat Al Shannaq and Mohammed Farid at the University of Auckland have devised the new ice bank system. They have installed a full size

Prototype IES ice-bank system in use in a Waikato dairy shed

prototype on a farm East of Gordonton - it is operating well.

This unit is housed in an insulated stainless steel container. It already has the highest energy storage density (in kWh/m3) and footprint (in kWh/m2) of any unit available. It is also the fastest (in kWh/hr) to refreeze and to melt if desired. The unit is affordable in its present development, but the next generation will be even cheaper. Moreover, the heat exchanger for cooling the chilled water/glycol with refrigerant is easy to build in strong, compact and leak-resistant form, unlike the dimple-pads on the current flat-bottomed tanks. This makes the unit ready for ammonia or CO_2 refrigerants.



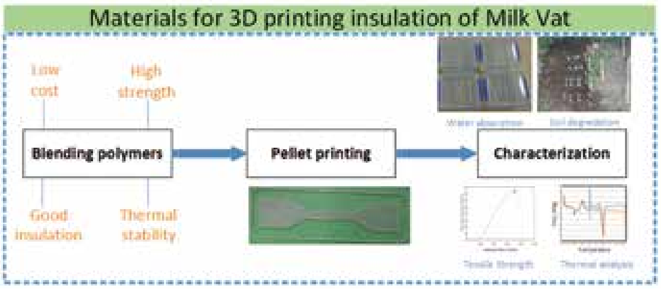
A temperature trace from the prototype shows the milk and chilled water (HTF) temperatures during milking. Milk enters PHE-2 at ~20°C and leaves at ~5°C over a sustained period. The chilled water temperature rises only a little and gradually as melting proceeds. The bulk milk accumulating in the vat will be well below 6°C.

3D Printed Insulation

For a tank to receive snap-chilled milk, and then hold that milk cold for two or three days, very good insulation is needed, avoiding thermal bridging via support structures. The tank should have to cool down as little metal as possible. These conditions can be met with a thin-walled tank that is held rigid in a strong plastic matrix. Ideally that insulating matrix is open-cell so that any condensation or milk can be drained or washed out. Ideally, it is repairable or replaceable in spots if necessary.

How do you build such a matrix, stronger in key places, more insulating in others? Only 3D printing offers the flexibility. Print must be at large scale, rapid and cheap, but still with sub-millimetre resolution. This is new and challenging technology and the subject of two FIET PhD programmes:

Kevin Silver at Massey University is developing the software tools to examine any imagined porous structure for thermal and mechanical performance. Then we use those tools to probe the likely performance of different structures made from different materials. He has devised and assessed a number of structures already, and has found some novel porous matrices that look well suited to insulation applications.



Mohammad Harris, also at Massey, is developing blends of commodity grade polymer and is printing from pellet stock. Vendors usually sell polymer for printing applications in filament form at prices far too high for insulation applications. Mohammad aims for a great mix of properties (compressive and tensile strength, elastomericity, tolerance to thermal cycling and to moisture and, above all, printability) so that we can make the sparse structures that will insulate well and consume little material. So far, he has developed a good low-cost, high strength biodegradable polymer blend and has moved on to non-biodegradable blends. This is looking promising.

This project clearly has applications far beyond static farm vats. We had always imagined tanks for the milk tankers of the future, but also pipe insulation and cladding, building components, white wear, aircraft parts and monocoque car bodies.

These two projects are proceeding well enough to give us confidence that large-scale printed insulation on hybrid tanks is indeed the way of the future. However, we will need to wait a few years yet. And it may not be New Zealand that first shows the innovative drive to make this technology real.

Industry developments

In the shorter term, the industry has more pressing needs. The industry sees that it needs solutions both now and in (say) five years.

The five-year solution for a system of cooling, storage and transfer of milk should solve all current and foreseen problems. It should

Bal Timilsina testing pump-around agitation in milk vats of different shapes

be cheaper than now, yet we must be happy to see it still on farms in 2050. It will almost certainly be a hybrid of polymer and stainless steel. Agitation will be much gentler. There may be no moving parts on the roof. Instead, all parts likely to require maintenance might be in a single inter-changeable component near ground level. The unit will measure temperature and fill-level. The manway will be bolted, opened infrequently. The vat will be designed for fast emptying by a gentle air-push, avoiding the pump on the tanker. It will be designed to CIP easily and be as suited to part fills as complete fills. The system will avoid air and foam and so prevent the losses and cleaning hassles that result.

So far, the favourite design is a dome-bottom, dome-top tank on a skirt mount, with a supporting insulation matrix all over. Mixing will be by very gentle pump-around with <5% the power used now. Milk will enter and exit via a large central nozzle at the bottom. The tank will vent and be CIP'ed via a large central nozzle at the top.

The short-term solutions will likely be variants on current flat-bottomed, dimple-pad vats, with improved agitation, refrigeration surfaces and with insulation. This will keep the New Zealand dairy industry in the game and compliant with NZCP1 but will not offer a step change in reduced cost or increased performance. It will not get us to best practice.

An industry grouping is working on both these approaches simultaneously.

Watch this space.

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 partners, Massey University (the host), Riddet Institute, University of Auckland, University of Otago, Plant and Food and AgResearch. Funding is $18m over six years (2015-2021) and targets pre-commercialisation activities. If you are interested in more information, then please contact either Ross Holland (R.Holland1@massey.ac.nz) or Professor Richard Archer, Chief Technologist, (R.H.Archer@massey.ac.nz).