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Ecolibrium

Sun (master)stroke

Solar trigeneration in action.

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FEATURE

The next phase


Every PCM system is different.

Understanding a substance's "phase" or "state" change has been the cornerstone of refrigeration for more than 150 years. Yet recent technological advances have seen new materials developed that enhance this concept even further. **Sean McGowan** looks at the next phase of refrigeration.

As the single largest electricity-consuming technology in Australia, refrigeration equipment accounted for more than 22 per cent of all electricity used nationally in 2012 (according to Cold Hard Facts 2).

And just as our society's demand for refrigeration has grown, so too have the price and availability of electrical energy.

Big consumers are encouraged (and for this read rewarded) by utilities companies to help reduce peak electrical demand on the grid through cheaper off-peak tariffs and alternative tariff structures.

Naturally, this has led the refrigeration industry to seek new methods and technologies that can satisfy the growing demand for refrigeration, all the while taking advantage of cheaper tariffs.

It really has become an industry onto itself.

One technology that has been recognised as a game-changer in this space is phase change material (PCM). In a relatively short time, and with just a few real-world trials under its belt, PCMs have shown to be more than capable of shifting refrigeration-related electricity loads from peak to off-peak, or from high cost to low.

Still in its infancy, significant research and development work continues to take place to help PCMs step out of the laboratory and into the real world.

Take for instance the use of PCM thermal storage at Parilla Premium Potatoes in South Australia (HVAC&R Nation, February 2015).

Faced with the prospect of replacing its 14-year old R22 refrigeration system, the family-owned company's isolated farm near the South Australia/Victoria border became ground-zero for the use of a low temperature PCM in a real-world refrigeration application.

The design is based on a 12kW thermal storage system researched and developed by Glaciem Cooling Technologies (formerly Quik-Cool) in partnership with the Barbara Hardy Institute at the University of South Australia.

Exactly 20-times larger than its test counterpart, the Parilla PCM system uses a central ammonia plant to operate only during evening off-peak times to cool a secondary refrigerant (HC30) to a lower temperature of -15°C.

> "PCMs have shown to be more than capable in shifting refrigeration-related electricity loads from peak to off-peak"

This cooled secondary refrigerant is then pumped through stainless steel coils located in four PCM storage tanks, each with a capacity of 720kWh, where it freezes a salt-based PCM before flowing back to a holding tank.

During the daytime operations of the farm, the ammonia plant is cycled off and the HC30 is circulated back through the PCM storage tanks. There it is cooled by the phase change that occurs – this provides cooling to the farm's six large coolrooms.

According to Glaciem's managing director Phillip Henshall, HC30 was selected for its viscosity at low temperatures.

"In the early days of our development, we needed to find a fluid that was still able to be pumped efficiently at temperatures from 20°C to -20°C," he told AIRAH's HVAC&R Nation earlier this year.

"The role of PCMs may also take on even greater significance in the future as energy markets change"

"Other glycol-like fluids were considered, but HC30 was by far the most energy-efficient fluid within the temperature range."

The PCM used at Parilla is a specialised salt-based product developed by the Barbara Hardy Institute and Glaciem Cooling Technologies.

It has undergone years of testing, with the necessary tank-sizing algorithm model for refrigeration loads developed using a pilot plant.

It provides secondary refrigerant temperatures of around -8° to -6°C, making it ideal for use in food-storage applications where coolroom temperatures are typically held between -1°C and 3°C.

RESEARCH MARCHES ON

The University of South Australia's detailed analysis of the system performance at Parilla has revealed positive results.

The analysis was able to demonstrate the capability of the PCM thermal storage system to charge and discharge near its rated capacity, as well as achieve a peak-demand reduction over the summer period.

The PCM tanks at Parilla Premium Potatoes in South Australia use a specialised salt-based product.

In addition, testing after one year has shown that the PCM in use has not degraded.

"We took a vast number of lessons away from the Parilla project," says Julian Hudson, M.AIRAH, director of JCH Refrigeration Consulting and Glaciem Cooling Technologies.

"Working on a small R&D system and then scaling it up to real-life brings up issues that you would not expect or see in a smaller test unit. And this is particularly true of controls and system integration.

"On the face of it, PCM systems appear to be very similar to a hydronic system, or any secondary fluid system. However, system integration, controls and the selection of pumps and valves during the charge and discharge cycles are quite complex. Experience with these challenges can only be gained by being involved with PCM projects."

Another limitation of PCM technology is the availability of suitable phase-change materials to suit various applications.

The salt-based material used at Parilla has unique characteristics, with a freezing point of -11°C and a melting point of -9°, making it suitable only for specific purposes.

Research therefore continues to find a material that will have broader appeal in the Australian market.

"The University of South Australia is currently developing a PCM with a freezing point of -6°, which will broaden the market for PCMs in Australia," says Hudson.

Hudson says there is R&D work under way to integrate solar PV with PCMs – a combination that promises to further reduce refrigeration's dependency on the electricity grid.

The role of PCMs may also take on even greater significance in the future as energy markets change and we arrive at a point where electricity consumers exist off the grid, on micro-grids.

"This is especially true in thermal energy storage (TES) where PCMs can be used with solar PV in the form of thermal batteries," Hudson says.

"Current lithium-ion batteries have a cost of around $500kW/h, whereas low-temperature PCMs are around $180kW/h, making them an extremely attractive option – especially when you have a cooling demand on site."

STICK AND CARROT

One company extending the reach of PCMs beyond commercial applications is Perth-based Phase Change Products (PCP).

Specialising in the manufacture of PCMs with a phase change point ranging from -21°C to 29°C, the company is currently working with major electronics manufacturer LG, with refrigeration in India.

The Ammonia plant at Parilla, which was a finalist in 2014 AIRAH Awards' Best HVAC&R Retrofit or Upgrade category.

According to PCP technical manager Gavin Colbourne, the application of PCM in the freezer compartment of domestic refrigerators achieves the aim of keeping both the fridge and freezer stable during long periods of power outages.

PCP has successfully developed a PC-7 material and, over the past two years alone, has implemented its PC-11 material into over one million refrigerators in the Indian marketplace.

This has significant benefits in developing nations, where electricity grid infrastructure is underdeveloped and supply is unreliable.

The company is also conducting tests on commercial refrigerators, with a view to using PCMs to reduce the number of compressor starts as well as maintain temperature stability when the refrigerator door is opened.

"Applications that require temperature stability, or have a product sensitivity or value, are applications where the use of PCM is evolving," Colbourne says.

He also points to locations where extreme weather can impact the performance of equipment; as can cases of intermittent power supply or restrictions on availability.

CONSIDERING PHASE CHANGE

Julian Hudson, M.AIRAH, director, JCH Refrigeration Consulting & Glaciem Cooling Technologies says those considering the use of phase-change material in refrigeration applications must keep three things in mind.

1. Every project has to be individually analysed to determine if PCMs are suitable, including in-depth analysis of the end user's electricity supply agreement.
2. A clear understanding of the customer's current and future refrigeration requirements needs to be addressed, especially on greenfield sites, where the refrigeration plant infrastructure needs to be installed at the beginning in order to accommodate future expansion of the PCM part of the system.
3. There is much written in the media of the lack of Australian will to tackle global warming, reduce CO_2 emissions and move to a clean-energy future.

But little is said of the work being done by Australian research institutions like the Barbara Hardy Institute, and the fantastic work being done in the RAC sector that is at the forefront of innovation in refrigeration technology, sustainability and in reducing CO_2 emissions.

These factors were behind PCP also dipping its toe into the agricultural industry when it retrofitted a PCM thermal storage system to a 405-hectare carrot farm about 100km north of Perth (Ecolibrium, August 2012).

Requiring increased cooling capacity, but unable to add more chillers to its existing plant due to restrictions with electricity delivery to the farm, PCP retrofitted a 1,600kW/hr thermal storage system that was charged at night to take advantage of off-peak tariffs.

This also provided the advantage of operating chillers during the lower night-time ambient temperature experienced in this part of Western Australia.

PCP's design used the farm's existing chiller set by connecting it to two large, insulated thermal storage tanks via a plate heat exchanger.

Each tank holds a proprietary PCM – in this case PC-4, which is a non-hazardous, inorganic hydrated salt solution –

PCM is used in many applications, including to refrigerate carrots on a farm north of Perth.

encapsulated in HDPE plastic panels. Chilled glycol is passed through the tanks at night, cooling the panels, with phase change occurring at around -6°C.

The temperature of the tanks then continues to fall to around -11°C, at which time the system is fully "charged" and is cycled off.

During daylight processing hours, harvested carrots are cleaned and chilled by a hydrocooler. This features glycol plates through which cold glycol from the storage tanks is circulated.

This system also uses a sophisticated control program to measure the temperature of leaving and returning glycol to achieve maximum system efficiency.

According to Colbourne, the latent energy from the PCM thermal storage tanks provides eight to 10 hours of additional cooling, depending on the through-put and load of the processing plant.

VIABILITY

Although Colbourne says the capital costs of PCM refrigeration systems are significantly greater than conventional systems, these are typically paid back through the use of cheaper, off-peak tariffs.

The higher capital costs can also be offset in some circumstances by avoiding the purchase of more equipment such as chillers, as was the case at the Gingin carrot farm.

With that being said, he warns that no two PCM systems are alike.

"Each PCM system is different, particularly in regard to how the energy is delivered," says Colbourne.

"The use of head units as heat exchangers, for example, to transfer energy via water or glycol, requires tanks for storage and is usually incorporated into the BMS. Fans are also very useful for transferring energy in passive PCM applications."

"According to proponents of PCM systems, the risks are few"

And he says knowledge and first-hand experience are critical.

"Knowing how PCMs operate is essential," says Colbourne.

"Information can be obtained by contacting reliable PCM suppliers, but hands-on experience always achieves the best results in understanding the function and factors required for success."

According to proponents of PCM systems, the risks are few and far between.

Aside from the obvious ones, such as damage to the PCMs via overheating, most of the risk exists at the design stage and the consequences associated with failing to then meet cooling demand.

GETTING IT RIGHT

Phase Change Products technical manager Gavin Colbourne has some direct advice around phase-change material (PCM).

1. Select the correct PCM for the application (i.e. refrigerator or freezer)
2. Determine the amount of PCM required for benefit
3. Consider the placement of PCM to deliver the best heat transfer
4. Use small fans to greatly increase energy transfer in passive systems.

Storage rooms at Parilla Premium Potatoes.

Hudson says a poorly designed system could become over-reliant on grid-fed electricity at peak times, which impacts on system operating costs.

"A system that fails to keep below the peak KVA demand during summer months and business hours; or one which has to run the main refrigeration plant during the day using more expensive peak electricity, are obvious risks," he says.

However, he says the risk of plant failure is generally mitigated by the "bolt-on" nature of PCM systems such as the one used at Parilla.

"If the PCM part of the system fails," he says, "the client's existing system still has the capacity to cope with the refrigeration demand."

"But overall, the feasibility of using PCMs in refrigeration applications is quite complex and depends on a number of factors, including the customer's energy contract, the existing refrigeration plant and the type of process."

CHANGE IS COMING

Sectors thought to be good candidates for PCM system retrofits in the future are food cold storage, and the dairy and wine industries where refrigeration demands are significant.

Modelling conducted by the University of South Australia, based on New South Wales energy tariffs, has shown a payback period of just over five years on a 2mW dairy facility.

"We believe that for a project of this scale," Hudson says, "a five-year payback is feasible.",

Payback periods should also decrease as the cost of energy continues to increase.

Greater take-up rate and acceptance of PCM systems are likely to reduce system cost, spur on greater competition and make large-scale installations more cost-effective.

Change, it appears, is just around the corner.