EYE FOR DETAIL

The replacement of an aging R22 refrigeration system storing potatoes became the catalyst for the first commercial implementation of a thermal storage solution years in development. Sean McGowan reports on an AIRAH Award finalist.

Parilla Premium Potatoes is one of South Australia's leading potato, onion and carrot growers. A 25-year-old family-owned business, it produces more than 55,000 tonnes of fresh produce annually for both local and international markets.

Crops are produced under centre-pivot irrigation at two properties – Parilla in the Mallee region bordering South Australia and Victoria (named after an Aboriginal word meaning "cold place") and another in Robe on the south coast.

This allows the company to take advantage of the varying climates at each location, where potato varieties such as Russet Burbank and Kennebec thrive.

Expansion over the years has seen the company supply the fresh potato market year-round, with major customers including McCain Foods and Woolworths.

To cater for demand, the Parilla property has become the centre of farm operations. It features a packing shed, carrot wash bay, and large cool-storage facilities capable of storing up to 3,000 tonnes of produce.

Given its location in the dry Murray Mallee, the facility's refrigeration system is under constant attack from high summer temperatures and dusty conditions, resulting in significant wear and tear.

In 2012 the company made the decision to upgrade its 14-year-old R22 refrigeration system. Evaporators had begun leaking, compressors were worn and running costs were rapidly escalating.

Additionally, the phase-out of R22 under Australia's obligations to the Montreal Protocol meant the cost of replacement refrigerant had become prohibitive.

RESEARCH AND DEVELOPMENT

Meanwhile in Adelaide, Alltech Refrigeration's research and development (R&D) arm, Quik-Cool Cooling Technology, was making significant headway in the development of phase change material (PCM) technology for the refrigeration industry.

Having partnered with the Barbara Hardy Institute at the University of South Australia, Quik-Cool was assisting the institute to commercialise the use of a specialised salt-based PCM with thermal storage unit technology (as featured in AIRAH's Ecolibrium, April 2013).

So when Parilla Potatoes contacted Alltech Refrigeration to upgrade its refrigeration plant, Alltech immediately recognised the potential to take Quik-Cool's theory to practice.

And as the farm's isolated location meant no more power could be delivered to the site, PCM technology appeared to be perfect for the application.

"The client wanted to replace the existing system with a best-practice system that was environmentally friendly," says Quik-Cool's director, Phillip Henshall.

"Alltech thought that it would be an ideal fit to implement Quik-Cool's commercial thermal storage solution to reduce energy consumption and environmental impact," Henshall says. "The project fit, and an Australian government CleanTech grant meant that economics worked to implement the first commercial prototype."

CONSIDERING OPTIONS

The Parilla cold storage facility consisted of five large, individual refrigerated storage rooms capable of storing over 3,000 tonnes of fresh produce.

They were serviced by a parallel rack featuring three suction gas-cooled semi-hermetic compressors operating on R22, with a capacity of 190.5kW at -10°C saturated suction temperature (SST) and 47°C saturated condensing temperature (SCT). The estimated total heat of rejection of the rack was 271.2kW.

Condensing was achieved by an air-cooled condenser with an estimated capacity of 39.9kW per K TD, operating at 6.79K.

Alltech Refrigeration presented three replacement options to Parilla Potatoes.

The first was to install an air-cooled direct-expansion system operating on R134a, a commonly used refrigerant in commercial medium-temperature applications of this type.

Although this solution offered lower initial capital costs, the introduction of the carbon- equivalent levy on HFC refrigerants in July 2012 moved the goal posts, with the list price of R134a rising to approximately $182/kg.

Of course, the carbon-equivalent levy has since been removed, but at the time of design and construction, there was no indication that the levy would be repealed.

So in order to reduce the R134a charge and "future-proof" the system, Alltech suggested that cooling be achieved by circulating R1270 (propylene glycol 30 per cent) in a secondary plant, requiring two semi-hermetic screw compressors with a capacity of 196kW at -10°C SST and 49°C SCT.

The other option, however, was to adopt a system that while still in its infancy, promised significant savings.

Quik-Cool's solution was to use a central ammonia (R717) plant to operate only during the evening using off-peak electricity to cool a secondary refrigerant (HC30) to a lower temperature. This in turn would freeze a PCM held in storage tanks.

During daytime operations, the R717 plant would be cycled off and the HC30 cooled by the phase change in the PCM.

Secondary fluid pumps that circulate HC30.

The proposed system consisted of two open-drive screw compressors with a capacity of 200kW at -18°C and 35°C SST.

All three systems were analysed in accordance with AIRAH's Methods of Calculating TEWI 2012 Best Practice Guidelines so as to quantify which would give the lowest power consumption, running costs, environmental impact and exposure to the HFC Levy.

The analysis determined that the PCM option would consume 37 per cent less power, even though it would operate at a lower SST.

To determine running costs, an on/off-peak electricity tariff of $0.23 and $0.11 respectively (supplied by the client) was used. Again, the PCM option was shown to be superior, with a 70 per cent reduction in annual running costs compared to the R134a alternatives.

Similarly, the total equivalent warming impact (TEWI) over a 15-year lifecycle for each refrigerant plant showed the PCM option to be 42 per cent less.

"Based on this analysis, it was clear that that the R717/HC30 plus PCM system was the best option," says Henshall.

"The key factor in its performance is the ability to only operate the central R717 plant during the night, using only off-peak electricity."

Henshall says the R134a option also had the disadvantage of being subject to the HFC levy, which at the time had only just been introduced.

TEWI calculations had predicted the total operational leakage over 15 years to be 561kg. At the then-price of $182/kg, this would equate to an additional $102,102 in refrigerant costs over the plant's life – an average monthly cost of almost $7,000.

"Although the capital investment for the PCM option was 51 per cent more," Henshall says, "the pay-back period, based on energy consumption, was less than three years."

Tanks that house the specialised salt-based PCM used commercially for the first time.

AMMONIA AND HC30

The ammonia design and specification was carried out by JCH Refrigeration Consulting. The ammonia chiller's primary function is to cool the secondary refrigerant, HC30, which in turn provides thermal energy to the PCM.

In order to keep the ammonia charge of the package to a minimum, Alltech designed water to circulate via a closed loop through a fluid cooler, and pump through both the condenser and oil cooling PHEs.

This drastically decreases the amount of ammonia in the chiller, such that it has an operating charge of less than 50kg.

During the charging cycle, HC30 is pumped from the warm tank through a flooded ammonia PHE, where it is cooled down to -15°C. Here, the system only requires enough ammonia to form a liquid seal in the accumulator vessel, and to flood the PHE with liquid.

The minimum level in the accumulator is maintained using a pressure differential sensor, which senses the change in pressure as the liquid level in the accumulator fluctuates. It sends a 4–20mA signal to the programmable logic controller (PLC), which then outputs a 4–20mA signal to a valve assembly, which injects liquid into the accumulator at the exact rate required.

This -15°C HC30 is then pumped through stainless steel coils located in four PCM tanks, each with a total capacity of 720kWh. Here, the HC30 freezes the PCM before flowing back to the cold HC30 tank.

The ammonia chiller has been installed in an air-tight plant room with explosive-proof extraction fan and motorised dampers. It is air conditioned using an HC30 evaporator piped to the main system.

According to Henshall, HC30 was selected due to 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," Henshall says. "Other glycol-like fluids were considered, but HC30 was by far the most energy-efficient fluid within the temperature range."

"For example, propylene glycol with a freezing temperature of -30°C would have a viscosity of 157cSt compared to 4.5cSt of HC30. This drastically reduces the amount of pump power required to circulate the secondary refrigerant, therefore reducing running and installation cost."

During the discharge cycle, the ammonia chiller is designed to be turned off, and the HC30 PHE on the chiller is bypassed with a three-way valve. The HC30 circulates through the stainless steel coils in the PCM tanks using latent heat stored in the PCM to provide cooling to the cool rooms.

THE PCM

The most commonly used PCM in such applications is ice, which has excellent thermal storage characteristics. Yet secondary refrigerant temperatures of around 1°C to 2°C are only possible as the melting point of water is 0°C.

Instead, the PCM used in the new Parilla Potatoes refrigeration system is a specialised salt-based product developed by the Barbara Hardy Institute with Quik-Cool.

It is able to provide secondary refrigerant temperatures of around -6°C to -8°C, making it ideal for food storage where room temperatures are typically around -1°C to 3°C.

According to Henshall, the PCM had been tested and the necessary sizing and thermal load algorithms developed using a pilot plant that had a thermal storage capacity of 72kWh.

But with the Parilla plant requiring thermal storage of 2,824kWh, the greatest challenge was in scaling the technology and sourcing components.

To manage it effectively, the total capacity was split over four tanks – each holding approximately 10,000 litres of PCM with a thermal capacity of 720kW each, 10 times that of the pilot plant.

"This required handling and mixing systems to be designed to mix and transport the fluid to site, as well as tanks designed and manufactured with stainless steel coils over 4.5km long," says Henshall.

Each tank is constructed of stainless steel and insulated with 50mm urethane.

Henshall says the design and manufacture of the tanks and coils took much longer than was planned.

PROJECT SPECS

WHO

Client: Parilla Premium Potatoes

Electrical contractor: Electric Solutions

PCM consultant:
Quik-Cool Cooling Technologies

PCM research:
Barbara Hardy Institute, University of S.A.

Refrigeration consultant:
JCH Refrigeration Consulting

Refrigeration contractor:
Alltech Refrigeration Services

WHAT

Chiller: Bitzer

Evaporators:
Quik-Cool Cooling Technologies

Fluid cooler: BAC

Heat exchangers: Alfa Laval

PLC: Schneider

Pumps: Grundfos

Thermal storage tanks:
Quik-Cool Cooling Technologies

Valve assembly: Danfoss

VSDs: Schneider

Lessons from: Phillip Henshall, director of Quik-Cool Cooling Technologies

1. Thermal energy storage for commercial and industrial medium-temperature refrigeration applications is a valid technology that should be considered for use in the industry.
2. It is very important to have a customer who is willing to take on the challenge of a ground-breaking technology.
3. It is a longer journey than one expects, from R&D to commercial application.
4. Government support for innovation by way of the Australian Cleantech Innovation Grant was important for companies like Quik-Cool and Parilla Premium Potatoes to take the risk to commercialise innovative technology

"Due to the labour time and cost, we had this specially made in China," he says. "While this reduced the cost, it meant it took longer and required close supervision to have it made to the quality required."

Subsequent to this project, Quik-Cool has re-designed the coil and tank to make manufacturing substantially cheaper and easier.

COOL ROOM DESIGN

Potatoes and onions require strict humidity control, temperature control and air flow to remain in good condition during storage.

However, because each vegetable's storage requirements are different, the system was designed to switch between potato mode and onion mode as the produce changed throughout the year.

The system also needed to bring the temperature down quickly after the rooms were filled from harvest, and then hold temperature, humidity and airflow for up to six months until all produce was moved.

The Parilla cool rooms have been designed such that the whole cooling space is controlled, together with temperature and humidity monitoring, while allowing the system to have flexibility with the recirculation/forced-air cooling section.

The system features specially designed evaporator coils that are coupled with electronic control to provide quick and accurate control over temperature and humidity.

The refrigeration system is controlled by a PLC that has more than 150 analogue input measuring points installed, as well as complex site-specific software routines that ensure the smooth interface of all refrigeration components.

Each room is fitted with three pulp probes, two air-temperature probes and two humidity sensors. These are placed evenly throughout each room to provide accurate readings for product temperature and humidity during storage periods.

A SCADA (supervisory control and data acquisition) monitors package logs, records all data points and allows for full remote web-based access. The mains supply entering the main electrical distribution board is also measured.

The evaporators for each room were specially designed and manufactured for the project, and feature a separate closed-loop circuit that uses warm HC30 for defrost.

"Not having any defrost heaters fitted to the evaporators drastically reduces the energy consumption of the evaporators, and significantly decreases the overall running cost of the system," says Henshall.

Additionally, all compressors and pumps (except warm glycol) have variable-speed drives (VSDs) fitted, further enhancing the overall efficiency of the plant.

COOL POTATOES

The new refrigeration plant at Parilla Premium Potatoes was commissioned in July 2013, with the PCM plant commissioned the following March.

It has since performed better than expected, as well as managing to handle the addition of a sixth cool room (outside the original system design specification) just a month after commissioning.

The Barbara Hardy Institute has been commissioned by Alltech to carry out energy analysis over an operating period of one year to independently verify the energy savings.

Preliminary results are promising, with savings in line with those predicted in the initial report. Validation is expected this summer.

"Our original detailed engineering analysis calculated a return on investment of approximately three years," says Henshall. "And we are very confident that over summer we will confirm the energy savings that were originally projected."

He says this project also demonstrates what can be achieved by industry collaborating with academia.

"It shows how new technology can be brought from conception through to research and development, and finally to the marketplace," Henshall says, "in order to meet the continuing challenges faced by the refrigeration industry." ▲