Ice pigging for dairy applications

Case study

Contents

Acknowledgements

The Carbon Trust would like to thank the University of Bristol, Yeo Valley, BV Dairy and the Regional Growth Fund for their work and support for this project.

Ice pigging is a method of cleaning pipework using an ice slurry. Trials carried out in commercial dairies indicate significant potential for ice pigging to improve productivity of dairies while reducing environmental impact.

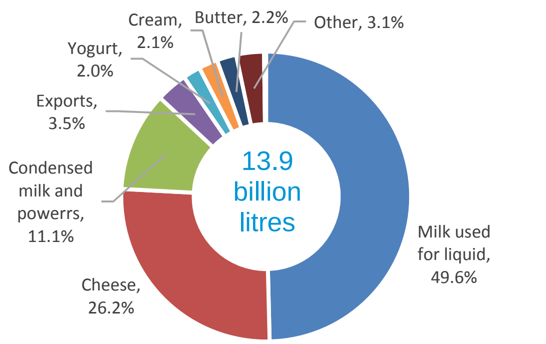
When operated on a standalone basis, ice pigging could generate an additional c. £132,000 in revenue per year for a single dairy site by recovering saleable product from production lines. When fully integrated into a dairy facility, ice pigging could deliver a further c. £115,000 per year though increased productivity by reducing the time needed for cleaning, thus allowing for increased production.

Additionally, ice pigging could offset the use of up to 25 tonnes of water per day, while also significantly reducing Chemical Oxygen Demand sent for treatment or sewerage.

1 Background

In 2013/14, UK dairies processed 13.9 billion litres of milk for a range of end uses, as shown in Figure 1. Approximately half is sold as liquid milk, a quarter is used to make cheese, and the rest is used to make other high value products like condensed milk and powders, yoghurt, cream, butter and sent for export.

Figure 1 - UK milk processed by end use in 2013/14



The British dairy sector globally delivers £9.81bn in annual sales[1], and during 2013 the then top five UK dairy processors' capital investment was in the region of £266 million[2] (the industry has since seen significant consolidation).

The dairy processing industry currently uses around 33 million m^3 of water per year[1], and many of those within the sector have agreed to reduce water brought on to site by 30% by 2020 compared with 2008 as part of the Dairy Roadmap[1].

In addition to this, the industry is also aiming for:

> **A 20% relative reduction in Chemical Oxygen Demand (COD)** load in discharged effluent by 2015

> **A 15% improvement in energy efficiency** by 2020

> **A 20% relative reduction in pre-primary treatment effluent** by 2020

One approach that may help the industry meet these targets is ice pigging.

Ice pigging

Ice Pigging is a method of cleaning pipework by injecting an ice slurry that scours the internal walls. Invented by Professor Joe Quarini at the University of Bristol, the process has been successfully used in the water industry since 2010, and its introduction into the dairy processing sector would provide a number of benefits:

[1] Dairy Roadmap, 2013, 'Dairy Roadmap 2013 – Environmental Sustainability Report' [Available Online: http://dairyroadmap.com/wp-content/uploads/Dairy_Roadmap_2013b.pdf]

[2] Dairy UK, 2013, 'The White Paper 2013 – A guide to the UK Dairy Industry'

> **Reduced duration of cleaning process** meaning less down time and possible increased productivity

> **Increased product recovery** resulting in fewer production and cleaning cycles required to produce the same quantity of product

> **Reduced water use** during cleaning process by replacing pre CIP rinse and therefore reduced effluent production

> **Reduced chemical disposal requirements** through reduction of Chemical Oxygen Demand

These may in turn give rise to a number of secondary benefits including energy and cost savings.

This project aimed to demonstrate the feasibility and achievable benefits of using ice pigging to clean dairy production lines. This formed part of a package of industrial demonstration projects across four sectors funded by the Regional Growth Fund (RGF) with a shared aim of promoting a step change in the energy efficiency in industrial processes.

The project was undertaken by four principle stakeholders, with support from the Carbon Trust:

> Yeo Valley

> BV Dairy

> Pure Clean Ice Pigging (PCIP)

> The University of Bristol

Successful trials were carried out at Yeo Valley and BV Dairy owned production facilities.

Yeo Valley Farms is the UK's number one organic dairy brand, producing a range of products including yoghourt, milk, butter and cream. Ice Pigging trials were undertaken at Yeo Valley Farms, Newton Abbot on the Surprise production line.

BV Dairy is an independent dairy manufacturer processing 28 million litres of locally sourced milk each year. Further Ice Pigging trials were undertaken at BV Dairy, Shaftesbury.

Ice pigging patent aquisition

In 2014, Aqualogy UK acquired global rights to the ice pigging patent developed at the University of Bristol, for use in all sectors[3].

Aqualogy has been carrying out ice pigging operations very successfully in the water sector since 2010, and is now seeking to expand its operations to provide ice pigging services in new sectors.

[3] Aqualogy UK is the global technology and solutions division of Suez Environment

2 Production

The Ice Pigging process was implemented in a number of trials on production facilities operated by Yeo Valley Farms and BV Dairy. These production facilities are described below and shown schematically in Figure 2, Figure 3 and Figure 4.

Yeo Valley Farms: 'Surprise' Custard

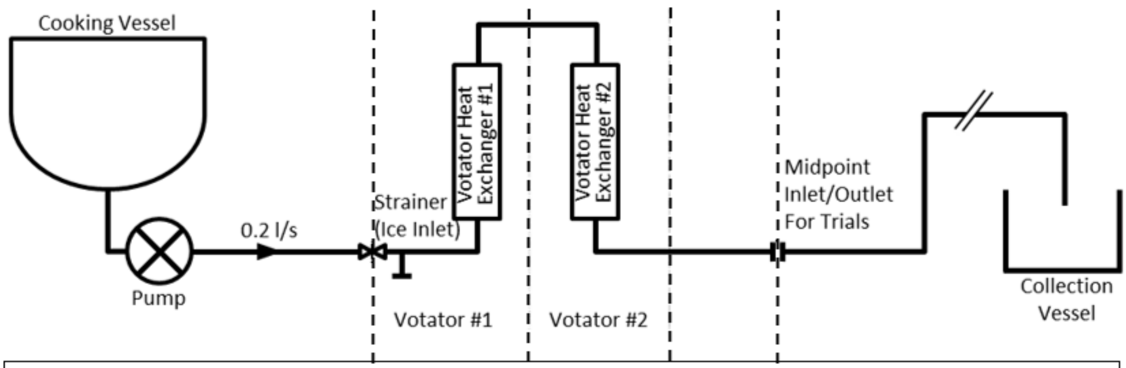
Surprise is a flavoured custard-like product produced in batches of 500 litres. Cooked in a low-risk area, the product – at 86°C – is pumped at approximately 0.2 litres per second through 6m of 2" internal diameter stainless steel pipework to two Votator scraped surface heat exchangers. This line contains a strainer to provide an inlet for the ice during the trials (Figure 2).

Each Votator consists of a 2" shaft holding multiple plastic blades, inside a tube of 4" internal diameter. Coolant is supplied to a jacket surrounding the tube and the shaft is rotated to aid heat transfer and reduce fouling on the cooled surface.

The first Votator is cooled by ambient water in the jacket, reducing the product to around 20°C. The second Votator is cooled by chilled water, which reduces the product temperature to 11°C.

The product then travels from the Votators to a collection vessel in a high-care area through 20m of 1.5" internal diameter stainless steel pipework. This delivery line can be broken at the midpoint forming an outlet for some of the trials.

Figure 2 - Yeo Valley Farms 'Surprise' Production Line



Temperature	86°C	Chills to 20°C	Chills to 11°C	11°C	11°C
Internal diameter	2"	4"	4"	1.5"	1.5"
Length	c. 6m	c. 3m	c. 3m	c. 1.5m	c. 20m
Volume	c. 12l		c. 48l		c. 23l

BV Dairy: Milk and Marscapone Delivery

Two products were trailed, Milk and Mascarpone. at trials. Milk is delivered to BV Dairy by tankers to two storage tanks through approximately 12m of 2" internal diameter stainless steel pipework. The tanker connects a flexible hose to a flow plate from which the milk passes through a centrifugal pump and magnetic flow meter. The milk arrives at a T-Junction through which the flow is diverted to one of two holding tanks. This delivery line is shown in Figure 3.

Mascarpone is made in batches of approximately 1000 litres during which it is held at 90°C. Part of this procedure involves circulating the batch from a storage vessel, through a powder mixer where ingredients are added, and back into the storage vessel. This cycle continues until the ingredients have been sufficiently incorporated into the mixture.

The batch is then transferred between the storage tank and the mixer through two 1.5" internal diameter flexible hoses, each 5m in length. The powder mixer contains two inline mixers as shown in Figure 4.

Figure 3 - BV Dairy Milk Delivery Line

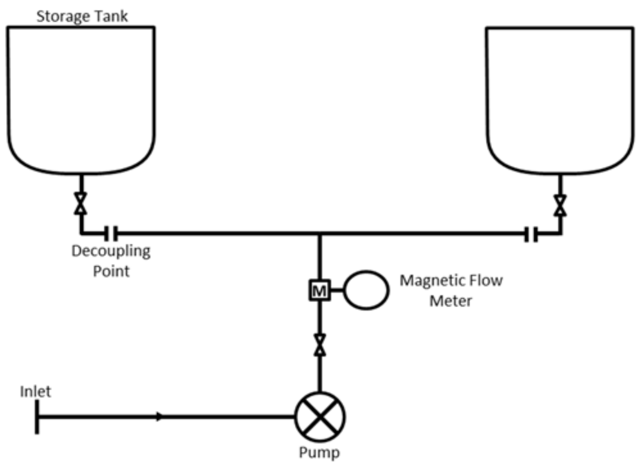
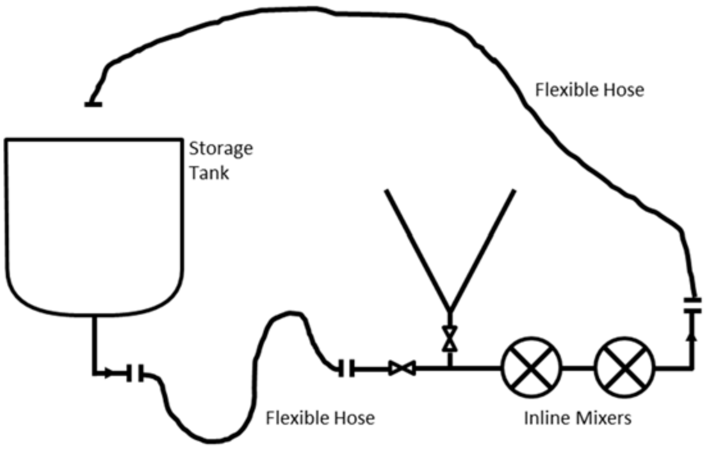


Figure 4 - BV Dairy Mascarpone Mixing Circuit



3 Cleaning processes

The three production line setups – one at Yeo Valley Farms and two at BV Dairy – currently employ broadly similar cleaning processes. These consist of a water based flushing phase followed by a caustic sanitation process. The ice pigging process provides a potentially more efficient alternative to the water based flushing phase.

Yeo Valley Farms: cleaning process

Once the cooling process through the Votator heat exchangers is complete the line remains full of product (c. 83 litres). Thirty litres of water are added to the cooking vessel and pumped through the system. This purges an additional 30 litres of product without risk of collecting a water/product mix. The remaining c. 53 litres of product in the line is considered unrecoverable.

The cooling water to the Votators is switched off and the system is then flushed with as much as 500 litres of water. Such a high volume is required as the water tends to 'rat' through the centre of the product pipes, only very slowly stripping away material from the pipe walls. This water/product mix becomes effluent which must then be disposed of appropriately at considerable cost.

Once the flushing is considered to have cleaned the system of product sufficiently a hot Clean in Place (CIP) sanitation process is employed.

BV Dairy: milk delivery and mascarpone cleaning process

The cleaning of the delivery line begins by flushing the line with a hot water pre-rinse. This is followed by circulating a hot caustic solution for 15 minutes, before a second water flush, and finally a disinfecting peracetic acid rinse.

The ice pig process

Purpose built equipment was constructed by PCIP and combined with appropriate instrumentation to monitor flow rates, temperatures and concentrations.

For both facilities (Yeo Valley Farms and BV Dairy) ice was made using a commercial ice maker rated at producing two tonnes of ice per day. It was fed with a solution containing 10% sugar (used as a freezing point depressant) from a horizontal stirred tank and returned high ice fraction slurry to the top of the tank. The sucrose solution was recirculated in this manner until the entire batch reached the desired ice fraction. Ice fraction was measured using a coriolis mass flow meter to determine the concentration in the remaining liquor. This was then confirmed using a cafetière. For each of the trials an ice fraction of 75-80% was desired.

A progressive cavity pump located at the base of the tank was capable of delivering the ice slurry at up to 12 bar and 2 litres per second. A centrifugal pump, also located on the rig, provided the ability to push the ice pig with water at the same specification.

The outlet of the ice slurry delivery unit was connected to 8m of 1.5" internal diameter reinforced flexible hose to allow connection to dairy equipment. For each trial, prior to connection to the dairy system the flexible hose was first purged with ice slurry until consistently thick slurry was received at the outlet.

Once the output from the ice pigging process is considered clean and free from product, the process can be continued depending on the specific requirements of the operation:

- provided there are no hygiene or cross contamination issues, the next product line can be immediately run through the equipment as the ice pig will have acted as a product separator, saving time;
- if hygiene is a sensitive issue, then a CIP procedure would be implemented, however, because the ice pig has removed most of the 'soil' from the pipework. The CIP process is completed faster and with less consumption of chemicals than a standard CIP sanitation process which had not benefited from a pre-ice pigging clean.

In both cases, the use of ice pigging results in water saving and valuable reduction in down time.

4 Trial results

A number of different trials were conducted at each of the facilities in order to get a complete picture of the potential of ice pigging as a cleaning process within dairy production facilities. These results are described below.

Yeo Valley Farms

The hose from the ice slurry delivery unit was connected to the Surprise product delivery line in one of two points: (a) in place of a strainer usually attached to the system upstream of the Votators, or: (b) a midpoint in the delivery line downstream of the Votators.

A total of seven trials were undertaken consisting of three variations of setup:

1. **Ice pigging only the Votators**. The ice pig is injected at the strainer and received at the midpoint downstream Votators
2. **Ice pigging only the delivery line downstream of the Votators**. The ice pig is injected at the midpoint downstream of the Votators and received at the product collection vessel
3. **Ice pigging the entire system**. The ice pig is injected in place of the strainer and received at the product collection vessel.

Details of each of the seven trials is summarised in Table 1.

During the **first trial** it was found that the ice slurry delivery hose would not connect onto the strainer fitting. It was instead attached upstream of the strainer. However, it was soon discovered that the strainer acted as a 'dewatering' device on the ice slurry, producing a solid bullet of ice which blocked the system. As a result, this first trial was abandoned until the correct fitting to attach the slurry delivery system in place of the strainer could be found. Hence, the second trial forms the first full trial of the process on the Yeo Valley Farms Surprise product line.

The **second trial** pushed ice into the Votators following the initial 30 litre water purge, meaning around 15 litres of water and 33 litres of product remained in this section. Thirty additional litres of product were recovered followed by a further 100 litres of water/product mix.

No ice was received at the outlet. This was thought to be caused by several factors. The coolant water was switched off after the initial transfer meaning the product in the system was still warm. The ice also pushed forwards the product at 86°C, which remained in the 4m pipe between the ice inlet and the Votators. This effectively meant the pipe was heated in advance of the ice pig causing a great deal of the slurry to melt. Given this situation, it could also be concluded that insufficient ice was injected to meet the energy demand.

To remedy this, for the **third trial** the injection rate was increased and the cooling water was left running for some 4-5 minutes after the product transfer. The trial was conducted in two stages. Stage A was conducted as per the second trial with the modifications described above. Once clean ice was received at the midway point, the transfer line to the collection vessel was reconnected and stage B pushed additional ice through the system.

The **fourth** and **fifth trials** then investigated ice pigging the delivery line from the Votators to the collection vessel with varying volumes and ice fractions. For the **sixth trial** the Votators were switched off to reduce mixing between the product and the ice pig. Following the ice pig the Votators were switched on and a further 150 litres of water pumped through the system removing additional fouling trapped within them.

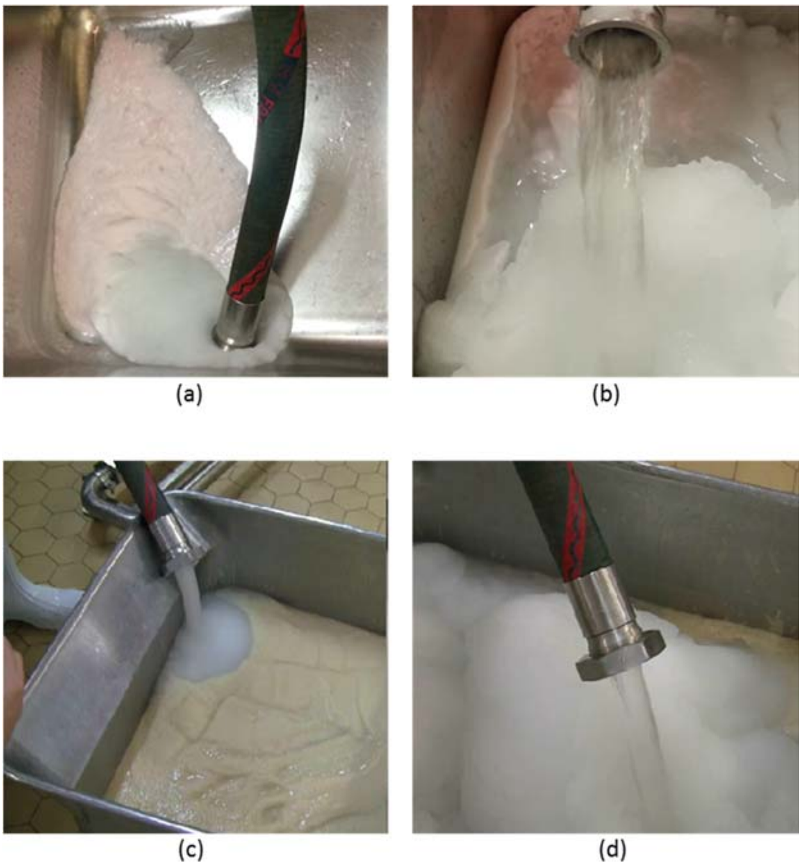
The **seventh trial** investigated the possibility of pigging the entire system in one go.

The trials demonstrated a clear division between recoverable product, mixed product and ice slurry, and clean water/ice. The ice at the outlet was considered clean very quickly following the purge of the product remaining in the system. The amount of mixed product and ice slurry was significantly less than the amount of mixed product and water produced using the existing process. This can be seen in the photos below (Figure 5). This means less effluent is produced for disposal, and may be indicative of the ice pig being more efficient at removing the product from the system. If true, this could also impact the chemical demand during the CIP sanitation process (explored in more detail in the BV Dairy trial).

Table 1 - Yeo Valley Farms Ice Pigging Trials Summary

	Existing	Trials							
		1	2	3		4	5	6	7
				A	B				
Product Line	All	Chocolate	Chocolate	Chocolate		Strawberry	Caramel	Caramel	Chocolate
Equipment	All	(1) Votators only	(1) Votators only	(1) Votators only	(2) Midpoint onwards	(2) Midpoint onwards	(2) Midpoint onwards	(1) Votators only	(3) Votators onwards (entire system)
Ice Slurry Fraction	N/A	75-80%	75-80%	75-80%	75-80%	55%	80%	80%	75-80%
Ice Slurry Volume	N/A	Abandoned	50 l	150 l		80 l	50 l	120 l	150 l
Injection rate		1 l/s	1 l/s	1.5 l/s	1.5 l/s	1.5 l/s	1.5 l/s	1 l/s	1.75 l/s
Additional Product Recovered	~30 l	N/A	~60 l	~60 l	~20 l	~ 20 l	~20 l	~60 l	~80 l
Total Product Recovered	~440l	N/A	~470 l	~470 l	~490 l	~ 460 l	~ 460 l	~470 l	~490 l
Mixed Product & Ice Slurry (or water)	500 l	N/A	100 l	80 l	150 l	<20 l	<20 l	90 l ice +150 l water	50 l ice + 100 l water

Figure 5 – (a) Trial 4 Transition between Product/Ice Mix & Clean Ice; (b) Trial 4 Transition between Clean Ice & Clean Water; (c) Trial 5 Transition between Product/Ice Mix & Clean Ice, and; (d) Trial 5 Transition between Clean Ice & Clean Water



BV Dairy

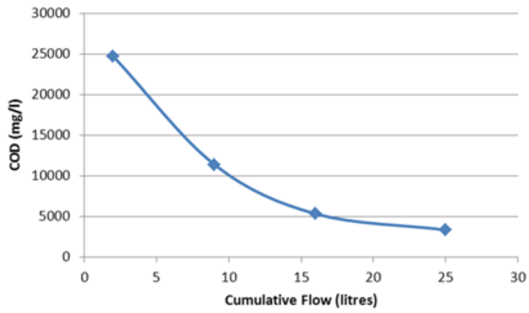
A total of four trials were undertaken consisting of two variations of setup:

1. **Ice pigging the milk delivery line.** The ice pig is injected into the line where the milk delivery tanker would normally connect to the system and received at the decoupling point just before the storage tank
2. **Ice pigging the mascarpone mixing circuit.** The ice pig is injected into the flexible hose upstream of the powder mixer and received at the end of the downstream flexible hose

The **first trial** was undertaken to test the feasibility of pumping a 75-80% ice fraction slurry through the milk delivery line, including the inactive high speed centrifugal pump normally used to move the milk from the tankers to the storage tanks. The ice successfully passed through the pump, displacing the milk in front of it.

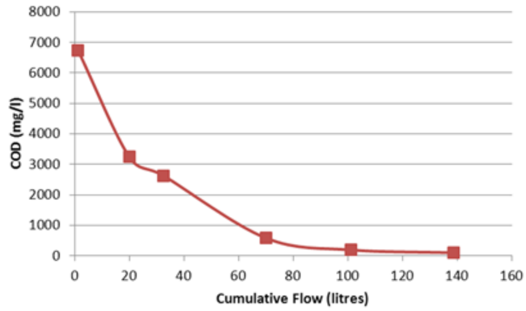
The **second trial** was carried out in the same manner as the first on one leg of the delivery line. A total of **22.5kg** of product was recovered from the line, purged by the pig. This was followed by **9.5kg** of mixed product and ice slurry. Samples were taken of the water immediately following the pig in order to measure the reduction in chemical oxygen demand (COD). The results are shown in Figure 6. The COD was initially very high, thought to result from the sugar in the ice and the milk remaining at the T-junction to the other storage tank. As such these results were considered inaccurate.

Figure 6 – Reduction in COD of Water after Ice Pigging Single Spur (Trial 2)



The **third trial** was undertaken as per the second, but on both legs of the delivery line such that a more accurate measurement of COD could be taken. Ice was first pushed into the original spur, before the outlet was sealed and the second spur opened. Ice was then injected into the second spur followed by water to purge the ice. The second spur was sealed and the original reopened. The ice in this spur was then purged with water and the water measured for COD. Figure 6 shows the reduction in COD after the entire delivery line has been flushed with ice.

Figure 7 - Reduction in COD of Water after Ice Pigging Both Spurs (Trial 3)



For the final trial ice was injected into the mascarpone circuit with the inline mixers turned off. Approximately **15kg** of pure product was recovered followed by **7.5kg** of product/ice mix, and then clean ice.

Ice pig production

Producing ice is an energy intensive process, requiring 9.15kWh per 50kg pig, though more efficient techniques are currently under development.

The trial at Yeo Valley took 24 hours to generate 2 tonnes of ice, and the ice was produced in advance.

The University of Bristol is developing a novel method to produce ice efficiently. The solution would be more economical with commercial scale ice making system.

5 Quantifying the benefits

There are two key processes that ice pigging could replace on commercial dairy production lines:

- Line flushes between production runs, e.g. between products of a similar type
- Pre-CIP rinse

Pre-CIP rinse

Each day, and between production runs of different product types (e.g. yoghurt and ice cream), the lines must undergo CIP, which is carried out using hot acid and caustic to neutralise any remaining biological material that may contaminate the following run.

Before each CIP, lines are flushed with cold water to remove any gross sediment. Ice pigging could significantly reduce the time taken and water needed for this pre-CIP flush by up to 25 tonnes (25 m^3) of water per day.

Depending on how the ice pig is integrated with the facility, this reduction in downtime may translate into greater productivity.

Line flushes between production runs

Lines are flushed when switching between different yet similar products, e.g. yoghurts of different flavours, where a full CIP is not necessary. Product is often removed using a water flush, resulting in wasted product, and a significant quantity of effluent.

As the ice pig has a clearly defined interface between pig and product, as much as 75% of the product in the line can be recovered and sold for additional value.

Analysis of benefits

The Carbon Trust has carried out an analysis that quantifies the benefits of ice pigging for a facility similar to that of the Yeo Valley facility used for the ice pig trial. Assumptions used and methodology can be found in Appendix A.

This analysis is based around two scenarios.

Standalone scenario

Ice pigging equipment is used on a 'standalone' basis, separate from production lines and is not integrated with the facility. Cleaning is carried out semi-manually by a trained operative who pigs each line when necessary.

Under this scenario, capital costs are kept low, as the only equipment needed is to produce and manipulate the ice slurry on an as needed basis.

It is also assumed that in this scenario there are no benefits accessible from reduced downtime, as the time required to set up and disassemble the ice pigging equipment will offset this saving.

Integrated scenario

Ice pigging equipment is fully integrated into the facility. This may involve centralised ice making equipment, an ice slurry distribution unit with delivery pipes and pipe ring mains installed throughout the facility. Ice pigs would be "tapped off" the delivery circuits when required.

Under this scenario, capital costs are significantly higher, but as the ice pigging is fully integrated with the facility and control systems, full savings in downtime could be converted into production. This would significantly increase the productivity of the facility and increase the volume of product that could be sold.

Table 2 - Potential value accessible through ice pigging per dairy per year[4]

Value from	Standalone	Integrated
Product recovery	£190,000	£190,000
Reduced downtime	N/A	£306,000
Total cost (annualised)	£58,000	£133,000
Net benefit	*£132,000*	*£364,000*
Payback	*1.6 years*	*2.2 years*

[4] Underlying assumptions in Appendix A. Figures rounded to nearest £1000.

6 Recommendations for further work

The trials at Yeo Valley and BV Dairy demonstrated that ice pigging has the potential to play a significant role in commercial dairies.

However further work would be valuable to explore a number of areas, including:

- Novel methods of producing ice for pigging more efficiently
- Investigation into energy and carbon benefits
- Integrating ice pigging processes into facility automation systems
- Assessment of opportunities for ice pigging in other sectors.

7 Appendix A – analysis assumptions

The analysis carried out to estimate the potential value accessible from ice pigging through increased productivity and product recovery was based upon a 'standard dairy, using the Yeo Valley facility as a reference point for key assumptions.

Assumptions

Our analysis makes the following assumptions:

- The facility operates continuously throughout the year
- An 'average product' is modelled, which can be sold at £1 per kg, has a density of 1.05 kg per litre, and flows through the lines at 0.2 litres per second
- The facility comprises three lines, which each undergo 3 flushes per day and 1.5 CIP processes per day (on average)
- Based on trial data, c. 85kg of product is recovered by the ice pig, of which 70% can be sold
- Use of ice pigging can reduce the duration of a single CIP by 15 minutes by replacing the pre-rinse, which would be entirely converted to increased production under the 'integrated' scenario
- The capital cost of installing the ice pigging equipment is £250,000 in the 'standalone' scenario, and £1,000,000 in the 'integrated' scenario
- The equipment has a lifetime of 10 years and has a residual value of £0
- Both scenarios require an operator costing £30,000 per year
- 9.15kWh are required to produce 50kg of ice
- The cost of the freezing point depressant (sugar) is considered negligible

Methodology

Value of ice pigging to dairy =
    Annual value of avoided downtime +
    Annual value of saleale produt recovered

Cost of ice pigging to dairy =
    Annual depreciation of capital +
    Annual operational cost (operator + energy cost)

Net value to dairy =
    Value of ice pigging –
    Cost of ice pigging

Payback time =
    Initial capital cost /
    (Annual savings - Annual costs)

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