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HEAT EXCHANGER CLEANING USING ICE PIGGING

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ABSTRACT

Ice pigging is an innovative method of removing fouling from topologically complex and demanding ducts. The process involves pumping ice slurry, a mixture of ice particles and a liquidus containing a freezing point depressant, through the fouled duct. The slurry acts in a similar manner to a solid pig, displacing material downstream of it as well as applying shear and hence mechanical cleaning effort to the duct walls. However, the ice pig is also able to navigate complex topologies which include bends, change in flow areas, open valves and multiple path junctions. This makes the technology suitable for retrofitting to existing process installations with minimal disruption or alterations to the lines. Additional benefits of this technology include: increase in product recovery within the lines, reduction in downtime required for cleaning, reduction in the volume of effluent produced and hence reduction in cleaning water and effluent processing costs, and, reduction in the use of expensive and potentially environmentally harmful cleaning chemicals. Experimental evidence will be presented displaying the performance of the ice pig in different applications from simple pipe topologies to complex plate exchangers. The paper will also identify future applications and required development work to ensure the successful implementation of this new and potentially paradigm shifting technology.

INTRODUCTION

Ice pigging is a patented process for the removal of fouling from ducts (Quarini, 2001), which has been in development, for a number of years at the University of Bristol. The process involves pumping a phase change slurry, of ice particles and liquid, containing a freezing point depressant, through the fouled duct, resulting the application of a high shear force at the wall surface.

Unlike solid physical pigs, which require launch and receive stations, the ice pig is capable of being injected through a small diameter inlet and expanding to fill a pipe, which can be up to 200 times larger in area. This results in minimal engineering work being required on existing pipelines to accommodate ice pigging as a fouling removal solution. Additional, the ice pig is able to adapt to large diameter changes, bends, valves, instrumentation and complex pieces of industrial equipment. When compared to standard water flush, research carried out by Shire (2006) indicates that ice slurry can produce a pressure drop which is at least an order of magnitude larger than that of water flowing at the same velocity.

The main factors influencing the behavior of the ice slurry are: ice fraction, ice particle size and freezing point depressant concentration. The ice fraction can be accurately predicted by measuring the temperature of the ice slurry solution and knowing accurately the initial concentration of freezing point depressant (Melinder and Granryd, 2005). The ice particle size is strongly coupled to the length of time the ice slurry has been stored for, with the particle size increasing with time, due to Ostwald ripening (Hansen et al., 2002; Pronk et al., 2005). The ice fraction and particle size, both contribute to the rheological properties of the slurry and there for the size and geometry of pipe which can be pigged, with a particular slurry. The higher the ice fraction the more the pig behaves like a solid, thus exerting larger cleaning forces on the pipe wall and generating larger pressure drops per unit length. However there is also the risk of blocking the pipe work with larger ice fractions (Shire, 2008). The freezing point depressant (FPD) is added in order to maintain the slurry condition, preventing the ice particles from fusing together, and forming a solid block of ice. Typically sodium chloride is used due to the low cost, minimal health and safety implications and small concentrations required. However many other FPDs have been tested for use in ice pigging, including: sugar, Sorbitol, hydrochloric acid, sodium hydroxide, sodium nitrite and polyethylene glycol. The selection of FPD largely depends upon the operating conditions of the pipeline, with the ideal solution being a component which is already present in the pipeline, present contamination problems.

In the years since the patent was taken out there have been several trials under taken in the food and pharmaceutical industries, where the ice pig has displayed an ability to not only provide a highly efficient cleaning medium, but also significantly improve the level of product recovery, which could be achieved (Quarini, 2002). The ice pig has achieved up to 90% product recovery, when pigging very viscous products in ambient temperature pipelines. These trials were carried out over a range of pipe diameters and lengths, ranging from 0.5 inch to 4” and up to 100m in length. During these trials the pig has also demonstrated the ability to negotiate numerous commonly used pieces of process equipment including: inline mixers, an extruder, mincing stations, dosing units, lobe pumps and mono pumps. In order to improve the efficiency of the cleaning operation and minimise the volume of ice pig required for each clean, Evan et al. (2008), developed a model which predicts the flow and melting behavior of an ice pig traveling through stainless steel pipes, and found good agreement with experimental results based on the ice slurry flowing through 2” stainless steel pipes.

There have been several detailed experiments carried out concerning industrial heat exchangers and ice slurry. As ice has a very high latent heat capacity(333.55 kJ/kg), when compared to the specific heat of water(4.18 kJ/kg/K), a thin ice slurry can provide large cooling energy with a minimal increase in pumping power, hence there have been several studies looking at ice slurry as a cooling fluid (Bellas et al, 2002). However there has also been a study carried out concerning the cleaning properties of the ice slurry on several different industrial units namely, the Tetra Plex C6-SR plate heat exchanger and Tetra Spirflo MTC70/W-3 tube in tube heat exchanger (Shire, 2008). The work demonstrates detailed pressure drop studies for the heat exchangers, using various ice fractions and flow velocities. In general the findings were in agreement with previous ice slurry studies carried out; indicating that the pressure drop increased exponentially with ice fraction and with the square of the velocity.

The prediction of pressure drop for a pumpable ice slurry, and consequently shear force on the pipe wall, is generally carried out through the use of an effective viscosity. Many relationships between the ice fraction and effective viscosity have been developed, with a wide range of results, however the Thomas equation (1) (Thomas 1965) has been the most widely used. This shall be used to estimate the effective viscosity of the ice slurries, used in the following experiments, relative to water. Theoretically this effective viscosity could be used to predict the desired ice fraction for fouling with a known adhesion to the pipe wall

$$\mu_e = \mu_L (1 + 2.5C + 10.05C^2 + 0.00273e^{16.6C}) \qquad (1)$$

Over the previous two years industrial trials have been under taken in conjunction with UK water supply company Bristol Water, to trial the process on live water mains. The fouling encountered falls into several different categories: loose sand on the pipe floor; iron deposits on the pipe wall; manganese deposits on the pipe wall and small stones on the pipe floor. Currently the largest volume of fouling removed with one pig stands at 160Kg, which was achieved with 4.5 tonnes of ice slurry at a cafetiere ice fraction of 80%. The process has been tested successfully on several different pipe materials, including asbestos concrete (AC), Cast Iron and PVC, representing the majority of pipe materials used in the water industry. The process has also been successfully trialed on a large range of pipe diameters and lengths, ranging from 6” to 15” and up to 2.6km in length. Recently Bristol water has reached the shortlist for the Water Industry Achievement Awards, for there work with ice pigging.

EXPERIMENTAL METHODS

Measurement of Ice Fraction

As mentioned the ice fraction has a large influence over the behavior of the slurry, however measuring this accurately can pose significant difficulty (Hansen et al., 2002). As a simple and repeatable method, for everyday laboratory use a standard coffee cafieterie is used, with a scale placed on the side. The container is filled with ice slurry, from a sample tap, shortly before the pig is dispensed, then the container is placed onto a flat surface and the mesh plunger inserted. Finally the plunger is pushed slowly downwards, until no more travel can be achieved.

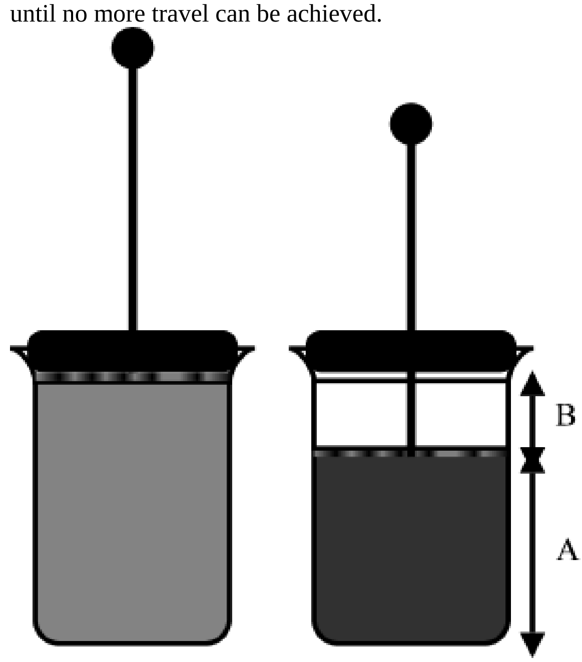

Figure 1 - Ice Fraction Measurement Method

The cafetiere ice fraction is defined as (see Figure 1):

$$\phi_i = A / (A+B) \qquad (2)$$

This method was calibrated against the calorimetric method by Evans (2008) and found to display good repeatability and a conversion factor of 0.66, such that the cafetiere method overestimates when compared to the calorimetric method.

Ice Generation and Storage

A 5% sodium chloride brine solution was circulated through a rotating screw, scraped surface ice slurry generator and stored in a 700 litre stirred tank. Depending upon the ice fraction required the ice machine was turned off when a set temperature was reached. The ice slurry was then recirculated through a Coriolis meter, measuring the density and volume flow rate, using a mono positive displacement pump, at a rate of 0.7 l\s. This was continued until the density measurement had stabilised, indicating a homogeneous ice slurry mixture. The desired flow velocity was set and the ice pig dispensed to the relevant piece of test equipment. Once an appropriate volume of ice slurry had been dispensed, the dispensing pump was stopped and water from a 1” main was used to push the ice pig out of the test equipment.

RESULTS

Four Way Manifold

Figure 2 - Sand Fouling with Water Flow

Figure 3 - Sand Fouling as Ice Pig Enters

Figure 4 - Sand Fouling Almost Removed

Figure 5 – Clean 4 Way Pipe System

The four way manifold is a small scale demonstration of the ice pig’s ability to flow through diameter changes and multiple paths. This geometry could be likened to a simplified pipe bundle. The geometry consists of a 22mm inlet, which splits into 4, 10mm pipes, before recombining to flow out of the 22mm outlet. However geometry inside the manifold is even more challenging shrinking to 4, 4mm diameter holes before enlarging back to the 100mm pipes.

The fouling used was fine grain sand, which is representative of loose small particulate fouling. The fouling was inserted into the pipes by disconnecting them from the manifold and physically pouring in the sand. The sand can be seen to remain relatively undisturbed by water flowing at 0.03l/s, with a total of 5 litres of water was pumped over the sand (Figure 2). The water was then followed by an ice slurry which measured to have a cafetierre ice fraction of 50% (Figure 3), at the same flow velocity, removing the sand from the pipes(Figure 4), and out through the manifold (Figure 5). The 50% cafetierre ice fraction represents a viscosity approximately 5.7 times that of water.

Inline Static Mixers

The ice pig was tested in two commercially available static mixers, the Sulzer and Kennix designs, with various contaminants and ice fraction. In the case of the Sulzer mixer, the pipe being used to contain and view the experiment was a 2.5inch flexible pipe(Figure 6); in the case of the Kennix mixer, the pipe being used was a 75mm solid Perspex pipe(Figure 9).

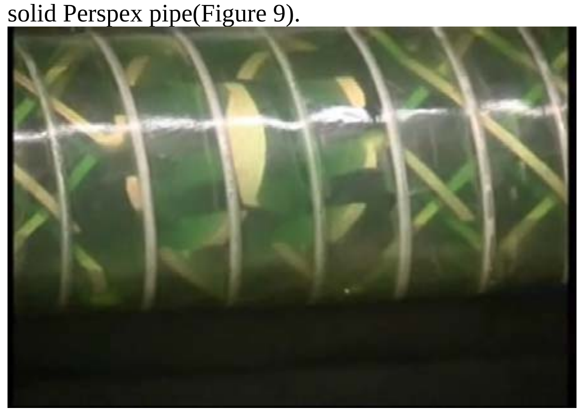

Figure 6 - Sulzer Static Mixer with Detergent


Figure 7 - Sulzer Static Mixer as Pig Enters


Figure 8 - Sulzer Mixer Pigging

Figure 9 – Kennix Mixer Before Pigging

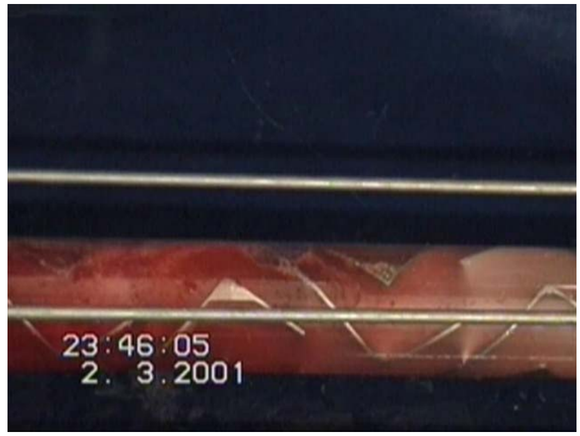

Figure 10 – Kennix mixer during pig insertion

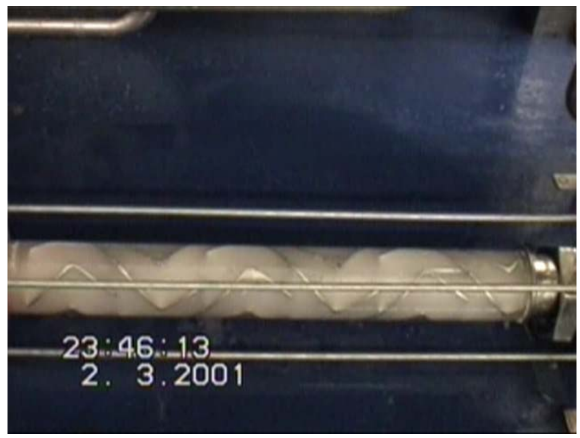

Figure 11 - Kennix Mixer with ice pig

The Sulzer mixer was tested with ice slurry flowing at 0.35 l/s and a cafetiere ice fraction of 80%. The 80% cafetierre ice fraction represents a viscosity approximately 25 times that of water. The test medium in this case was a detergent. The Initial interface of ice and detergent can be seen in Figure 7, and the end of the ice pig in Figure 8. The Kennix mixer was tested with ice slurry flowing at 0.1 l/s and a cafetiere ice fraction of 70%. The 70% cafetierre ice fraction represents a viscosity approximately 12.5 times that of water. The test medium in this case was merely colour water being used as an indicator of location. The Initial interface of ice and detergent can be seen in Figure 10, and the end of the ice pig in Figure 11.

Plate Heat Exchanger Visualization

The plate heat exchanger demonstration consists of a single plate section, which has been mated with a transparent acrylic plate. The transparent plate has been molded to the correct plate profile. In this demonstration the fouling material is a standard jam which was applied to the surface of the clear acrylic, before being assembled along with the matching plate and allowed to set overnight (Figure 12).

Figure 12- Jam fouling before water flow

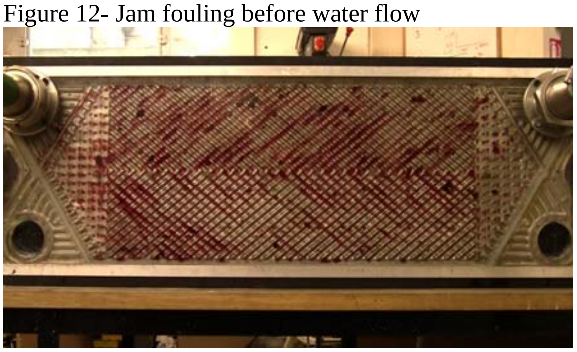

Figure 13 – Jam fouling after water flow

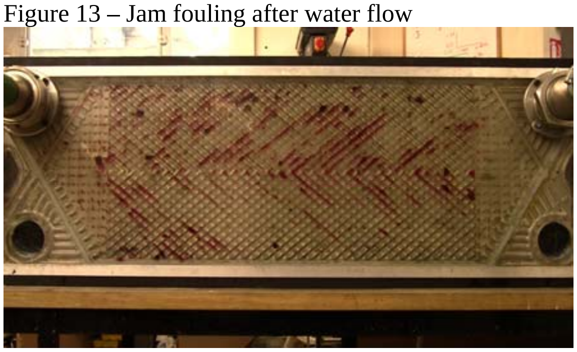

Figure 14 – Jam fouling shortly after ice pig entry

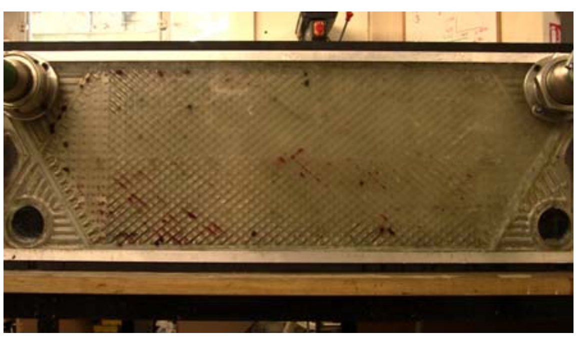

Figure 15 – Jam fouling at the end of the ice pig

Initially mains water at 15 degrees was circulated through the heat exchanger at 0.1l/s, entering and exiting through a 3” port, removing a relatively small volume of the jam (Figure 13). The ice pig was then circulated through the same geometry and was seen to remove the majority of the remaining fouling (Figures 14 and 15). This experiment was carried several times, as initial tests led to the section becoming blocked with ice. This final test was carried out with an ice fraction of 50% by cafetiere.

DISCUSSION

In all four of the tests demonstrated the ice pig was inserted into an inlet which was significantly larger, in effective diameter, than the test piece requiring cleaning. It is also worth noting that the ice slurry was also capable of filling the larger outlet found on both the 4-way manifold and plate heat exchanger. Both were also cleaned to a superior level, when compared to water, with no change in flow velocity or the volume of fluid used. This is due to extensively studied effect of the effective viscosity of the ice slurry increasing with ice fraction (Kitanovski et al, 2005).

The method by which the ice pig removes the fouling is significant, especially for the removal of fouling from small scale pipes. Instead of building up a solid wall of fouling media in front of the pig, as a typical solid pig would do, the ice pig tends to entrain the fouling, removing small amounts gradually. This is particularly visible in the sand and jam tests, 4.1 and 4.3. The entrainment is an important factor resulting in the pig rarely getting stuck in the pipe, due to the fouling blocking the exit point. On occasions when the pig does get stuck, due to the ice slurry being to thick for the application, or particle size being above a critical level, which Hirochi et al(2002) found to be between a tenth and a fifteenth of the pipe diameter, as occurred in the plate heat exchanger, it is a relatively simple process to melt a small amount of the ice and release the blockage. The ice pig never requires disassemble of the equipment, as a solid pig would.

The key issues from the two static mixer tests were the ability of the pig to maintain a plug flow regime under intentional mixing systems. This was particularly important with the detergent trial: the detergent being used reacts with salt in the liquid, to form a liquid with a viscosity several orders of magnitude larger. Hence the detergent had to be removed with minimal mixing; otherwise what was left behind would have been essentially set onto the mixer. This is equally applicable in many situations, where the product or fouling being removed will thicken up as the temperature is lowered.

The Plug flow regime is also critical in the product recovery situation, where minimal mixing with the product is essential. The detergent test carried out was found to recover up to 70% of the detergent over the relatively short experimental route, compared to just 10% with water. It is generally through that with a longer run the recovery rate would have been improved, as the ice-product interface would represent a lower percentage of the total product volume.

When considering the ice pig for real world applications, the type of fouling present on the pipe surface should be investigated. The ice pig is suitable for applications where the fouling could theoretically be removed with water, however operational conditions prevent either the required flow rate being achieved or the cost of the resultant volume of effluent being significant.

Hence hard deposits are not suitable for cleaning with the ice pig.

CONCLUSIONS

1. The ice pig has the ability to flow through various demanding geometries, maintaining a plug like formation. These include multiple paths, static mixers, changes in diameter and plate heat exchangers
2. Ice slurry is capable of applying a high shear at the pipe wall, removing fouling which water, flowing at the same rate, was unable to remove
3. Through tuning the production of the ice slurry, in terms of both FPD and ice fraction required, a particular fouling situation can be successfully met and the fouling efficiently removed.
4. Future work required includes investigating the ability of the pig to deliver a "magic bullet", for example a volume of highly concentrated sanitizer, to a problem area and then remove the magic bullet, with minimal mixing occurring. Thus reducing the effluent produced in chemical cleaning
5. Current ice pigging research being carried out at the University of Bristol, is aimed at improving the reliability of the ice pigging system through creation of an automated unit. The unit is intended to carry out specified cleaning tasks with minimal operator interference.

NOMENCLATURE

ϕ Cafetiere Volume Fraction
A Height of separated Ice
B Height of separated Brine
μ Viscosity
C Volume Ice Faction

Subscript
i ice
e effective
L Liquid

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