WAX REMOVAL FROM LARGE DIAMETER PIPES USING ICE SLURRIES

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Abstract
Ice Pigging is a cleaning technique, mature in the water / wastewater industries, which is being developed for the Oil and Gas industry.

A high-solids ice slurry is pumped under pressure to deliver a wall shear stress on the pipe, cleaning it through physical abrasion. Made of just water and salt, ice pigs do their cleaning, unblocking, debris entraining and transport before melting back into their original components (commonly salt and water); offering a physical clean thousands of times more effective than flushing, without chemicals or risk of getting stuck.

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Introduction
Ice pigging slurry flows like a liquid and cleans like a solid. Although difficult to pump, ice pigs can be pumped through process equipment or any line that will accept liquids, making them very versatile and viable on existing complex pipework with minimal enabling work.

They have some of the carrying capacity of a gel pig and some of the mechanical wall shear of a solid pig. However, ice slurries do not replace 'conventional' utility pipeline pigs, or 'conventional' gels due to having a broadly different operating envelope, ice pigging is being offered as a new option for "unpiggable" pipe cleaning.

To clean a pipe, the ice pig is injected into one end of a flooded pipe under pressure, typically through a ~80 mm inlet, and is propelled along the pipe by the process fluid, push water or perhaps 'dead oil'. The dirty ice and its melt then exits the pipe at the other end and is disposed of or processed, this can also be through a similarly small outlet fitting. The amount of ice required to clean a pipe before it melts away depends on the pipe volume, material, temperature and velocity it is pushed through the pipe – but usually pipe volumes between 6 and 10 times the ice pig volume. In the water industry 35 m3 ice slurries are deployed regularly.

The ice pig's acts like a 500-metre-long pumpable sponge. The largest diameter ice pig used successfully so far is 700mm. The upper limits of ice pigging are not well known and restricted only by existing equipment volume and pressure limits.

The ice slurry used in ice pigging is a high solids mixture of ice and water with an added freezing point depressant (FPD) to prevent it from freezing into a solid block, thereby remaining flowable. The FPD choice varies according to any chemical function required in the pipe, in addition to the abrasion of the ice. If the pig is required to melt back into the sea in an environmentally friendly manner, for example to clear seawater intake pipes, then salt is chosen. FPD's that make functional chemical ice pigs can be used and include sodium hydroxide for degreasing and nitric acid for pickling steel pipes, alcohols are sometimes used if the customer objects to salt. In other industries FPD's include glycols, citric acid, sugar, lactose, biocides etc.

The crucial attribute of ice pigging slurry is its ability to exert a cleaning wall shear as it flows through the pipe. This is largely dependent on ice fraction (solids fraction), but crystal size, shape and FPD concentration also play a part. The ice can be made to suit specific cleaning requirements, for example to gently lift settled solids from fragile pipes we might use a soft ice that exerts an 80 Pa wall shear, whereas to remove a strongly adhered petroleum wax we might have to go above 400 Pa wall shear– which has logistical challenges on a large scale.

Due to its fluid nature and eventual melting, ice pigs can be used in dual or multi-diameter pipes, tight radius bends, tees and wyes, butterfly and check valves, pumps, complex process pipework, pipes with probes, flexible risers, tie backs etc. etc. all without risk of getting stuck (for very long) or lost. However, their finite longevity means they can only be used effectively for short pipe lengths compared to conventional solid pigs.

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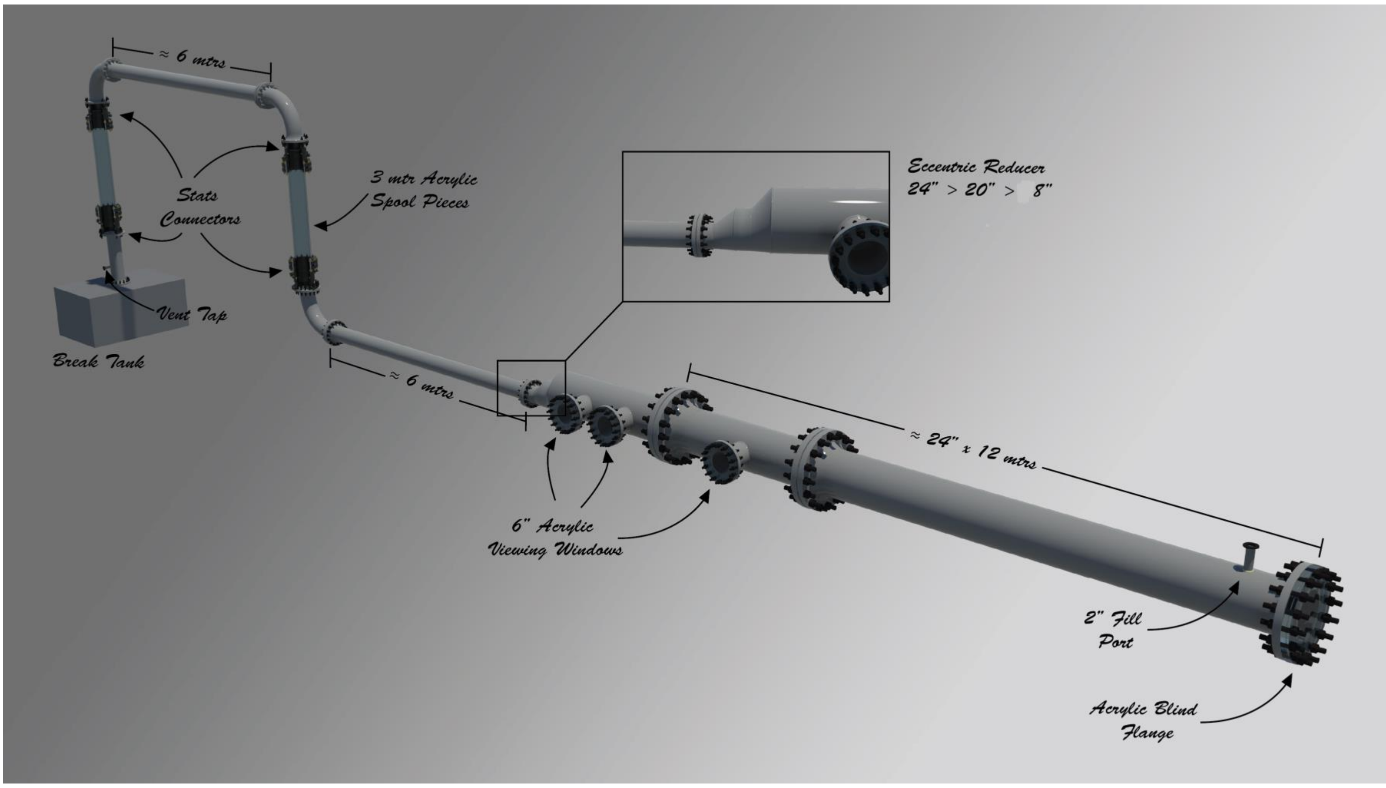
Ice pigs exert their shear progressively along their length as they have softer fronts than solid pigs due to melting, this tends to prevent ‘bulldozing’ of debris into blockages which is another flow assurance safety feature. Also, debris which is often abrasive itself, is lifted from the wall and is entrained in the bulk of the ice pig, rather than being squeezed between the pig and wall, preventing pipe damage. The friable and permeable nature of ice pigs means that they can’t be pushed by air, and also that their use for product separation between hot products is limited (depending on the contamination threshold) as the melt will penetrate the product in front and travel at its fastest velocity. Pipe topologies that go from one-to-many and many-to-one channels, such as some heat exchangers, can offer challenges for ice pigging, however this is an active area of research with much potential benefit.

The main difference between gel and ice pigs is down to rheology, gels (even with fibres added) flow with a non-slip flow profile whilst ice pigs display plug-flow; so wall velocities with gels are low and shear forces are spread throughout the bulk of the fluid, whereas all relative velocity in an ice pig is at the wall region, giving much higher shear exactly where the deposits are, leading to greatly enhanced cleaning. Gels, like ice pigs are good at entraining debris removed by solid pigs, but to achieve comparable wall shear must have extremely high Reynolds number flow – something that in practice would be impossible to achieve in large diameter pipes.

Aim

The purpose of the experiments is to demonstrate that an ice slurry can convincingly, repeatably remove 95% of an introduced contaminant (sand at 30% by volume and wax at 15% by volume) from a 3m test section of 24” carbon steel pipe. As part of an unpiggable test rig.

Diagram



Procedure
Tool box talk
Assemble test rig with contaminated spool in place
Pressure test system to 10 Barg checking for leaks
Tool box talk
Set up camera rig and ensure functioning properly
Introduce 5T of ice slurry
Pump ice slurry through system and flush with water at 500/lpm for 5/min
Measure level of contamination in water received in holding tank
Drain system
Remove contaminant carrying spool piece
Remove any contaminant left in the spool and take weight for records
Thoroughly clean spool piece and all other accessible parts of system
Reassemble system and flush with water

Repeat testing with various contaminants as required

Results
Testing was conducted over a period of 2 weeks. Using various thicknesses of ice slurries determined by inferring a Pa (pascal) number from the pressure drop experienced by pumping the slurry through the same fixed length of pipe, until the desired cleaning capability was reached. 400Pa ice was needed to remove the 107kg of paraffin wax from the system and 200Pa ice to remove the 250kg sand.

Weights of contaminants were taken using indicators on forklift truck and a set of calibrated scales.

Discussion
The experimental program was affected by some initial technical challenges. The design of the test rig using an eccentric reducer from 24” to 8” (see diagram) causing blockages in the system when using ‘thick’ ice ~400Pa. The reducer design was originally specified to keep the length of the test rig to a minimum. When the ‘thick’ ice is introduced into a purely water filled system as the slurry reaches the restriction a build-up in pressure in the system was observed and then quickly the pressure dropped off as the push water ‘rat holed’ through ice slug. Leaving the majority of the wax and ice in the pipework. This test rig is not representative of a real world situation as the ID to length ratio is very large. In order to cope with this restriction a method of pumping the ice mimicking the process that would occur in a longer length on pipe was developed (see figure 6). Where by a thin slurry was pumped before the thick ice was introduced and it was then chased by a slug of thin slurry, which allows the thick (mechanical working ice) to build up quickly in to a homogenous slug and prevents the push water rat holing through the thick ice before it can achieve the wall shear effect required to remove the wax from the system and flow around the restriction.

Once the process of introducing the ice slurry to the test rig was understood the removal of the wax and sand from the test spool was able to be repeated and data gathered. On multiple tests including those where the client (Shell) was present we were able to demonstrate that 100% of any containments put in the system by measured weight.

No bulldozing of the sand or wax was observed in any of the tests conducted. The contaminant was removed from the test spool and carried through the system in a progressive way.

Conclusions
Based on experience from other industries, ice pigging is seen to have potential uses in the O&G Industry at all stages of the pipe’s life. It has been used very successfully to clean fabrication debris such as swarf, dirt and even air from new pipes in other industries during pre-commissioning. During its operational life, pipes may be ice pigged as part of preventative or active maintenance to reduce obstruction build-up and maintain hydraulic performance. As O&G products are sometimes incompatible with ice, these operations are foreseen as occurring during outage, and perhaps in conjunction with ‘dead oil’ to prevent hydrate or wax formation.

The main potential for ice pigging, however, is seen to be in the decommissioning of pipe-lines, and temporary ‘de-oiling’ of them during pipe alteration work. Ice pigs can be deployed from a single entry point, and through flow volume and pressure drop measurements (compared to water insertion), an effective wall shear can be calculated and used as a measure of clean of the pipework to allow the opening of the pipe to the environment or workers. All without chemicals or specialist pig launching / receiving installations. Shell have officially confirmed that "the technology has been developed to meet the strict test environment requirements set by Shell".

To decommission conventionally un-piggable pipework so that it poses no risk to the environment, the choices are few and often there is incomplete data on the structural integrity of the pipe or even its dimensions and layout. In cases like these where chemical or water flushing are seen as the only methods, ice pigging could provide a much more effective solution, and will hopefully become a standard method for decommissioning pipework.

Figure 1 The ice slurry used in ice pigging is very thick and dry, whilst still flowable. It cleans tough deposits by abrasion.

Figure 2 Flowing from left to right: an ice pig removes soft petroleum wax smeared in an 8” clear pipe.

Figure 3 Ice pigging was performed on a dual diameter 24” to 8” steel pipe. The ice and push-water were inserted through a 2 ½” hose connected to a 2” inlet. Frozen condensation on the pipe shows the progress of the ice plug through the constriction.

Figure 4 A 3m portion of the 24” pipe was loaded with 250 kgs of sand in one test, and 100 kgs of dyed petroleum wax in another, ice pigging cleaned both contaminants very effectively.

Figure 5 A compressed ice pig holds its shape as the pipe is opened up for inspection.

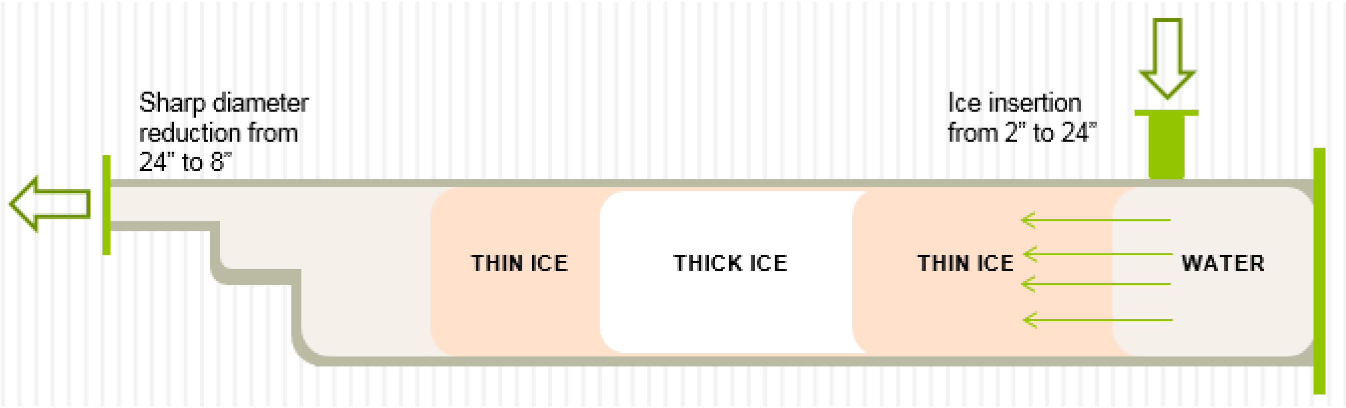


Figure 6, diagram showing how the ice slurry was injected to account for length to diameter ratio of the test rig.