Available online at www.ijpab.com

DOI: http://dx.doi.org/10.18782/2320-7051.2971

ISSN: 2320 – 7051

Int. J. Pure App. Biosci. **5 (6):** 1132-1138 (2017)

Review Article

International Journal of Pure & Applied Bioscience

OPEN ACCESS

Ice Pigging: Economical and Novel Method for Cleaning-In-Place of Food and Dairy Processing Equipment: A Review

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Received: 11.05.2017 | Revised: 19.06.2017 | Accepted: 26.06.2017

ABSTRACT

The effectiveness of cleaning is dependent on 'physical action' or 'force applied' by a cleaning solution. Therefore, high turbulent systems are desired for efficient cleaning. For obtaining 'physical action' at fouled surfaces and smooth flow at normal surfaces, some "smart material" is required that acts like a fluid squeezing through complex geometries but behaves as 'tough' as it is a solid scraper which cleans the fouled surfaces. The 'crushed ice in water' or 'ice pig' is able to achieve many of the desirable characteristics of desired smart material. 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 liquids containing a freezing point depressant, through the fouled duct. The slurry acts in a similar manner as solid pig, displacing material downstream by applying shear. Hence, mechanical cleaning effect to the duct walls is achieved.

Key words: *Freezing Point Depressant, Ice Pig, Ice Particle Size, Ice Slurry and CIP.*

INTRODUCTION

In modern milk processing, cleaning is the primary treatment and this should be carried out immediately after processing work is over. It is a precondition, for the production of hygienically satisfactory and high quality products, that milk and milk product processing plant is scrupulously clean. Now a day, in almost all dairy plants, CIP (Cleaning in Place) is used i.e. the plant is cleaned by circulation or by a once thorough mechanical cleaning process without dismantling. The removal of soil depends on the kind of soil and its state, nature of support of soil (surface finish) and mechanical action depending on the velocity of flow, presence of foam etc[3]. The effectiveness of cleaning is dependent on 'physical action' or 'force applied' by a cleaning solution. Therefore, high turbulent systems are desired for efficient cleaning.

Cite this article: Thyarla, A., Agrawal, A.K., Srikanth, K., Umapati, K.S. and Velpula, S., Ice Pigging: Economical and Novel Method for Cleaning-In-Place of Food and Dairy Processing Equipment: A Review, *Int. J. Pure App. Biosci.* **5(6):** 1132-1138 (2017). doi: http://dx.doi.org/10.18782/2320-7051.2971

Adequate physical action can be ensured by the selection and utilization of proper pumps to provide sufficient turbulence of the cleaning solution through the pipelines and equipment to achieve maximum efficiency[1]. For obtaining 'physical action' at fouled surfaces and smooth flow at normal surfaces, some smart material is required that acts like a fluid squeezing through complex geometries but behaves as 'tough' as it is a solid scraper which cleans the fouled surfaces. The 'crushed ice in water' or 'ice pig' is able to achieve many of the desirable characteristics of the smart material. The ice pig can traverse through very complex topologies for cleaning and can recover and separate products. Further, it does not get stuck, and even if it did, it will be melt into water, which can then be easily drained[12].

Importance of Ice Pigging

Pushing a piston like object through a pipe to clean the pipe walls is known as pigging. In ice pigging, the 'pig' consists of crushed ice in water with a freezing point depressant. The void fraction is carefully controlled so that the ice/water mix move like a solid plug in free flow areas, but is able to flow like a fluid in constricted areas[12]. 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 minimum engineering work required on existing pipelines to accommodate ice pigging as a fouling removal solution[2].

It offers to be innovative de-fouling technology. The non-Newtonian behaviour of ice pig gives it a special flow characteristic; it appears to achieve plug flow whenever it can. Plug flow means that there is little mixing through the ice pig. The ice slurry acts in a manner of displacing material downstream of it by applying shear and hence mechanical cleaning of all surfaces comes into its contact[2].

Why Ice Pigging can be used

Ice pigging is a process for the removal of fouling, deposition, dirt particles etc. from the pipes, ducts, narrow spaces in a pipe or network of pipes. Ice pig can navigate obstructions such as bends, T's, valves, partially closed valves, pumps, and contractions/expansions by realigning aggregate's shapes to fit the shape of equipment.

There is no need to change layout of pipe lines for ice pigging. Ice pigs can easily pass through large diameter pipes, bends, valves sockets etc. Only limiting thing is that ice slurry produces higher pressure drop in the pipes when compared to cleaning or disinfecting solutions at the same velocity.

Properties of Ice Slurry

The main factors in ice pigging intended for cleaning process are ice fraction, ice particle size and freezing point depressant concentration. Ice fraction can be estimated by measuring the temperature of the ice slurry solution and initial concentration of freezing point depressant[9]. The size of ice particle mainly depends upon the method employed for its storage and length of time since its formation. The particle size increases with time elapsed[11]. The ice fraction and particle size, both contribute to the rheological properties of 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[13].

Performance of Ice Pigging

Several trials are performed in food industries where the ice pigging process provided not only cleaning of pipes but also resulted in efficient product recovery[12]. In some investigating trials, the ice pigging has achieved up to 90% recovery for a viscous product at ambient temperature pipe line. These trials were carried out over a range of pipe diameters and lengths 1 cm to 10 cm and up to 100 m in length. It has demonstrated its ability to pass and clean various process equipment i.e. inline mixers, extruder, lobe pumps, dosing units and mono pumps[2].

In their experiment on ice pigging[2], used four-way manifold to demonstrate the ice pig's ability to flow through diameter changes and multiple paths and successfully scoured fine grain sand, representative of loose small particulate fouling. It has been reported that the largest volume of fouling material approximately 160 kg removed by using the 4.5 Tons of ice slurry. These processes have also been tested on several different pipe materials like cast iron, PVC and stain less steel.

In a study, satisfactory cleaning properties of ice slurry was reported on different industrial heating units namely plate heat exchanger (Model: C6-SR, Make: Tetraplex) and tube in tube heat exchanger (Model: MTC70/W-3, Make: Tetra Spirflo)[13].

Modelling of Ice Pigging

For cleaning process[4], developed a model for predicting the flow and melting behaviour of ice slurry passing through stainless steel pipelines. However, in a study carried out of using ice pigs in a plate heat exchanger and tube heat exchanger, it was reported that pressure drop increased exponentially with ice fraction and with the square of the velocity[13].

Freezing point depressant

The Freezing Point Depressants (FPD) is added in order to maintain the slurry condition, preventing the ice particle from fusing together and forming a solid block of ice. Typically, sodium chloride is used due to low cost, minimal health and safety implications and small concentrations required. Other FPD’s are also used which includes sugar, sorbitol, hydrochloric acid, sodium hydroxide, sodium nitrate and poly ethylene glycol.

The selection of freezing point depressant mainly depends on the ideal solution or product which is already present in pipeline. The chemicals such as acids, alkali, anti-corrosion and pacifier’s agents are added as part of freezing point depressant. This is particularly important for materials such as “yoghurt or curd” where cleanliness and hygiene are important in determine the safety and product stability.

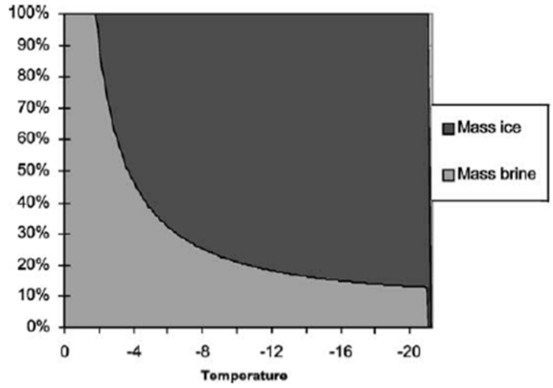


Fig. 1: Variation of ice to brine proportion with temperature (3% $NaCl_2$)

The principal effect of the depressant is to produce an ice-water mixture which is stable over a range of temperatures. The above figure explains the percentage of ice to brine variation with temperature for a 3% sodium chloride ($NaCl_2$) solution[12].

It decreases the viscosity while thermal conductivity of the fluid phase increases. It replaces corrosive behaviour of acid/alkali solutions used in CIP with gentle effect on adjacent metal surfaces. FPD’s prevents agglomeration of ice crystals used in CIP by ice pigging.

Ice slurry, Ice particle size and manufacturing

Peter and Kauffeld[10], explained ice slurry is nothing but fine–crystalline ice particles with an average characteristic diameter, which is equal or smaller than 1 mm. Nowadays, mostly ice slurries produced by mechanical scraped type generators, which produces ice particles of approximately 200 µm size.

However, the particle sizes were approximately one to four millimetres before growth occurred. The effect of this crystal growth behaviour is that physical properties are time dependent. Storage and mixing of ice slurry lead to a decrease of the rheological parameters (the viscosity and the critical shear stress) up to 60%.

In simple terms, the ice slurry from being pumpable and conforming to different topographies like a liquid, and yet behaves in pipe as a solid, providing an enhance shear stress on the pipe walls and therefore more efficient cleaning of the pipe walls.

Controlling and maintaining the ice slurry consistency is important. A good quality of ice is subject to Ostwalds ripening where by ice crystals tend to stick together and form a solid mass as the ice ages. To overcome these problems a freezing point depressant and mechanical agitation is used.

The ice pigging technology requires an ice making facility (Scraped Surface Heat Exchanger), flow analysis unit, storage tank, and delivery pump, conductivity meters etc. The ice is generated with portable water, a freezing point depressant, table salt etc.

Mechanical type Ice slurry generator

In mechanical – scraper type ice slurry generator, the refrigerent evaporates in a double – wall cylinder. Through the inside space, bounded by the inner cylinder, the water or brine solution flows. In their experiment[2] generated ice pig by circulation of 5% sodium chloride brine solution through a rotating screw, scraped surface ice generator and stored in a 700 liter stirred tank. Depending upon the ice fraction required, the ice machine was turned off when a set temperature was reached.

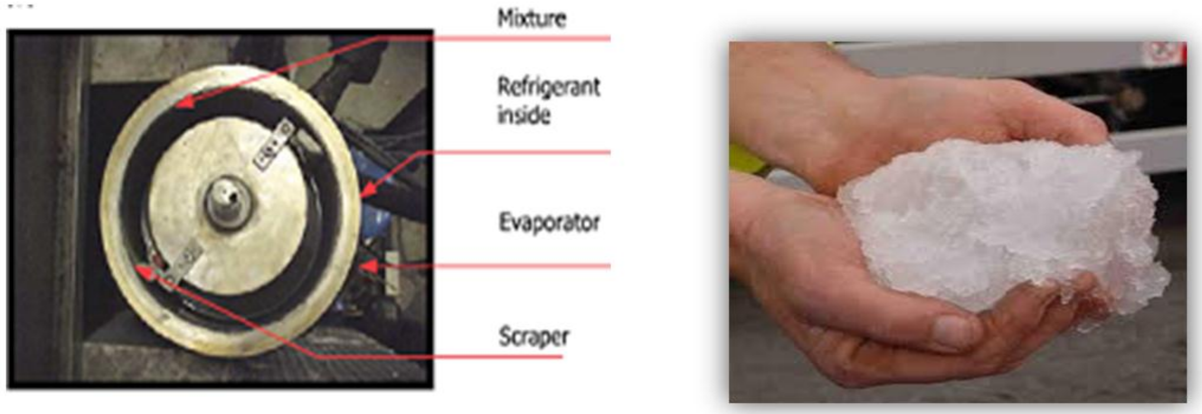


Fig. 2: (a) Mechanical scraped surface ice generator, (b) Ice pig

Ice fraction in ice pig

Ice fraction is more important in behaviour of the ice slurry. It affects flow behaviour and rheological properties of ice slurry[8]. A simple and repeatable method is used with a standard coffee press (a container with mesh plunger). The ice slurry is fully filled in this container and then mesh plunger is slowly inserted. Finally, the plunger is pushed slowly downwards, until no more travel can be achieved. The ice fraction was calculated as ratio of volume of water to the total volume of coffee press.

Thermo – physical properties of ice slurry

1. Density

The ice slurry contains ice with a density lower than the liquid phase, the difference between densities gives a buoyancy force to ice particles. Due to this phenomenon, the density cause stratification of the fluid in the pipes and in storage tanks ducts. We need to agitate continuously for preventing the stratification more significant with ice slurry for lower temperature applications because the lower freezing point requires a higher concentrations of additives or FPD's, which increases the density difference between the liquid phase and the ice particles, except for alcohols and ammonia[7].

The density of ice slurry can have derived as follows:

$\rho = m/ V_i+V_w+V_a$

Where,

ρ = density of ice slurry (kg/m^3)

V_i = volume of ice (m^3)

V_w = volume of water (m^3)

V_a = volume of additive (m^3)

2. Viscosity

In cleaning by ice pigging, the shear force on the pipe wall is generally carried out through the use of an effective viscosity. A number of experiments show that ice slurry behaves as a Newtonian fluid at low ice fractions, and as a non-Newtonian fluid at high ice fractions. Many relationships between the ice fraction and effective viscosity have been developed[14].

Theoretically, this effective viscosity could be used to predict the desired ice friction for fouling with a known adhesion to the pipe wall.

$$\mu_e = \mu L\,(1+2.5\,C + 10.005\,C^2 + 0.0027 \times 10^{16.6\,C})$$

Where:

μ_e = effective viscosity of ice slurry i.e. ice water mix (Pa.s)

μ = viscosity of water (Pa.s)

L = volume of water (fraction)

C = volume of ice (fraction)

3. **Thermal properties:** low viscosity, high ability to transport energy by at least 20% of ice at -35˚C with a freezing point of -25˚C[7].
4. **Chemical characteristics:** pH 7 – 9.5
5. **Environmental impacts:** non-toxic, non- polluting, without use of any chemical
6. **Material compatibility:** chemically stable, non-corrosive, compatible with iron, copper, aluminium, stainless steel and polymers.
7. **Freezing point:** -2˚C to -20˚C.

Cleaning efficiency

The cleaning ability of the ice pig was measured on a straight 20 mm diameter length of glass pipe[12]. Different materials were smeared on the inside wall of the pipe. The ambient water (20˚C) and then ice pig was circulated throughout the pipe at constant mass flow rates. The fluids were pumped through the solid pipe until the pipe appeared clean. Cleaning factor was defined as follow:

Cleaning factor = Time taken to clean with 20˚C water/Time taken to clean with ice plug

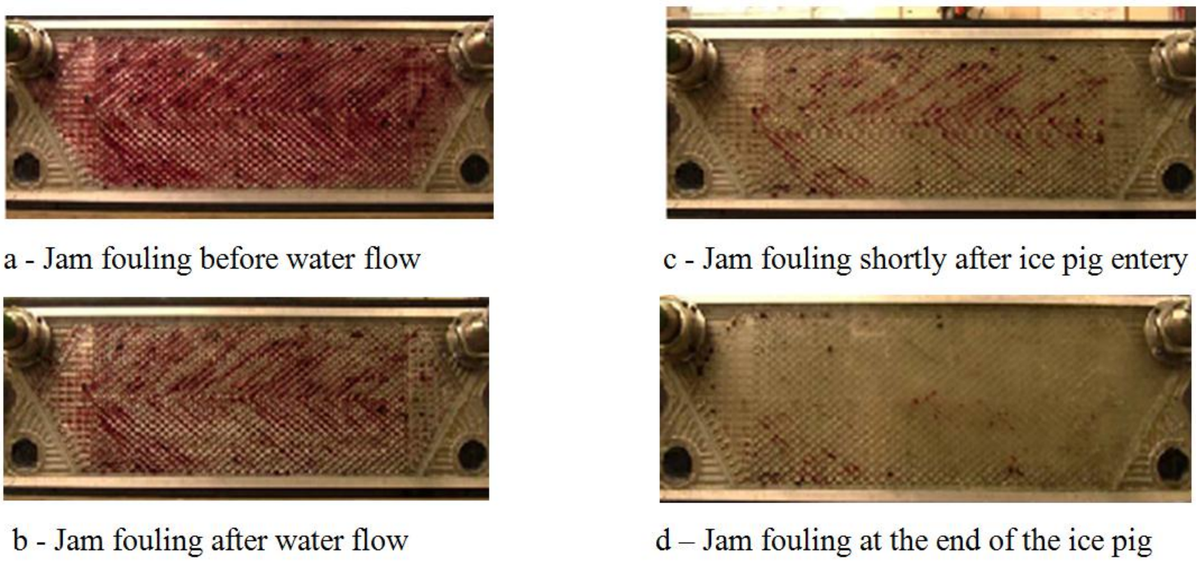
Table 1: Comparison of cleaning factors

S. No.	Fouling materials	Cleaning factor for ice pigging	Cleaning factor for hot water
1.	Jam	10	3
2.	Salad cream	5	4
3.	Margarine	15	10
4.	Toothpaste	15	-

The above table represents the result of the experiments with jam, salad cream, margarine and toothpaste smeared on the pipe walls. The higher the cleaning factor value, the better the system is at cleaning the fouling material off the walls. The ice pig or ice slurry is better at cleaning soil of the tube wall than an equivalent volume of hot water and much better than cold water.

Ice pigging to plate heat heat excahngers in jam industry

In an experiment[12] the ice pig was pumped through very complex geometries including a plate heat exchanger, with an average gap width of 3 mm between the corrugated plates. With smaller ice particles, beside a set of plates, the other geometries included 90^o bend, T-junction and orifice plate with area ratios of 12:1 (contraction), 1:9 (expansion).



a - Jam fouling before water flow

c - Jam fouling shortly after ice pig entery

b - Jam fouling after water flow

d – Jam fouling at the end of the ice pig

Fig. 3: The ice pig successfully passed through PHE

The ice pig was found successfully scouring through these complex topologies and appeared to do so as a plug. Even the most complex geometries appears to generate very little disruptions or mixing in the ice.

After the arranging of the plates in plate heat exchanger, initially mains water at 15˚C was circulated through the heat exchanger at 0.11m/sec velocity, it removes small amount attached jam from plate surfaces. After the circulation of water, the ice pig or ice slurry 20 – 30% volume to the total circulated geometry volume, it removes the majority of the reaming fouling of jam. This circulation is continues for several times for efficient cleaning, with the ice slurry contains ice fraction ($\emptyset_i$) is 50% by coffee press.

The ice pig was cleaned to superior level, when compared to water, with no change in flow velocity or the volume of fluid used. This is due to the effective viscosity of the ice slurry increasing with ice fraction. The gap between the plates in plate heat exchangers is 3 mm. it was found that best results were obtained when the ice particle sizes were optimized.

Benefits of ice pigging:

Ice pigging can be considered as an alternative to traditional flushing. Ice pigging provides the following benefits:

1. Ice pigging is more suitable technology than other cleaning methods because it uses significantly less water during the cleaning process[5].
2. The waste can be easily collected and dispensed of eliminating contamination of nearby steams or ponds.
3. It is more effective than flushing for removing sediment and biofilm.
4. It is possible to add treatment materials (chemicals such as acids, alkali, anti-corrosion, and pacifier agents) as part of the freezing point depressant.
5. Increase in product recovery within the processing lines.
6. Reduction in down time required for cleaning.
7. Use less water than flushing
8. Efficient removal of loose material at slow speeds (high wall shear).
9. In expensive, “single use” and reduce man – time.
10. It is environmental friendly as it reduces the need of expensive and potentially hazardous cleaning chemicals.
11. Reduction in cleaning water and effluent processing costs.

Benefits *vs.* other cleaning techniques:

Ice pigging can be considered as an alternative to traditional flushing, uni – directional and CIP. Compared to these alternatives ice pigging provides the following benefits:

1. More effective than flushing for removing sediment and biofilms.
2. Ice pigging can easily and efficiently remove ‘soft’ fouling; using a volume of ice pig less than one tenth of the volume of water[6].
3. Can be used in locations where flushing is not practical or possible.
4. Can navigate obstructions such as bends, partially closed valves, butterfly valves, and changes in pipe diameter.
5. No need of chemicals usage as in CIP.

CONCLUSION

In some investigations ice pigging technology has proved to be successful in food processing operations. Based on their findings, food industry is also using ice pigging technology for CIP purposes. Looking to the similarity with food processes, ice pigging has a great potential in dairy processing also. This would result in lower material cost, lower operational cost but require other infrastructure for manufacture of ice pigs in dairy processing plant itself.

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