International Journal of Science, Environment and Technology, Vol. 6, No 2, 2017, 1223 – 1230
ISSN 2278-3687 (O)
2277-663X (P)

ICE PIGGING IS AN EMERGING METHOD OF CLEANING-IN-PLACE INDAIRY AND FOOD PROCESS INDUSTRIES: REVIEW

Subhash Prasad*, TanmayHazra, Ch. V.K., Sudheendra, Parmar Manish Kumar Pratapsinh and Parikshit D Chauhan
College of Dairy Science, Kamdhenu University, Guj-365-601, India
E-mail: prasadsubhash91@yahoo.com

Abstracts: Ice pigging is an emerging method of removing fouling from complex geometry ducts, pipes and narrow spaces in a networks of pipe lines. The process involves pumping ice slurry, a mixture of ice particles and a liquid containing a freezing point depressant, through the fouled duct and pipe. 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 or pipe walls. However, the ice pig is also able to complex geometry which include bends, tees, partially closed valves, pumps and contractions/ expansions by realigning aggregate's shapes to fit the shape of equipment. This makes the technology suitable for addition to existing process installations with minimal alteration to the lines.
Keywords: Clean-in-place; Pigging; Ice pig; Cleaning efficiency.

Introduction

In modern dairy and food 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 milk and food products. Cleaning in Place (CIP) system of cleaning the interior surface of pipelines, vessels, filters, process equipment and associated things without dismantling. The efficiency of cleaning and sanitation of milk and food contact surfaces are widely influenced by many factors like the character of contamination, micro topography of surfaces, straightness of passage ways, compatibility of surface agents, application methods, mechanical action depending on the velocity of flow and related speed of penetration in to biofilm structure (Jones et al., 1986).The effectiveness of cleaning is dependent on physical action by cleaning solution. Therefore, high turbulent systems are desired for efficient cleaning. Pushing a piston like object through a pipe to clean the pipe walls is known as 'pigging'. This technique is widely used in the hydrocarbon recovery and is beginning to be adopted in others such as food, dairy and pharmaceutical production. Conventional pigs can only be used in relatively simple geometries. Specifically, pigs can be 'pushed' through uniform pipes with constant diameter, but find it difficult to

*Received Feb 24, 2017 * Published Apr 2, 2017 * www.ijset.net*

negotiate bends or minor changes in cross-sectional area/shape (Cordell, 1991). 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 scrapper which cleans the fouled surfaces. Further, this smart material should be such that it never gets stuck in the geometry it cleans. The 'ice pig' is able to achieve many of the desirable characteristics of the smart material. The ice pig can transverse through very complex topologies for cleaning and can recover and separate products. Further, it does not get struck, and even if it did, it will be melt into water, which can then be easily drained (Quarini, 2002).

Technology of ice 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 (Quarini, 2002). 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 (Ainslie *et al.*, 2009).

It offers to be innovative de-fouling technology. The Non Newtonian behaviors of ice pig gives it a special flow characteristics; it appears to achieve plug flow whenever it can. Close analysis of videos suggests that the ice pigs are slipping at the solid surfaces. Plug flow means that there is little mixing through the ice pig. It is therefore able to act as a good product recovery device and as a product separator. The ice slurry acts in a manner of displacing material downstream of it by applying shear and hence mechanical cleaning of all surfaces come into its contact (Ainslie *et al.*, 2009).

Properties of ice slurry

The main factors in ice pigging intended for cleaning process are ice fraction, ice particle size and freezing point depressant concentrations. Ice fraction can be estimated by measuring the temperature of the ice slurry solution and initial concentration of freezing point depressant (Malinder and Granyard, 2005). The size of ice particle mainly depends upon the method employed for its storage and lent of time since its formation. The particle size increases with times elapsed (Pronk *et al.,* 2005). 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 (Shire *et. al*., 2008)

Thermo-physical properties of ice slurry:

Density: The ice slurry contains ice with a density lower than the liquid phase, the density difference gives a buoyancy force to the ice particles. As a result of this phenomenon, the density difference causes stratification of the fluid in the pipes and in the storage tank. To prevent stratification in the tank, an agitating system is required and in the pipes, the velocity has to be high enough to avoid a stationary bed. The problem is more significant with ice slurry for low temperature applications than for medium temperature applications since the lower freezing point requires a higher concentration of additives, which increases the density difference between the liquid-phase and the ice particles, except for alcohols and ammonia. The density of ice slurry can be derived as follows

$$\rho = m/V = m/(V_i + V_w + V_a)$$

Where, ρ = density of ice slurry(kg/m^3) ; V_i = volume of ice slurry(m^3); V_w= volume of ice water(m^3); V_a= volume of ice additive(m^3)

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 (Thomas,1965). Theoretically, this effective viscosity could use to predict the desired ice fraction for fouling with a known adhesion to the pipe wall.

$$\mu_e = \mu L [1 + 2.5 C + 10.005 C^2 + 0.0027 x 10^{16.6C}]$$

Where, μ_e = effective viscosity of ice slurry (Pa.s); μ= viscosity of water (Pa.s) ;L= Water fraction; C= Ice fraction.

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

Chemical characteristics: pH: 7-9.5:

Environmental impact: Non toxic

Material compatibility: Chemically stable, non-corrosive, compatible with iron, copper, aluminum and polymers.

Freezing Points: -2 °C to -20°C.

Ice slurry, ice particle size and manufactures:-

Ice slurry is nothing but fine- crystalline ice particles with an average characteristics diameter, which is equal or smaller than 1 mm (Egoff and Kauffeld, 2005). Now a days, mostly ice slurries produced by mechanical scraped type generators, which produces ice particles of approximately 200 µm size. However, the particle sizes were approximately 1 to 4 mm before growth occurred. The effect of this crystal growth behavior 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%. A good quality of ice is subject to Ostwalds ripening whereby 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 required. 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 refrigerant evaporates in a double – wall cylinder. Through the inside space, bounded by the inner cylinder, the water or brine solution flows. Ainslie *et al*. (2009) used to generate, 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.

Method for measurement of ice fraction:-

Ice fraction is more important in behavior of the ice slurry. It affects flow behavior and rheological properties of ice slurry (Hansen *et al*, 2002). 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 pushes 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 (Hansen *et al*, 2002).

Calculation the performanceof 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 (Quarini, 2002). In some investigation trials, the ice pigging has achieved up to 90% recovery for various product at ambient temperature pipeline. These trials were carried out over a range of pipe diameters and length 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 (Ainslie et al., 2009).

In their experiment on ice pigging, Ainslie *et al.*(2009) 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 Stainless steel.

Cleaning efficiency

The clean ability of the ice pig was assessed on a straight 25 mm diameter length of glass pipe (Quarini, 2002). Different materials were smeared on the inside wall of the pipe. The ambient water (20°C) and then ice pig was circulated through the pipe at constant mass flow rates. The fluids were pumped through the soiled pipe until the pipe appeared clean. The time taken to reach the 'clean' state was used as a measure of cleaning efficiency. 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 of hot water (65°C)
1	Jam	10	3
2	Salad cream	5	4
3	Margarine	15	10
4	toothpaste	15	-

The table-1 represents the result of the experiments with jam, salad cream, margarine, and toothpaste smeared on the pipe walls. The higher the factor, the better the system is at cleaning the fouling material off the walls. The table clearly indicates that the ice pig is better at cleaning soil of the tube wall than an equivalent volume of hot water and much better than cold water.

Performance of ice pigging to plate heat exchangers

In an experiment (Quarini, 2002) the ice pig was pumped through very complex geometries including a plate heat exchanger with a 40–45° and an average gap width of 3 mm between the corrugated plates. It was found that best results were obtained when the ice particle sizes were optimized for the particular geometry. With smaller ice particles, beside a set of plates, the other geometries including 90° bend, T-junction, orifice plates with area ratios of 12:1 (contraction), 1:9 (expansion). One of the interesting findings was that the ice pig would go through these complex topologies and appeared to do so as a plug. Even the most complex geometries appears to generate very little disruption or mixing in the ice; the ice would flow like a fluid where it had to but would quickly knit itself together and then move as though it were a solid plug when it was allowed to do so. 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 remove small amount attached jam from plate surfaces. Then the ice pig 20-30% volume to the total circulated geometry volume, it remove the majority of the reaming fouling of jam, this circulation is continued for several times for efficient cleaning. 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. It was found that best results were obtained when the ice particle sizes were optimized.

Modeling of Ice Pigging

For effective cleaning process, Evan *et al*. (2008) developed a model for predicting the flow and melting behavior 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 (Shire, *et al.,* 2008). The freezing point depressant (FPD) is added in order to maintain the slurry conditions, 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.

Advantages of ice pigging

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

(i) Ice pigging is more suitable technology than other cleaning methods because it uses significantly less water during the cleaning process. (ii) The waste can be easily collected and dispensed of eliminating contamination of nearby streams or ponds. (iii) It is more effective than flushing for removing sediment and biofilm (iv). It is possible to add treatment materials (chemicals such as acids, alkali, anti-corrosion, and pacifier agents) as part of the freezing point depressant. (v) Ice Pigging uses less water than traditional pipe cleaning methods. The Pig is pushed through the pipe using just one pipe volume of water and then the pipe is flushed for a short period returning the water quality to its usual limits typically using 1/4 to 1/2 of the pipe volume. Total water usage is therefore typically 1.5 times the volume of the pipe to be cleaned. (vi)Increase in product recovery within the processing lines. (vii) Reduction in down-time required for cleaning. (viii) Low operational risk and easy implementation. The Ice Pigging process can be used in pipes of any material and will not damage the internal structure of the pipe. (ix) Efficient removal of loose material at slow speeds. (x) Easy introduction and removal. (xi) The Ice pig is inserted into the pipe in a semi liquid form and can adapt to the topography of the pipes as well as large changes in diameter. (xii) In expensive, single use and reduce man time. (xiii) It is environmental friendly as it reduces the need of expensive and potentially hazardous cleaning chemicals.

Scope of future research

The ice pig exhibits a complex, non-Newtonian rheology with the added complication that enthalpy changes result in phase changes, and solid/liquid fraction variations. This immediately questions the viability of the ice pig; the environment in which it operates is likely to have a temperature well above the melting/freezing temperature of ice, and so melting is likely to occur. This might reduce the stiffness of the pig and may eventually undermine its usefulness as a pig. Extensive experimental work has been undertaken in both the laboratory and in full-scale food manufacturing plants to document the performance of the ice pig and, more importantly, to understand better what is happening. The experimental work provides clear evidence that the pig survives as a useful entity for much longer than might have first been envisaged, making it a very attractive commercial alternative to conventional pigging techniques in a dairy and food process industry.

Conclusions

A novel and innovative new pigging technique, where the pig is made of crushed ice, is presented. It has a number of significant advantages over traditional pigs. Specifically, it is able to ‘pig’ very complex geometries including heat exchangers. It never gets stuck and, being made of water has considerable environmental benefits. Simple exploratory experimental work provides encouraging evidence of the viability of this technique. 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 similarity with food processes. Ice pigging has a great potential in dairy processing also.

References

[1] Ainslie, E., Quarini, M., Herbert, T., Deans, D., Ash, D., & Rhys, D. 2009. Heat exchanger cleaning using ice pigging. In H. Muller-Steinhagen(Ed.), heat exchanger fouling and cleaning, Austria; Eurothem Conf. Pichl/Schladming.

[2] Cordell, J.L. 1991. Pigging research, Pipeline Pigging and Inspection Technology Conference, Houston, February 1991.

[3] Egolf, P.W., and Kauffeld, M. 2005. From physical properties of ice slurries to industrial ice slurry application. Int. J. Refr. 28(2005) 4-12.

[4] Evans T.S., Quarini G.L., Shire G.S.F. 2008. 'Investigation into the transportation and melting of thick ice slurries in pipes' Int. J. Refrigeration 311 (2008): 145–151

[5] Jones, M.B., Miller, J.J. and Brown, W.E. 1986. Effectiveness of a quaternary ammonium compound in the presence of hard water and organic soil. Dev. in Ind. Microbiol. 25: 771–777

[6] Melinder, A., and Granryd, E. 2005. Using property values of aqueous solutions and ice to estimate ice concentrations and enthalpies of ice slurries. Int. J. Refrig. 28(1) (2005) 13-19.

[7] Pronk, P., Hansen, T.M., Infate Ferreira, C.A. and Witkamp, G.J. 2005, time dependent behavior of different ice slurries during storage, Int. J. Refrig. 28(1) (2005) 27-36.

[8] Quarini, G.L. 2002. Ice-pigging to reduce and remove fouling and to achieve clean-in-place' Appl. Therm. Eng. 22 (2002): 747–753

[9] Shire G.S.F., Quarini G.L., Rhys T.D.L., Evans T.S. 2008. 'The anomalous pressure drop behaviour of ice slurries flowing through constrictions' Int. J. Multiphase Flow 34: 510–515

[10] Thomas, D.G. 1965. Transport characteristics of suspension. VIII. A note on the viscosity of Newtonian suspensions of uniform spherical particles. J. Colloid Science 20, 267-277