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CHALLENGES IN THE HYGIENIC APPLIATION OF PIGGING TECHNOLOGIES TO MAXIMISE WASTE REDUCTION IN FOOD MANUFACTURE

Ian Sterritt[1*], Bryn Craggs[2], Jeremy James[1]

[1]Martec of Whitwell Ltd, 12 Midway Centre, Bridge Street, Clay Cross, Derbyshire, S45 9NU, UK
[2]Beechroyd Consultancy, 19 Curzon Rd, Southport, Lancashire, UK

[*]e-mail: ian.sterritt@martec-conservation.com

Abstract

Food manufacturers are being driven to improve processing yields through increasing pressure on costs and profitability, more frequent production changes and the environmental impact of waste streams. The use of pigging technology to recover product left in pipework at the end of batch runs offers significant cost and flexibility advantages while helping address smaller batch sizes dictated by increased consumer variety. However, there are significant technical challenges with the hygienic deployment of the technology.

Pigging technology evolved in the oil and gas industry where the primary aim was to keep pipe bores open, aiding flow. The drivers in the food industry are very different; we are more likely to be concerned with yield and productivity, and with reducing the clean in place (CIP) load. In all cases though, food and pharmaceutical manufacturers need to place an emphasis on hygienic design and operation that petrochemical applications do not require.

Comparisons are drawn with non-pigging and traditional pigging approaches using a variety of pig designs as well as alternative new techniques of ice and air pigging which have had different degrees of effectiveness across the hygienic manufacturing environments of food, beverage and pharmaceutical manufacturing.

The interaction of product recovery systems with automated CIP adds an extra degree of complication where pigging equipment needs to be designed for hygiene as well as operational efficiency. In this article we review how hygiene can be incorporated into the design process.

Key words: *Marplug, Pigging systems food, product recovery solutions.*

1. Introduction

Pigging is a technique of inserting a plug (pig) into a pipeline and pushing the contents ahead of it. Pigging systems can be designed to recover a variety of liquid or solids-in-suspension products. The pig may be driven by a variety of propulsive means but most commonly by compressed air, potable water or by a following batch of product. The pig is introduced into the line via a Launch Station and, depending on the client's process, the product recovery sequence operated through to a Receive Station and controlled manually, semi or fully automatically. Fully automated systems provide a reliable and repeatable process with minimal operator involvement consolidating best practice process design. Manual systems are normally used for low cost, infrequent recovery of low risk products.

The use of pigging technology to recover product left in pipework at the end of batch runs (a Product Recovery System) offers significant cost and flexibility advantages. However, deploying pigging in a hygienic production context offers challenges beyond mere straightforward cross-sector adoption from the Oil & Gas industry where pigging originated.

2. Hygienic Pigging Challenges

2.1 Food production context

Food manufacturers are being driven to improve processing yields through increasing pressure on costs and profitability, while addressing smaller batch sizes dictated by increased consumer variety with more frequent production changes. Deploying pigging holds one of the best hopes for cost effectively addressing hygienic process wastage and the environmental impact of waste streams.

Having advanced from artisan production methods, many types of food production now employ a high degree of automation, and so production of foods such as desserts, ready meals, condiments, dairy products and many others involve passing both ingredients and the finished product along a network of pipes during manufacturing before they reach the packing stations. Depending on the physical layout of the manufacturing site the routing of some of this pipework can be quite long, with several hundreds of meters not uncommon.

At the end of a production batch, when the line has to switch to another product or at the end of a shift prior to cleaning, the process will leave behind it a pipe full of food-grade material which holds a tangible financial value and an unwelcome cleaning (clean-in-place, CIP) challenge.

Recovering that material in most instances should be considered an economic and environmental necessity. The unit cost of ingredients may be measured in pence per litre, but if there are a thousand litres potentially lost in the pipes, and perhaps four or more product changes every day, the value of product to be recovered starts appearing as a significant overhead. For a marginal product even a small cost saving and increase in yield has the potential to make a substantial impact on profitability.

2.2 The origins of pigging

The Oil & Gas industry pioneered the use of closefitting bungs which ran inside pipes to separate out different grades of oil product. The squealing sound of a metal plug scraping along a metal pipe gave rise to the name 'pig'. An alternative, but just as credible reason for the term, is that PIG is an acronym for 'pipeline inspection gauge' reflecting that versions of the insert were also used to identify faults in pipework. Whatever the reason, the generic word has stuck and is widely recognised and used throughout many process industries.

Figure 1 shows an Oil industry application where the pig has been used to remove debris from within a length of pipeline.

Figure 1. Oil & Gas industry pig removing debris

The technology proved so effective that its use spread through to chemical and other process industries and eventually to hygienic applications within food and pharmaceutical manufacturing. Unfortunately, in the early days, when used in hygienic contexts significant problems were encountered. Hygiene is of profound importance because after contacting the pig at the end of production the food will generally receive no further process; any contamination at this stage is therefore "locked in". The need to carefully and actively manage hygiene in food process systems has resulted in a market differentiation; Food and Pharmaceutical industry pigging is now fundamentally different to other process industries. Cleanability, hygienic design, and materials of construction have a significance that is simply not understood by the other industry sectors.

2.3 The benefits of pigging

There are some overlaps as well as differences when comparing the use of pigging between traditional and hygienic applications. The primary aim in Oil and Gas is usually on maintaining the integrity of the pipeline, keeping bores open, aiding flow. The drivers in the food industry are very different; we are more likely to be concerned with yield and productivity, and with reducing the clean in place (CIP) load. In all instances, food and pharmaceutical manufacturers need to place an emphasis on hygienic design and operation that petrochemical applications do not require.

The primary objectives when considering the hygienic use of pigging are often supplemented by other, direct or indirect, knock-on benefits, some of which are not initially obvious.

- Faster changeover times between batches
- Reduced cross contamination (allergens)
- Reducing dilution of product (flush water)
- Marking the stage of product changeover
- Enabling traceability
- Mass balance checks
- Cleanliness of production area
- Mechanisation of process
- Operator safety
- Reduced concentration of caustic materials
- Less rinsing water required
- Reduced effluent discharge & associated costs

There have even been instances of pigging technologies increasing the effective capacity of a production line through facilitating the removal of a production bottleneck. The size of pipe selected at factory design is often a compromise between being large enough to deliver a given flow rate but small enough to minimise losses at end of production. By using a pigging system the size of pipe no longer correlates with end of batch losses and the pipe bore can be increased to remove associated bottlenecks. A positive choice of pipe size can replace a reluctant acceptance of convention.

Pigging has also been used to replace labour intensive production methods by offering a simple mechanical handling or conveying method, for instance, in removing chicken offal from processing areas.

2.4 Hygienic application challenges

There are significant technical challenges with the hygienic deployment of the technology. In this article we review how hygiene can be incorporated into the design process. As is often the case when a technique crosses application boundaries, the first recovery systems in the food and beverage sector simply drew on the oil industry experience and used a metal sphere or cylinder as the 'pig'. Engineers talk in terms of an interference fit to describe how tightly one component moves within a socket or a recess of an almost identical size. Too tight and the pig got stuck at bends or any roughness or protrusion in the pipe's inner surface. Too loose and fluids squeezed past. The seal, such as it was, broke at full bore off-takes, where a pipe splits into others of the same diameter, stopping the advance of the pig. The fit became even less secure when the pig's surface was scratched or damaged and potentially created foreign body problems at the same time.

Given that the device had to be a close fit to the pipe, anything less than a perfectly circular cross section could prevent its smooth passage. One of the problems was a pig's susceptibility to 'real world' dents, oval deformation of pipe at bends, welds and other imperfections in the pipework. A quick look at the pipework within any normal food manufacturing environment tells us that dents and other pipe imperfections are the norm rather than the exception. The wall thickness of dairy standard stainless steel proves less rigid than the schedule standard pipes used throughout process industries. It is not uncommon when pipework is man-handled for it to be 'eased' back into place on reassembly. Asking a fitter what he uses for this 'easing' can bring forth stories of adjustable wrenches, rubber mallets etc., often applied in frustration and bad temper.

A rigid object making limited contact with the pipe walls proved a less than ideal recovery tool for the food industry. The fine lines that were scratched into the pig's surface at each pass through the pipe could prove to be culture generation hotspots. Any material not cleared from pipework has the potential to harbour various pathogens. Designs incorporating, for instance a standard Oil & Gas approach of cleaning brushes, are unsuitable due the contaminating risks of foreign material (bristles). The pig design must be suitable for hygienic cleaning.

Some early food application systems had the pig stored within the main production product flow. We now recognise that best practice is to store the pig under clean hygienic conditions off-line when it is not in use; this reduces any risk of carryover contamination between product formulations.

Similarly there is a need to have minimal physical handling of the pig which would otherwise increase the risk of introduction of contaminants. Obviously it would be feasible to extract the pig once it has traversed the pipework and clean it manually. However once clean/sterile pipework has been breached there is a serious risk of introducing contamination and/or pathogens. Therefore unlike the Oil & Gas industry pigs should not be removed for manual cleaning but rather cleaning of the pig should be fully integrated into the CIP cleaning regime itself.

The interaction of product recovery systems with automated CIP adds an extra degree of complication where pigging equipment needs to be designed for hygiene as well as operational efficiency. Whatever the reasons for considering pigging it should be recognised that changes from existing production and cleaning methods will be involved. These changes must achieve their purpose while not negatively impacting the existing objectives and performance of either the production or cleaning processes. Best practice uses experience and know-how to design an overall system which optimises the most desirable outcomes and minimises consequences.

The pig has to be able to do its job efficiently, leaving no residue, without the option of opening up the pipe for additional cleaning which would compromise hygiene standards.

2.5 Solution approaches

Comparisons are drawn with non-pigging and traditional pigging approaches using a variety of pig designs as well as alternative new techniques of ice and air pigging which have had different degrees of effectiveness across the hygienic manufacturing environments of food, beverage and pharmaceutical manufacturing.

2.5.1 Non pigging approaches

<u>Draining</u>

The most basic method of clearing a pipeline at the end of a batch is by simply opening a drain and allowing the contents to empty naturally under the force of gravity. When the contents of the pipe are of low value, the viscosity is low, there are no urgent production time pressures and the environmental consequences are inconsequential, this is often the most effective solution. However, care should be taken to ensure all material can be evacuated as there are hygienic risks from residual material contained in dips in pipework or pipe runs that are lower than the draining point.

Water flush

A common method, especially where cleaning (CIP) of the equipment is the usual follow on process, is to flush the pipework through with rinse water. The water progressively dilutes the material in the pipe eventually washing all material to drain. Turbidity meters can be used to signify when threshold dilution levels are reached. This method is very commonly used for the dairy, brewing and beverage sector. There can be resulting high volumes of water and significant effluent discharge issues with this approach in addition to the obvious product wastage.

Product flush

Where products are compatible the changeover from one batch of product can be affected by using the following product to drive out the former. There clearly is major cross contamination with this approach so the management of the production sequence of a variety of products can be achieved by the use of a compatibility hierarchy, for instance, a table of ingredients for soups. Lack of flexibility to react to urgent customer requests for an out of sequence batch of product is a significant drawback of this approach. In addition, there is still the need to deploy another method to clear the pipework when the final batch is finished. It is also unwise to try and manage allergens in this somewhat relaxed manner.

2.5.2 Pigging

Figure 2 shows a cross section of available styles of pig used in small bore pipework (not all pigs shown are made from food grade, FDA approved materials [1]).

Figure 2. Example selection of pig designs

Cylindrical/Bullet shape pigs

In its simplest form a pig is a cylinder which forms a tight fit to the inside diameter of the pipe. The cylindrical shape does tend to create difficulty negotiating bends. This requires either greater clearance between the pig and the inside pipe diameter, a degree of flexibility in the material of construction and/or a limit to the length of the cylinder relative to the diameter. The bullet shape derivative provides a leading edge to steer the pig into bends. The greater the clearance between the pig and the inside diameter the more thickness of film will be left on the pipe walls. To achieve a hygienic surface finish, or if there is a build-up of food product to be removed, cylindrical pigs may need additional cleaning steps potentially including full disassembly.

Spherical & conjoint sphere pigs

A sphere has the distinct benefit over a cylinder of being able to negotiate very tight bends. However, this shape has the drawback of reducing contact to a single point thereby reducing the efficiency of clearing action and potentially leaving a thicker surface coating in its wake. A pig shape which attempts to overcome this limitation is the conjoint sphere design. It can be recognised that clearing performance will be better than a pure sphere but not as effective in straight pipe as the cylinder.

Flexible vane pig (Marplug)

Due to the significant hygienic risk of residue biofilm a key requirement within food and pharmaceutical applications needs to be addressed. The concept of a series of squeegee vanes on a central body was created and patented [2] by Walter Suttie, founder of UK based specialist Martec of Whitwell Ltd. The central core (Figure 3) is flexible to ease the negotiation of bends as tight as one and a half times the bore diameter being feasible. Therefore, for a 2 inch dairy standard pipe (50 mm), the tightest curve would have a 75 mm radius.

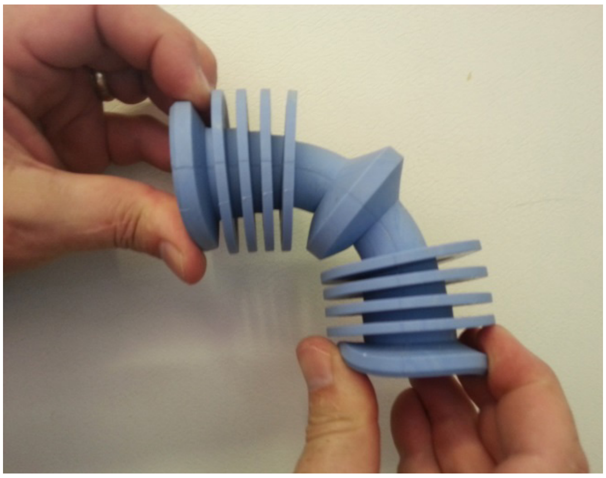

Figure 3. Flexible core of 8 vane pig

The pig is a single moulded piece and by having several vanes a seal (Figure 4) can be maintained even across full bore branches. Creating a seal, and hence reducing the effect of bypass, has the additional impact of reducing the pressure required to propel the pig. This pressure varies depending on the viscosity of the product, the tightness of the bends and restrictions within the pipe but typically a compressed air pressure of between 2 and 4 bar is usually sufficient. With typically eight of these vanes along the device, the likelihood of the material in the pipe escaping past it is significantly reduced even when dents, flow plates, and junctions are navigated.

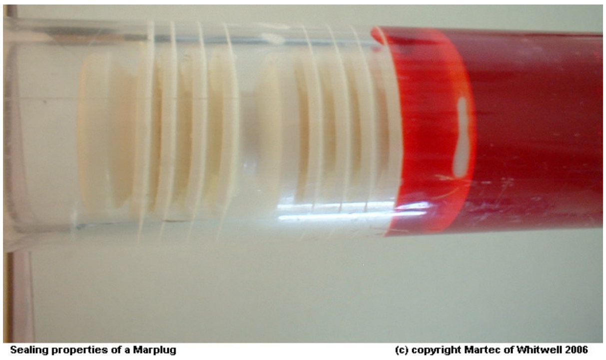

Figure 4. Sealing properties of flexible vane pig

Although the majority of the product within the pipeline will be cleared ahead of the first wiping vane there can be instances of product getting in between vanes (when negotiating bends, traversing flow plates, flexible hoses etc., or when accommodating pipe deformities). In comparison to conventional pigs with smooth surfaces the vanes would appear to breech EHEDG good practice design guidelines [3]. To overcome this issue a highly effective countermeasure mechanism is used.

A patented vortex chamber [4] (Figure 5) is deployed as a cleaning station with cleaning of the pig undertaken in parallel to cleaning of the main process line, thus not increasing changeover time.

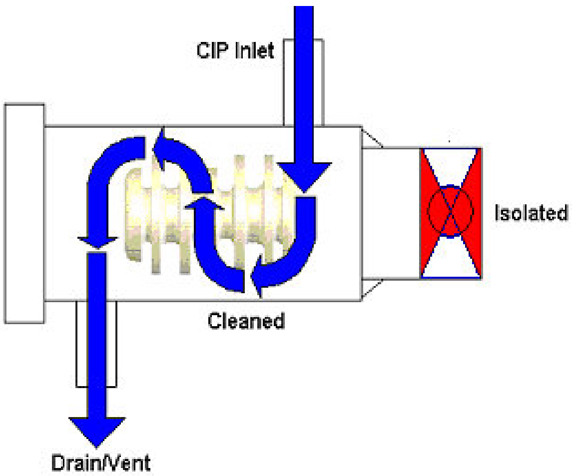

Figure 5. Schematic of patented vortex cleaning technology [4]

2.5.3 New techniques

Ice pigging

Arising from research by Professor Joe Quarini [5] of Bristol University is the concept of using ice to act as a pig. Rather than a single solid plug of ice which could become stuck the technique pumps thick ice slurry into the piping; the slurry is then propelled through the pipe sweeping away debris and sediment. Once it has left the pipe, the ice melts into water, making it easily disposable and hazard free.

The ice slurry is able to adapt its shape to fill the most complex of pipe configurations. There is however, no clear barrier between product and ice but a degree of mixing in the same manner as water flush. Nevertheless, unlike water flush there is a scouring from the abrasive nature of the ice particles. This makes ice pigging particularly useful for removing debris or silt. Therefore, in addition to the melting nature of the ice, major applications tend to be found in the water industry.

Air pigging (Whirlwind)

Air pigging, using air to drive product from pipe, originally developed by Keith Roscoe [6] in Nigeria is a sophisticated development going beyond the capabilities of factory supplied compressed air. Applying compressed air to a pipe full with product will result in the air cutting a small central pathway before the pressure drops. Laminar flow then leaves much of the product adhering to the pipe wall boundary layer.

The Whirlwind system compensates by the using two different phases for the air. The phases differ in the balance of air pressure to flow volume. Once a pathway has been cleared through the pipe in phase one, the second phase switches in automatically and this provides a high volume of air to wipe off the residuals adhering to the pipe wall. Further sophistication has been added to the system by offering subsequent cleaning and drying of the pipe as a direct alternative to normal CIP processes.

The range of product viscosities suitable for air pigging can be quite restricted. The know-how to operate the system is not widely understood and hence the ability of fault-fixing while in production is limited. Needless to say to meet hygiene requirements the cleanliness of the air must be assured adding further to the overall cost of the system.

3. Conclusions

Context is vitally important to determine whether pigging technology is beneficial and on which is the most appropriate approach. For low viscosity, low value products pigging offers few if any benefits over more basic methods, for instance, draining of lines. A quick look-up comparison chart (Table 1) can be useful in determining the scenarios for which different solutions can be appropriately deployed.

Pigging can provide significant benefits but it would appear that refinements to the nature of pigging reflecting the hygienic challenges means that more advanced pig designs offer notable performance benefits in comparison to conventional pig shapes. Care needs to be taken to fully integrate pigging and CIP processes.

The alternative ice and air (whirlwind) pigging methods, while being technically very sophisticated, can have some important drawbacks. As well as the significantly higher capital investment involved they can be susceptible to performance reliability concerns arising from the critically sensitive and restricted range of optimum operating parameters.

4. References

[1] Code of Federal Regulations, Title 21, (21 CFR) Section 177.2600: "*Rubber articles intended for repeated use*" Food and Drugs Administration.

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[5] <URL: http://www.bris.ac.uk/research/impact-stories/2012/ice-pigging.html. Accessed 18 March 2013.

[6] <URL: http://www.aeolustech.co.uk/index.php?pid=1. Accessed 18 March 2013.

Table 1. Comparisons of techniques and application of pigging in food and pharmaceutical manufacturing

Technique	***Application***	***Pros***	***Cons***
Draining	Low viscosity, low value product	Readily available	Effluent discharge, Draining Time, Completeness of evacuation
Water Flush	Pre-CIP, Low viscosity, low value product	Readily available	High water usage, Effluent discharge
Product Flush	Compatible low risk products without intermediate CIP	Changeover time (high viscosity, low mix products)	Cross contamination, Batch order inflexibility, Final batch clearing
Cylindrical pig	New installation straight pipe runs	Pig easy to clean	Residue biofilm, Liable to get stuck on bends Product bypass, Incomplete clearance, Perfect pipework required
Spherical pig	Low risk applications	Pig easy to clean, Negotiates bends	Residue biofilm, Product bypass, Incomplete clearance, Perfect pipework required
Flexible vane pig	Majority of hygienic applications	Wipe action effectiveness, Bends & 'real world' imperfect pipes, Barrier seal, Low driving force (pressure)	Specialist pig cleaning (CIP integrated)
Ice pigging	Water industry Debris & sediment clearing	Low risk disposable pig (melts), Complex pipe configurations	Separation between product and ice slurry
Whirlwind (Air)	Low viscosity	Integrated CIP alternative	Limited viscosity range, Requires sterile air supply, Poor usage know-how, Cost