ULTRACLEANPIPE Report Summary

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Final Report Summary - ULTRACLEANPIPE (Ultrasonic detection and removal of fouling inside industrial and domestic pipes)

Executive Summary:
Process pipes are the basis of many industries, from food production to oil refining. Frequently, they are operated in such a manner that may cause their internal surface to develop a layer of deposited material, known as fouling. This is made worse when elevated temperatures lead to the creation of lime scale, which is the most common fouling one of the most difficult to remove. Ultra Clean Pipe has developed a tool that can remove hard incrustations of fouling, like calcite, from the inner wall of industrial and domestic pipelines.

This build-up is undesirable for a number of reasons. Firstly, a significant decrease in process efficiency may result from either thermal transfer losses or the required increase in pumping pressure due to the reduced bore. In some highly industrialized countries, these lead to economic costs approaching 0.25% of GDP (1). The heightened energy usage coupled with the use of chemicals (e.g., acids and detergents) currently used to clean pipes clearly presents environmental impacts. Furthermore, in food and drink production, fragments of fouling can break off and enter the finished product, potentially leading to health hazards and social impacts—not to mention damaging corporate reputations.

The Ultra Clean Pipe Project addresses the problem of fouling in industrial pipes by using an ultrasonic method to remove buildup of scale. Ultrasound has been used for cleaning for many years, but mainly in immersion tanks—Ultra Clean Pipe has developed a method to clean components while still in service, removing the need for acids and other chemicals while reducing the downtime associated with cleaning cycles. This will allow savings on materials and energy resulting in a more environmentally friendly cleaning process.

A multidisciplinary consortium including industrial and academic partners from across Europe has collaborated to this end, reporting their findings periodically at conferences and seminars over the course of the project. The final results were presented in late 2012, when prototypes and procedures had been fully developed and validated.


Project Context and Objectives:
Process pipes are the basis of many industries, from food production to oil refining. Frequently, they are operated in such a manner that may cause their internal surface to develop a layer of deposited material, known as fouling. This is made worse when elevated temperatures lead to the creation of lime scale or any other products likely to precipitate in the pipe bore. There are a number of varieties of fouling that may occur, involving different elemental compositions and chemical structures.

UltraCleanPipe provides an environmentally friendly method to remove fouling from the inner wall of working pipelines. Fouling build-up is undesirable for a number of reasons. Firstly, a significant decrease in process efficiency may result from either thermal transfer losses, a reduction in the amount of product that can be processed or an increase in pumping pressure required due to the reduced bore and the increase in friction produced by internal deposits. In industrialized countries, these lead to economic costs approaching 0.25% of GDP. The heightened energy usage coupled with the use of chemicals (e.g., acids and detergents) currently used to clean pipes clearly has environmental impact. Furthermore, in food, pharmaceutics and...
drink production, fragments of fouling can break off and enter the finished product, potentially leading to important health hazards and social consequences—not to mention damage to corporate reputations. The UltraCleanPipe final prototype can avoid these problems by removing the fouling as it forms maintaining the inner wall of pipes clean.

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Fouling deposits in industrial process pipes are difficult to avoid, and pose a significant problem to plant operators. The formation of fouling inside pipes often causes chemical reactions leading to significant operational problems. Effects on the pipe itself may include corrosion, blockage and in extreme cases rupture or deformation. The product carried in the pipe may become contaminated by microorganisms such as bacteria, fungi and algae.

Different tools have been developed to remove fouling. Some are chemical methods, while others employ simple pressurised water or gas. Many conventional approaches rely on production outages and require the use of large amounts of chemicals. This is an obvious environmental concern with an associated economic impact. There are many mechanical tools available, ranging from simple tube cleaning brushes to sophisticated Pipeline Inspection Gadgets (PIGs). A whole support industry has developed in this area. However such methods have a number of different disadvantages in comparison with the final UltraCleanPipe prototype which could be considered as the ideal tool for cleaning working pipelines because it does not stop the production, and it does not need chemicals.

Project Results:
The initial phase of UltraCleanPipe project focused on the definition of the specifications of the requirements of the final prototype based on the demands of the food processing industry. This was done following a basic questionnaire in a brainstorming session at the first meeting with the SMEs at Heinz at Kitt Green. This has helped to set the scene and focus on the objectives of the project. The type of fouling, pipe material, the diameter of the pipes, pipe wall thickness and typical temperature and pressure were defined. This information which can be found in the deliverable D1.1, was produced according to a specific line of the food processing plant of Heinz in Wigan, UK. This initial specification not only included the target pipeline conditions but also operational considerations like: portability, health and safety, user friendly interface, simple operational system, and component durability.

The key proposed UltraCleanPipe (UCP) operating system architecture takes a number of high power ultrasonic transducers attached to a working pipe. These transducers are excited with a portable high power signal generator that produces the resonance frequencies of the transducers attached to a working pipeline which will be submitted to the cleaning process. The wave traveling through the pipe generates cavitation in the liquid surrounding the inner pipe wall due to the leaking of the guided waves into the liquid carried by the pipe. This equipment is intended to be employed from the very beginning of the fouling creation in order to avoid problems associated with the existence of fouling which spoils the production as soon as the first precipitation occurs. It is, for instance, important to avoid the detachment of large particles into the solution that can be generated by the ultrasonic cleaning process. The final prototype includes an ultrasonic guided wave detection module which can be used for the location and measurement of fouling. Guided waves for detection systems are well known and can improve the performance of the UCP final tool. The combination of detection and removal of fouling within the same tool, as in the UCP final prototype, gives a promising solution to the maintenance of industrial plants in a safety and productive manner for much longer than the current existing methods. The developed method allows detection of the location of the fouling and its thickness indicating when it is necessary to apply ultrasonic cleaning and detecting when the cleaning period has finished.

During the specifications of the project Calcite was identified as the most common fouling in industrial pipelines. Calcite is present in any natural water and it leads thermodynamically to the creation of crystalline calcite, which grows in any piping system that carries water. Therefore calcite creation was the first objective of the empirical investigation of the project in
order to have a replicable method to produce laboratory samples for analysis. Calcite as a mineral needs very long time for growth, therefore specific chemical methods have been used for a speedy creation of fouling. Another problem associated with fouling simulation is that calcium carbonate can grow as Calcite or other polymorphs such as Aragonite, Varetite or monohydrocalcite depending on the environmental conditions. Therefore considering these disadvantages and based on scientific publications two different methods were developed to produce pure calcite as scale on plates and pipelines. These methods were used successfully during the rest of the project. A number of samples with lime scale as a fouling have been generated for further laboratory trials. These samples have been analyzed with different methods including SEM (Scanning Electron Microscopy), EDX (Energy Dispersive X-Ray) and XRD (X-Ray diffraction) analysis proving every time the samples under study consisted of calcite and not any other fouling.

At the same time as the experiments for calcite creation, a number of modelling cases were carried out by Cereteth. These models were a key reference for the rest of the project and have given an important approach to the problem from a theoretical point of view. As can be seen in the deliverables D2.1 and D2.1 numerical methods of simulating the wave interactions between a steel pipe and a substrate of calcite have been performed both for its detection and removal. At that this stage it was possible to demonstrate theoretically that it would be possible to remove fouling from a pipe inner wall and what type of signal changes could be expected to permit detection when a layer of calcite was attached to a pipe. This information was used during the rest of the project as a starting point.

Although the most important efforts were focused on the removal of fouling from pipelines some preliminary experiments were carried out with the removal of lime scale from plates. The geometry of plates is simpler to analyze and the transducers existing on the market can be attached easily to flat surfaces. Thus plates were used to analyze the generation of cavitation on the surface of an object carrying the wave energy for cleaning. These plates were created with the same material properties as the target pipelines and the same wall thickness, therefore the results obtained from these experiments could be correlated with the pipe experiments. At this stage of the project it was proved that the energy leakage to the liquid of a wave traveling through the sample under study could produce cavitation powerful enough to remove calcite fouling from the surface of the samples.

After the results with plates, experiments were conducted on pipes, and small tubes were used to prove the concept of cleaning such structures by using ultrasonic guided waves propagating through the sample to be cleaned. For these experiments it was important to specify the type of transducers that were going to be used. CRIC provided a number of existing transducers tailored for the proposed of the project. These transducers had a concave contact surface that ensured the best coupling with the outside wall of the pipe. This better contact not only improved the attachment of the transducer to the pipe but also increased the amount of energy transferred to the pipe.

In parallel to the design of the transducers some effort was applied to the attachment mechanism of the transducer to the pipes. It was necessary to design a transducer holder with the appropriate mechanical properties that ensured proper attachment, ease of use and durability to ensure a long lasting support to satisfy the specifications defined at the beginning of the project. These supports were produced by CRIC, which was working in parallel with the Brunel University so that the performance of the supports could be improved to the level required by the industry and the application.

The most important and auspicious results of the project have been to clean working pipelines with ultrasonic guided waves while the pipes were working under common industrial conditions. This was proved at the food processing plant of Heinz in Wigan where the final prototype of UltraCleanPipe was tested with really promising results. In a 1.5 mm of an industrial pipeline a thin layer of calcite was grown with the methods mentioned before. These pipes were attached to a laboratory industrial circuit with common working conditions following the project requirements. Then a number of UCP transducers were attached and excited at their resonance frequency with the final UCP prototype. The pipes were cleaned in the places where the waves were generating constructive interferences producing a perfectly clear metallic surface with no damage.

The UCP project has been carried out with a view to maintain industrial plants in a safe manner. Cavitation is a really powerful phenomenon. This was a potential concern from the very beginning of the project: UCP had to generate cavitation powerful enough to remove calcite but not to damage the pipes. This has been achieved. To prove these encouraging results different metallic analyzing methods have been including SEM and metallography, which proved that the wall of the pipe remained intact after applying the UCP method.

In parallel to the empirical research regarding the removal for fouling, which was performed mainly with equipment available
in the market including signal generators and power amplifiers, the design of a high power ultrasonic generator was developed. This apparatus produces the signal necessary to excite the transducers in their resonance frequency as long as it is needed. This generator works mainly at 40 kHz (which is the resonance frequency of the UCP transducers) with a power output of 50 W per transducer. This signal generator has the option of changing the exciting frequency because the resonance frequency of the transducers can change depending on the allocations of the transducers and pipeline wall thickness. The equipment can also produce a sweep signal at the resonance frequency. This is to avoid the system to collapse because extreme conditions that are reached next to the resonance frequency like; the extremely fast reduction in the impedance or the high increase in the current. Potentially, at this resonance frequency there is another mechanical problem owing to the increase of the displacement with each cycle which can lead to a mechanical collapse of the equipment.

We believe that these results represent a really important improvement in pipe cleaning methods because it does not stop production, it is low cost and environmentally friendly.

A detailed breakdown of the work performed and main results for each WP is shown below:

**WP1 - Work package 1 is complete, and the objectives have been fully met.** The most significant result of this work package is the identification of the most problematic and frequent types of fouling that are experienced in industry, and the pipes in which they occur. There have been no deviations from Annex I, and all objectives have been achieved.

Specifically, Deliverable D1.1 investigated the background to the project, to ensure the problem was still relevant and focus the aim. It was concluded that as much as 3.2% of the total turnover of process industries (2) is lost due to fouling, whether through inefficiencies or down time. D1.2 went further so as to identify problem areas in the oil and gas and food and drink production industries to ensure that the UltraCleanPipe project is as useful as possible.

**WP2 - Work package 2 is completed, with deliverables D2.1 and D2.2 submitted.** These developed computerized numerical modeling methods of investigating the behavior of sound with fouling deposits. Specifically, D2.1 looked at how fouling may be detected effectively with ultrasound and D2.2 looked at how it may be broken down with ultrasound. Moreover, this work package was a feasibility study to determine if the assumptions and hypotheses made at the start of the project were actually correct, ie, is it possible to detect fouling deposits at a significant distance, and can it be destroyed using only ultrasound.

D2.1 adopted finite element methods of numerically predicting the interactions between localized fouling buildup and incident ultrasonic waves. It was determined that the change in acoustic impedance (ie, the resistance of a structure to the propagation of a sound wave, governed by its inherent properties such as stiffness) presented by fouling deposits, some incident wave energy is reflected back towards the excitation location. This has two useful implications for fouling detection. Firstly, a detection technique can listen for the reflected signal. Combining the arrival time of this reflection with knowledge of the velocity of the wave allows an estimation of the location of the fouling. Secondly, as some energy is reflected by the fouling, less energy continues to propagate, so there is attenuation to the amplitude of the onward propagating signal. This can be used to estimate the overall extent of fouling deposits. D2.2 further developed finite element (numerical and discrete) methods of studying fouling deposits on steel substrates to predict how they may be removed ultrasonically, but the research in this deliverable also investigated analytical (continuous and exact) approaches to wave propagation in pipes with various layers of fouling. Interestingly, it was found that, as a wave propagates along a pipe with a localized area of fouling, there is a large differential in displacement amplitudes between the outer surface of the pipe and the internal surface of the fouling (ie, the face closest to the central pipe axis). This was very useful knowledge, as it indicated there will be large forces between the steel and fouling layers, making ultrasonic cleaning in this manner feasible. D2.2 also studied the effects of clamps on the propagation of ultrasonic waves through the pipe to allow an estimate of how many cleaning transducers would be required, which was fed in to later prototyping stages of the project.

**WP3 - Work Package 3 is completed.** The development of practical techniques both for detection (deliverable 3.1) and removal (deliverable 3.2) of fouling have been achieved. Initial trials showed that significant levels of calcite deposits could be removed using ultrasonic waves at a rate of approximately 1mm thickness per hour over small areas. Initially, stainless steel plates were studied instead of pipes as this is completely analogous ultrasonically if thicknesses are constant, yet considerably easier from a practical stand point. For example, it is difficult to inspect the inside of a pipe for any remaining fouling, and it is much
more practical to attach transducers to flat surfaces. These practical issues were addressed in both Work Package 3 and 4, where the integrated system and the de-fouling prove were developed. It is worth noting that application on flat surfaces can be directly useful for large storage tanks with large surface areas, which may also have issues with fouling deposits. In order to enhance the probe performance, a concave curvature in the contact surface of the transducers was machined in commercial transducers to get the highest contact surface between the probe and the pipe. It is important to note that at the moment, different geometry transducers have to be designed and made for any specific outside diameter to ensure the best contact between surfaces. A significant amount of effort was been devoted to developing reproducible laboratory methods for creating representative test specimens that closely replicated the correct crystal polymorph of calcium carbonate, Calcite, to ensure that the laboratory tests were reproducing the real characteristics of industrial fouling.

WP4 - Work Package 4 included the design of an assembly of high power transducers for cleaning, which were tested during Work Package 3 after which a number of results from the laboratory trials were obtained. The scientific mile stone of cleaning a small plate with 1mm of Calcite attached was progressed to the second important mile stone which was to clean a plate with the acoustic wave traveling through the sample rather than traveling through the liquid as is the conventional methods of ultrasonic cleaning. All the knowledge developed and applied in the previous experiments was used to achieve the most important milestone of the project which was to clean a small pipe inner surface using ultrasound. In deliverable D4.2 the result of this milestone was presented where sections (e.g. 30 cm) of pipes with a calcite fouling were cleaned with ultrasound with one or two transducers developed during the project. The probes used in these experiments were developed in Work Package 3. It was shown after cleaning the pipe with ultrasound that the cavitation generated for the cleaning was powerful enough for cleaning but did not damage the inner wall of the pipe, which was an important concern related to the use of this technique.

WP5 - Work Package 5 (Field Trials) The Heinz R&D labs in the industrial plant in Wigan was selected as the best place to run the field trials. At this lab a close circuit simulating a chemical plant was assembled for the field measurement of the ultrasonic removal of fouling. Under real conditions the final scientific mile stone was achieved. A working pipeline was cleaned in some regions using ultrasonic guided waves. This technique can be improved but the current results are very promising and the concept of cleaning pipe lines using ultrasonic guided waves seems to be a realistic option in the near future.

WP6 - Work Package 6, Exploitation and Dissemination, is a continuous task of the project. The project website has been kept up to date with technical and non-technical developments, initial findings of fouling detection have been presented at an international conference, and discussions have taken place with politicians (Ministry of Trade and industry representatives in Denmark, for example) about the benefits of the project. Several unsolicited enquiries about the Ultra Clean Pipe project have been received by the consortium, indicating a noteworthy level of industrial interest in the results. The advantages and the progress of the project has been presented in a number of conferences:

- Dr Sattar (InnotecUk) presented the project to a power outages conferences as invited speaker:
  - Sattar, T.P. (2010) Chair and Expert Panel Speaker, Robotic NDT for Effective Planning and Optimising Execution of Major Outages , 3-4 October 2010, Amsterdam
Dr Sattar described progress on the project to a team from Sellafield Nuclear Power in a “Research Capability” presentation on 1st November 2012, TechnoPark, London South Bank University.

A flyer (available via the website) to publicize the project was distributed by project members during national conferences, seminars and workshop and is available for download from the ULTRACLEANPIPE project website.

WP7 - Brunel was responsible for carrying out all the administrative tasks related to this Work Package. All the Deliverables were submitted and all the Milestones, as were set on the Description of Work, were met.

The current UltraCleanPipe prototype has been demonstrated through a 5min video which has also been submitted at the end of the project.


Potential Impact:

The project has delivered a working prototype equipment that can be retrofitted to existing working pipes which have known fouling issues. This equipment not only establishes the severity of any fouling deposits, but also aids in their removal, ideally as a continuous, in-situ system. This prototype can reduce operating costs, thereby reducing costs to EU consumers while making EU industry more competitive globally. The environmental performance of industry and could also be improved by the elimination of vast quantities (many thousands of tons) of cleaning chemicals such as acids and detergents, and the energy associated with this intensive and currently environmentally unfriendly process.

In the short to medium term, the benefits to the population and stakeholders will only be the indirect quality of life benefits of lower costs of living and a ‘greener’ environment, but in the longer term the same technology could be applied to domestic systems to de-scale, pipes and water heating systems which should save maintenance and energy costs overall. This could prolong the life of equipment that would otherwise have to be scrapped and replaced, with obvious economic and environmental impacts on the consumer.

List of Websites:

[http://ultracleanpipe.com - Please contact info@ultracleanpipe.com](http://ultracleanpipe.com - Please contact info@ultracleanpipe.com)