EXECUTIVE SUMMARY

Demonstration of Ice Pigging Technology to Remove Biofilms in Water Distribution Systems

ESTCP Project EW-201510

MARCH 2019

Distribution Statement A
This document has been cleared for public release

Page Intentionally Left Blank

This report was prepared under contract to the Department of Defense Environmental Security Technology Certification Program (ESTCP). The publication of this report does not indicate endorsement by the Department of Defense, nor should the contents be construed as reflecting the official policy or position of the Department of Defense. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the Department of Defense.

Page Intentionally Left Blank

EXECUTIVE SUMMARY

Project: EW-201510

TABLE OF CONTENTS

Page

1.0 INTRODUCTION 1
2.0 OBJECTIVE 3
3.0 TECHNOLOGY DESCRIPTION 5
3.1 ICE PRODUCTION 5
3.2 ICE DELIVERY 7
4.0 PERFORANCE ASSESSMENT 9
5.0 COST ASSESSMENT 12
6.0 IMPLEMENTATION ISSUES 14

LIST OF FIGURES

Page

Figure E-1. Ice Production Setup Showing the Delivery Rig (left) and Ice Machines (right)... 6
Figure E-2. French Press Method of Testing the Ice Fraction 6
Figure E-3. Schematic Diagram of Ice Pigging Operation 8

LIST OF TABLES

Page

Table E-1. Comparison of Conventional Flushing and Ice Pigging Performances. 9
Table E-2. Cost Model for Ice Pigging at NASL 12

Page Intentionally Left Blank

1.0 INTRODUCTION

Department of Defense (DoD) water distribution systems are critical infrastructures and essential to all DoD missions. All DoD facilities have water distribution systems to provide safe drinking water for personnel living or working on-base. Total water consumption at all DoD facilities is estimated at about 90 billion gallons/year. Distribution system operations require proper cleaning of the water mains because distribution pipes are not sterile. As soon as finished water leaves a treatment plant and travels into a distribution system, the quality of the water begins to degrade due to time-dependent transformations. Over time, sediments and debris that build up in water mains can cause pressure and flow problems. Complex microbiological, chemical, and physical interactions occur between water biofilms, debris, and pipe wall materials that can degrade water quality.

Excessive buildup of biofilm and sediment in DoD water distribution systems can lead to the loss of residual disinfectant in the pipelines as well as the generation of elevated levels of disinfection byproducts, such as nitrite/nitrate and trihalomethanes (THMs), which could cause Safe Drinking Water Act (SDWA) violations. Water system operators commonly address these water quality concerns by implementing extensive hydrant flushing programs to discard water which no longer has adequate residual disinfectant levels and continue flushing until adequate residual is restored. An alternative to this practice is to address the problems directly by removing biofilm and sediments using a new technology known as ice pigging. This technology uses an ice and water slurry that is introduced into the pipe network and is propelled through pipes using the distribution system's own pressure to achieve cleaning and removal of loose materials on pipe walls, with minimal impact on water system operation. The ice plug forms a compact durable mass which very effectively scrapes pipe surfaces without the risk of permanently blocking choke points in the system. Unlike conventional pipeline pigs, the ice-water slurry is able to maneuver itself through pipes having different sizes, bends, valves, and fittings without risking system blockage or damages. The ice pigging waste is collected through downstream hydrants for disposal.

Field demonstration was conducted at the Operations Area (OPS Area) of Naval Air Station, Lemoore (NASL), California in May 2016. The study was performed by the Naval Facilities Engineering Command (NAVFAC), Engineering and Expeditionary Warfare Center (EXWC) in collaboration with the US Army Engineer Research and Development Center (ERDC), and two private companies, SUEZ, and National Resources Consultants.

The project conducted ice pigging on 55,845 feet of water mains having diameters ranging from 8 to 16 inches. The project team performed pre- and post-ice pigging monitoring and sampling to collect data for technology evaluation and validation. Data collected include amounts of sediment removed, residual chlorine, water used for hydrant flushing, chlorine consumption, bacterial testing and bacterial community analysis.

Page Intentionally Left Blank

2.0 OBJECTIVE

The objective of this project is to demonstrate the removal of biofilms and sediment buildup in drinking water distribution systems using a pipe cleaning technology known as ice pigging. Effective removal of biofilms will reduce the need for periodic water system flushing events, which waste significant quantities of water.

The main benefit of this technology stems from the water savings resulting from reduced flushing that is currently performed routinely to maintain water quality. Ice pigging technology is an innovative pigging technique acceptable to DoD utility and energy managers to implement into their routine Operation and Maintenance (O&M) protocols.

Page Intentionally Left Blank

3.0 TECHNOLOGY DESCRIPTION

Ice pigging is a technology that combines the operational advantages of traditional flushing with the cleaning impact of soft pigging, with minimal interruption to water services during pigging. Ice pigging overcomes operational limitations commonly found in traditional cleaning methods. A main feature of ice pigging is that it does not get stuck in the pipeline or appurtenances; if for some reasons the pig would get stuck, operators would allow the ice to melt and flush it out from the main. Pipe bends, changes in pipe diameters, or butterfly valves can all pose problems for swabbing or pigging, yet ice pigs can easily overcome these obstacles. To launch and receive traditional pigs, excavations have to be made to allow the installation of launch and reception stations. These can result in very costly and extensive interruptions to water system operations, and can require the installation of bypass pumping to provide water supply.

An ice pigging process includes two major operations, ice production and ice delivery, described in the following sections:

3.1 ICE PRODUCTION

Ice is made on-site using the potable water from the existing distribution system. To maintain the correct consistency of the ice pig, food grade table salt approved by the National Sanitation Foundation (NSF) is used as a freezing point depressant. The salt is dissolved in potable water obtained from installation's water supply to form brine. The current maximum batch capacity for ice slurry is 2,700 gallons.

The brine is prepared in a 316 stainless steel delivery tanker with hoses connected to ice machines that are mounted on a separate trailer (Figure E-1). The brine is fed into the ice machines which, in turn freezes the liquid and returns it to the delivery tanker. This cycle continues until the ice slurry is at certain consistency labeled as the ice fraction. Ice fraction measures the amount of ice crystals as a percentage of total volume. Ice fraction is related to the cooling capability of the slurry compared to pure ice (100%); this is known as the Calorimetric Value. Ice pig operators use a simple French press coffee plunger (Figure E.2) to test the "ice fraction" (or the ice thickness) on site prior to pumping the slurry into the main. Typically, the thickest ice slurry is used on plastic and sound concrete lined pipes as well as asbestos cement pipes (ACP). But when older unlined cast iron pipes are cleaned, to avoid pipe damage a thinner ice slurry is used that does not clean as aggressively. The thinner ice slurry will not disturb the buildup of tuberculation, which could damage the integrity of an old heavily corroded unlined cast iron pipe.

Figure E-1. Ice Production Setup Showing the Delivery Rig (left) and Ice Machines (right)

Figure E-2. French Press Method of Testing the Ice Fraction

3.2 ICE DELIVERY

Setup for ice delivery varies slightly for different applications. A typical setup for a potable water main is shown in Figure E-3. The delivery rig connects to the inlet hydrant or other suitable fitting (2" or greater tapping with valve control), and at the outlet, a Flow Analysis System (FAS) is connected. The FAS measures and records the flow rate, pressure, conductivity, turbidity, and water temperature as the water and ice are discharged. Once set up, the main is flushed briefly to note and record pre-flush readings. The main is then isolated by the owner's operators and the required amount of ice is pumped into the main. At the same time, the outlet hydrant is opened to create a flow and allow water to be displaced as the ice enters the main. With careful control between the inlet and outlet, the flows are balanced to allow slightly more ice into the main than the amount of water being displaced. This has the effect of the ice forming as a pig against a pressurized wall of water.

Once the required amount of ice is in the main, the delivery pump is turned off and the upstream valve is opened to allow the system flow and pressure to "push" the ice pig along the main toward the outlet hydrant. The flow rate is controlled by the outlet operator at this time. The line pressure is maintained above 20 psi to eliminate the need for the utility to issue a boil order. As the ice passes along the pipe, it removes and collects sediment, biofilm or debris that has accumulated around the circumference of the pipes. As the ice pig approaches the designated outlet, the conductivity reading will rise as the salty water of the melting pig arrives in front of the pig.

The monitoring equipment will show the water temperature falling and conductivity rising as the ice arrives. At this stage, the operator may collect samples of the ice at regular intervals for later analysis. The temperature and conductivity will return to pre-flush levels when all the ice and salty water have flushed out of the system and the flushing is continued briefly to allow the turbidity levels to return to pre-flush levels or lower, according to instructions from the owner. The main is then returned to normal service. No disinfection is necessary.

Disposal of the ice pig waste is typically through sanitary sewers; however, it can also be hauled away for disposal via a tanker for job sites that do not have access to sanitary sewers.

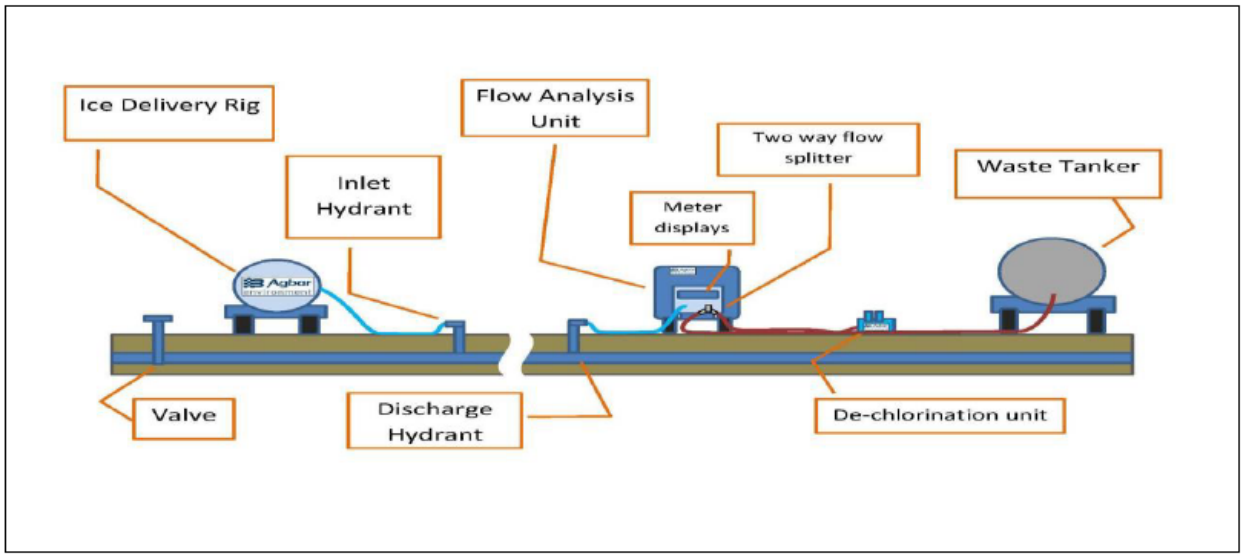

Figure E-3. Schematic Diagram of Ice Pigging Operation

4.0 PERFORANCE ASSESSMENT

Demonstration results showed significant improvement to the operation of the water system post-ice pigging. Sediments removed by ice pigging ranged from 8.3 to 81.8 lbs per mile of pipe cleaned, whereas conventional hydraulic flushing did not remove any sediment. Residual chlorine did not change significantly before and after ice pigging and was steady at a level above 1.0 mg/L. Water used for hydraulic flushing was reduced from 5.5 million gallons per year before ice pigging to 2.3 million gallons per year post-ice pigging. Ice pigging can be financially justifiable at water rate of $0.008/gallon or higher due to this water saving. Sodium hypochlorite consumption for re-chlorination was reduced by 465.1 gallons per year post-ice pigging. There was no total trihalomethane (TTHM) violation after ice pigging, whereas four violations were recorded the year prior to ice pigging when only conventional hydraulic flushing was performed for system maintenance.

Results of the bacterial community analysis study in water distribution pipelines using 16S rRNA (genome sequencing analysis) sequencing procedures showed that ice pigging removed entrenched biofilms and bacterial species highly resistant to the disinfectant, whereas conventional flushing only removed bacterial species closer to surface of biofilms in contact with water. Also, in pipelines with extreme levels of chlorine, highly resistant *bacilli* predominated, whereas, under less extreme conditions, proteobacteria formed the predominant species. Biofilms can exert chlorine demand and generate THMs, and hence the effective cleaning provided by ice pigging can help maintain distribution system water quality for a longer time horizon.

Table E-1 shows the comparison of conventional hydraulic flushing and ice pigging performance. Although the overall results are positive, they cannot all be attributed to ice pigging alone because the site has also implemented other improvement measures, such as the addition of a booster pump station to lower the water ages of parts of the distribution system, and a recirculation system to improve water circulation in the water storage tanks. It is a combination of the cleaning of water mains and the water age reduction measures that were undertaken that have resulted in the improvements.

Table E-1. Comparison of Conventional Flushing and Ice Pigging Performances.

Parameter	Conventional Hydraulic Flushing	Ice Pigging	Improvement
Sediments removed	0 lbs sediments/mile of pipe	8.3 to 81.8 lbs sediments/mile of pipe	Ice pigging removes sediments
Water used in hydrant flushing	5.5 million gallons per year	2.3 million gallons per year	3.2 million gallons annual reduction
Residual chlorine	Met minimum requirement	Met minimum requirement	No significant change
Chlorine for re-chlorination	694.7 gallons/year	229.6 gallons/year	465.1 gallons annual reduction
Annual TTHM violations	4 violations	0 violation	Avoided violations post-ice pigging
Biofilm Removal	Bacterial species close to the biofilm-water interface	Entrenched biofilms highly resistant to disinfectant	Remove bacteria close to pipe interior surface

Page Intentionally Left Blank

5.0 COST ASSESSMENT

Table E-2 summarizes the cost elements associated with ice pigging performed in this demonstration.

Table E-2. Cost Model for Ice Pigging at NASL

Cost Element	Quantity		Unit Cost	Total ($)
Ice pigging contract cost	55,845	ft	3.22	180,036
Contract fee, 2.3%	1	LS	4,141	4,141
SIOH, 6%	1	LS	10,802	10,802
Total ice pigging cost				194,979

The main cost drivers associated with ice pigging are the size (such as pipe diameters and lengths) of the water distribution system to be pigged, and complexity of the system (such as availability of insertion and extraction ports for ice pigging).

The size of distribution system required to be pigged in terms of linear feet of pipe length, and pipe diameters determine the number of loads of ice needed for the project. Each load consists of 2,700 gallon of ice slurry and requires a whole day for production on-site. The greater the number of loads for a particular project, the lower the unit cost of ice pigging. For example, ice pigging projects at Naval Base Ventura County Port Hueneme and NASL required 3 and 12 loads of ice, respectively, corresponding to unit costs of $8.08 and $5.56 per gallon of ice.

Long water mains that do not have access for insertion and extraction ports would incur additional costs to install appropriate ports. It is very rare that this would be required.

The project team performed life-cycle cost analysis to compare the cost of ice pigging with conventional hydrant flushing. Cost analysis results show that ice pigging does not result in a net cost saving. Although the water saving is significant, it does not translate into a net cost saving due to the current low water rate of $0.004 per gallon. Sensitivity analysis showed that ice pigging could have cost benefit when water rate is $0.008 per gallon or higher. Ice pigging also has other intangible benefits such as proper maintenance of water distribution system, improved hydraulic capacity, and it also aids in water quality compliance that might offset the cost burden.

Page Intentionally Left Blank

6.0 IMPLEMENTATION ISSUES

Ice pigging technology has been commercialized, and SUEZ is the only company that can perform ice pigging as the sole licensee of the technology. Implementation is typically achieved through standard contracts to procure ice pigging services.

Ice pigging is an effective water main cleaning technique that might help in improving the operation of DoD drinking water distribution system. Water systems may not need water main cleaning when routine conventional hydraulic flushing is sufficient to attain adequate disinfectant residuals within the water system as well as attaining compliance with SDWA water quality standards. Water main cleaning by ice pigging would be a good option to consider when water systems require aggressive hydrant flushing in order to comply with water quality standards. It could have a cost saving effect from reduced water wastage for flushing if the water rate is $0.008 per gallon or higher or if water rates are expected to escalate rapidly due to droughts. For water systems where free chlorine is used for disinfection, typical water quality issues arise from the loss of disinfectant residuals, and from violations of the TTHM maximum contaminant level requirement. For water systems using chloramine as disinfectant, nitrification (elevated nitrate/nitrite levels and low disinfectant residual) is the main water quality issue. Water systems experiencing stagnant water issues should implement other measures to reduce water age first because water main cleaning will not increase water demand or cause the water to move faster to reduce water age.

The risk of damage to water pipes is very low since ice pigging uses a water system's own water pressure for pigging. A water distribution system planned for ice pigging should be in fair operating condition. Water mains meeting requirements for normal water distribution system operations are suitable for ice pigging.

Furthermore, based on lessons learned from this project, installations should consider the issues listed below when planning for ice pigging.

- Water service disruption could be very problematic for DoD facilities performing critical missions. It is difficult to communicate water stoppage schedules to all affected facilities. Project planning should include adequate coordination with affected facilities to work out acceptable water stoppage schedules. Ice pigging operations can be completed within three hours if preparation is adequate and there are no abnormal problems in the field affecting implementation. Thus, with proper coordination, water stoppage can be scheduled for early morning hours before normal business hours such that water service can be restored during business hours. It can also be scheduled during weekends to minimize impacts to facilities performing critical missions.
- Ice pigging requires support from the water distribution system operators to perform tasks such as operating valves for ice pigging operations, shutting off and turning on water supplies to affected facilities, coordinating with facility access and locating valves. Planning should account for the availability of needed resources to support ice pigging.
- For instances where valves cannot be located due to inaccurate drawings, a metal detector is very helpful for locating valves and other appurtenances.