Refereed Proceedings

Heat Exchanger Fouling and Cleaning:

Fundamentals and Applications

Engineering Conferences International *Year* 2003

The Practical Application and Innovation of Cleaning Technology for Heat Exchangers

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THE PRACTICAL APPLICATION AND INNOVATION OF CLEANING TECHNOLOGY FOR HEAT EXCHANGERS

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ABSTRACT

The fouling of heat exchangers not only has a negative impact on heat transfer efficiency but also may restrict the output or production capacity of the facility. Given the cooling medium and the process, heat exchangers may be lightly fouled with organic deposits or may be severely blocked from hardened process chemicals. The probability of success in cleaning the heat exchanger is dependent on the selection of the appropriate cleaning technology under the specific fouling conditions. Early identification of fouling characteristics and a fundamental knowledge of cleaning system capabilities are essential in determining the most effective cleaning technology and the frequency of cleaning required. Unique circumstances may require innovative solutions. *State-of-the-art* cleaning technologies for shell and tube heat exchangers and air-cooled heat exchangers are introduced. The practical application and innovation of cleaning technology is discussed. Methods for effective removal of various deposit types are presented.

INTRODUCTION

The proper performance of heat exchangers within a process can affect the cost of the final product, or even the production rate. Unfortunately, heat exchangers are prone to fouling, its nature depending on the fluids flowing within and over the tubes or particulates in the atmosphere when discussing air cooled heat exchangers. The reduction in heat transfer that results almost invariably has an impact on product cost. Putman (2001) tells us to reduce this impact, heat exchanger performance should be intelligently monitored and the heat exchanger cleaned at intervals that are determined from optimal economic criteria.

Heat Exchanger Fouling and its Effects

The principal types of fouling encountered in process heat exchangers include:

- Particulate fouling
- Corrosion fouling
- Biological fouling
- Crystallization fouling
- Chemical reaction fouling
- Freezing fouling

Types of fouling encountered on the external surfaces of air cooled heat exchangers may include:

- Dirt, dust and debris
- Pollen and leaves
- Insects and bird carcasses

In most cases, it is unlikely that fouling is exclusively due to a single mechanism, and in many situations one mechanism will be dominant. Fouling tends to increase over time, the trajectory being very site specific. Recognizing this, the Tubular Exchanger Manufacturers Association (TEMA, 1988) recommends that designers of heat exchangers include an allowable fouling resistance in their calculations, in order that some fouling can be tolerated before cleaning becomes necessary. But even though these allowances tend to prevent frequent process interruptions, fouling still has an economic impact. Thus, determining when to clean often requires striking a balance between maximizing the quantity of finished product from the process and its cost.

HEAT EXCHANGER CLEANING METHODS

Regardless of the tube material, the most effective way to ensure that tubes achieve their full life expectancy and heat transfer efficiency is to keep them clean. Each time the tube deposits, sedimentation, biofouling and obstructions are removed, the surfaces are returned almost to bare metal, providing the most effective heat transfer and the tube itself with a new life cycle, the protective oxide coatings quickly rebuilding themselves to re-passivate the cleaned tube.

While cleaning can be performed *on-line*, the majority of cleaning procedures are performed *off-line;* the most frequently chosen, most effective and fastest cleaning method being mechanical cleaning.

Among other off-line methods is the use of very high-pressure water, but since the jet can only be moved along the tube slowly, the time taken to clean a heat exchanger can become extended. Great care must be taken to avoid damaging any tubesheet or tube coatings which may be present; otherwise the successful removal of fouling deposits may become associated with new tube leaks or increased tube sheet corrosion, only observable after the unit has been brought back on-line.

This paper introduces technologies for:

- Mechanical cleaning of shell and tube heat exchangers
- HydroDrilling of shell and tube heat exchangers
- Automated and Semi-automated cleaning of external surfaces of air-cooled heat exchangers

Mechanical Cleaning of Heat Exchanger Tubes

Off-line mechanical cleaning is especially useful where fouling problems exist and are too severe to be handled by any of the other methods. Obviously, the tool selected has to be the most appropriate for removing a particular type of deposit. Molded plastic cleaners (pigs) are quite popular for some light silt applications. Brushes can also be used to remove these soft deposits as well as some microbiological deposits. Brushes are also useful for cleaning tubes with enhanced surfaces (e.g. spirally indented or finned), or those tubes with thin wall metal inserts or epoxy type coatings.

With harder types of deposits , calcium carbonate being a notable example, metal cleaners of various designs have been developed for effective removal. Figure 1, Conco Type C3S Tube Cleaner and Figure 2, Conco Type C4S Tube Cleaner show some of the current versions of mechanical cleaners with spring-loaded blades. The use of spring-loaded tube cleaners was identified as "Proper Maintenance" by Putman and Walker (2000).

The blades are mounted on a spindle, at one end of the spindle is a serrated plastic disk that allows a jet of water to propel the cleaners through a tube with greater hydraulic efficiency. The water is directed to the tube being cleaned by a water gun. The water is delivered by a pump operating at 300 psig (2.07 MPa). Since the pump is usually mounted on a wheeled base plate, the system can be conveniently moved from unit to unit within a plant or even moved to another plant. See Figure 3 Conco Water Gun and Portable Booster Pump.

Figure 1
Conco Type C3S Tube Cleaner

Figure 2
Conco Type C4S Tube Cleaner

Another advantage of using water for tube cleaner propulsion is that the material removed can be collected in a plastic container for later drying, then weighing to establish the deposit density (g/m^2) and followed in many cases by X-ray fluorescent analysis of the deposit cake.

A water pressure of 300 psig (2.07 MPa) is very effective for propelling the cleaning tools through the tubes, preventing their exit velocity from rising above a safe level. Some other cleaning systems use air or a mixture of air and water to propel the cleaner, but air pressure is compressible and dangerous to use.

Figure 3
Conco Water Gun and Portable Booster Pump

Most metal cleaners are designed to have a controlled spring-loaded cutting edge: but, if effective deposit removal is to be the result, the dimensions of the cutting surfaces have to be closely matched to the internal diameter of the tube being cleaned. This not only improves the peripheral surface contact, but also ensures that the appropriate spring tension will be applied as the cleaner is propelled through the tube. See Figure 4, C4S Tube Cleaner in Action. The effective life of cleaners with this design can be as high as 12 tube passes.

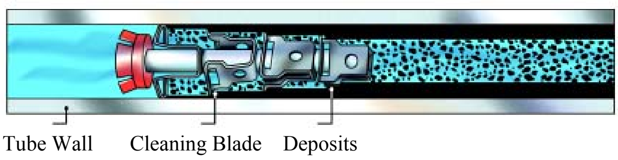

Figure 4
C4S Tube Cleaner in Action

Tube cleaner innovations. As a result of an innovative research program organized to resolve problems encountered in the field and to develop new products where existing equipment was found to be inadequate, new tube cleaners were developed. For example, in order to provide the blades with more circumferential coverage of the tube surface, the Conco Hex Cleaner was developed. The increased contact surface provided by the greater number of blades was found to be more efficient in removing tenacious deposits such as those consisting of various forms of manganese.

A later development involved a tool for removing hard calcite deposits, which were found to be difficult to remove even by acid cleaning. The Conco Cal Buster consists of a teflon body on which are mounted a number of rotary cutters. These are placed at different angles around the body, which is fitted with a plastic disk similar to those used to propel other cleaners through tubes. Used on condenser tubes that had accumulated a large quantity of very hard deposits, Stiesma et al (1994) described how cleaners of this type removed 80 tons (72.48 tonnes) of calcite material from a large surface condenser. It has now become a standard tool whenever hard and brittle deposits are encountered.

Additional developments for the removal of manganese dioxide, iron, and silica deposits, include the stainless steel brush (SSTB), it is made from stainless steel, with over 1,000 contact points per cleaner.

The experience gained from using these techniques has allowed the cleaning duration to be forecasted with confidence and cleaning to be performed on schedule. For instance, a normal crew can clean 5,000 tubes during a 12-hour shift. Clearly, the number of tubes cleaned in a day can rise with an increase in crew size, limited only by there being adequate space for the crew to work effectively

The concern is occasionally expressed that mechanical cleaners can possibly cause damage to tube surfaces. With cleaners that have been properly designed and carefully manufactured, such damage is extremely rare. Indeed, Hovland et al (1988) conducted controlled tests by passing such cleaners repeatedly through 30 feet long, 90-10 CuNi tubes. It was found that after 100 passes of these cleaners, the wall thickness became reduced by only between 0.0005 and 0.0009 inches (12.5 and 22.86μ). If a 50% reduction in wall thickness is the critical parameter, extrapolating this series of tests would be equivalent to 2800 passes of a cleaner per tube or 1000 years of condenser cleaning!

Clearly, all off-line cleaning methods sometimes need assistance where the deposits have been allowed to build up and even become hard. In such cases, it may still be necessary to acid clean, followed by cleaning with mechanical cleaners or high-pressure water to remove any remaining debris.

Chemicals are also used for the off-line cleaning of heat exchanger tubes. Several mildly acidic products are available and will remove more deposit than most other methods, but it is expensive, job duration is excessive, and the subsequent disposal of the chemicals requires serious consideration due to potential environmental hazard. It has also been found quite frequently that some residual material still needs to be removed by mechanical cleaning methods. One very effective technique for removal of difficult deposits is HydroDrilling which will be discussed in the next section.

Very few on-line methods are available to clean heat exchanger tubes but the best known is the system which uses recirculated sponge rubber balls as the cleaning vehicle. These systems often operate for only a part of each day and, rather than maintaining absolutely clean tube surfaces, tend to merely limit the degree of tube fouling. Although the tubes may become cleaner if abrasive balls are used, tube wear is often the unfortunate consequence of such cleaning. What's more, this system is not effective on hardened process chemicals or refining products.

Mussalli et al (1991) showed some uncertainty concerning sponge ball distribution and therefore, how many of the tubes actually become cleaned on line. It is also not uncommon to find that numerous sponge balls have become stuck in tubes and these appear among the material removed during mechanical cleaning operations. For these reasons, the tubes of heat exchangers equipped with these on-line systems still have to be cleaned periodically off-line, especially if loss of capacity is of serious concern.

Hydrodrilling of Severely Fouled or Blocked Heat Exchanger Tubes

Since its invention in 1970, the HydroDrill, shown in Figure 5, Global HydroDrill in Action, has been used in refineries, petrochemical plants, pulp and paper plants, electric power plants and other process industry plants throughout the world. While the HydroDrill provides an aggressive cleaning action it can be used frequently and routinely. Detailed information is provided in The Global Heat Exchanger Services Company Statement of Qualifications, 2003.

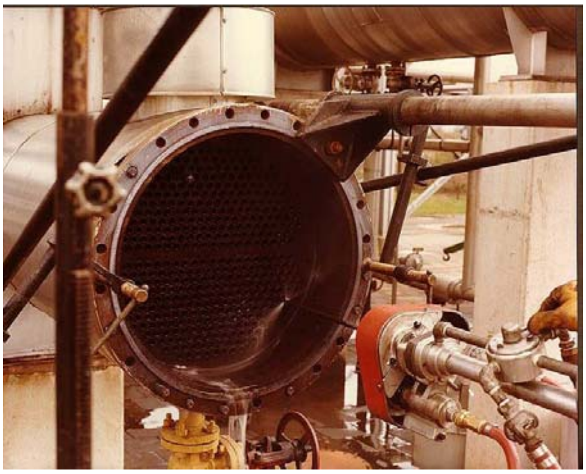

Figure 5
Global HydroDrill in Action

The HydroDrill is extremely effective on hard, tough deposits, and after drilling it is often possible to salvage heat exchangers previously thought to be useless. Hydrodrilling can also be performed on-site therefore eliminating the need for bundles to be sent off-site for cleaning treatments. Completely blocked tubes can be restored to 100 percent of the original tube internal diameter in one pass of the HydroDrill, cleaning tubes in one pass reduces labor costs. Typical cleaning speed for a 20-foot long tube is 30 to 90 seconds each. Formerly compromised tubes can be cleaned and polished to 100 percent efficiency so that inspection can be performed.

For example, in one case the same bank of heat exchangers fouled so severely that they required cleaning every two months, resulting in 30 cleanings over five years. On inspection it was reported that the heat exchanger tubing had maintained its original condition. Further detailed testing has been performed by a Japanese company, confirming the HydroDrill is safe to use. Fouled bundles that were designated as scrap, often following the failure of other cleaning methods, can be recovered and placed back in to service.

The HydroDrill can effectively clean hard deposits such as:

- Coke
- Calcium
- Sulfur
- Bauxite
- Asphalt
- Oxides
- Baked-on hard polymers

The HydroDrill is designed to maximize cleaning effectiveness with minimal risk. The bit, spinning at 1000 to 2000 RPM removes deposits with a rotary scraping action. Bits range in size for tubes from 3/8" up to 6 inches, the most common tube sizes being ½", ¾", 1" and 1 ½". The various bits are shown in Figure 6, Various HydroDrill Bits.

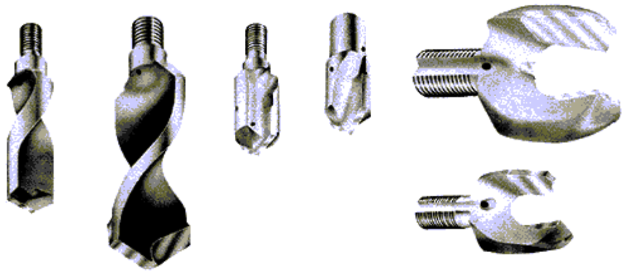

Figure 6
Various HydroDrill Bits

The bit is designed to ensure no tube damage occurs during the drilling operation. The bit is designed with a long shank to ensure that the axis of the bit and the axis of the tube are in complete alignment. Carbide scrapers are only on the leading edge of the bit. Corners of the bit are rounded, so there are no sharp corners to gouge the tube wall. The drill rides on a thin layer of liquid (water) for lubricating bearing surfaces between the bit and the tube wall.

The system can accommodate tubes that are bowed. The long, slender "kelly" rod that drives the bit inherently bends to follow the tube. The system is also easy to setup and operate, a two-person crew can set-up the equipment in one hour or less. Control of the equipment is straightforward, a foot pedal and 4-way valve are the extent of the controls. A complete setup is shown in Figure 7, Complete HydroDrill Setup. There are no complicated settings or adjustments that need to be made. Approximately 80 gallons of water and air utilities are the only requirements from the plant. The HydroDrill uses a small a volume of water (2 to 3 GPM at 200 to 300 PSI) that is filtered and recycled through a booster pump.

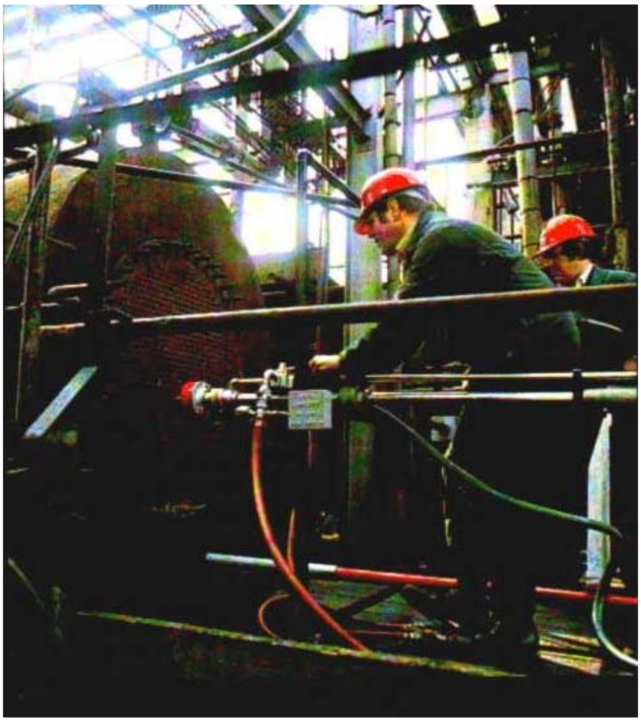

Figure 7.0
Complete HydroDrill Setup

Since the HydroDrill does not use high-pressure water or hazardous chemicals, the risk of personal injury or property damage is significantly less than other methods. The HydroDrill design has been verified by the successful cleaning of thousands of exchangers as well as by tests and inspections performed by Global Heat Exchanger Service's clients.

Tough hardened deposits can be removed faster and at lower overall cost. For over 30 years, the Hydrodrill has proven itself to be an effective and aggressive cleaning method for use in process plants within many industries. Its effectiveness, safety and affordability have made it an indispensable technology for many sites.

HydroDrilling heat exchanger tubes results in:

- Less scheduled cleaning time and cost
- Greater heat transfer efficiency
- Less risk of personnel injury or property damage
- Less waste and less cost associated with waste disposal
- Low risk

Developing an Appropriate Cleaning Procedure

The selected cleaning procedure should remove the particular deposits that are present as effectively as is possible, and will render the unit *out of service for the minimum amount of time*. Some other major considerations in the selection process are as follows:

Removal of obstructions. Many tube-cleaning methods are ineffective when there are obstructions within tubes, or when various forms of macrofouling are present. When such obstructions are found it is inadvisable to proceed with the cleaning regimen as planned. Attention should be given to shell-fish which constitute macrofouling, and can include Asiatic clams and zebra mussels in cooling water. Other obstructions generated directly from the process medium must be considered as well. The selected tube cleaner must have the body and strength to remove such obstructions. The cleaning method must also be able to remove the byssal material that shell-fish use to attach themselves to the tube walls, and hardened aged deposits.

There are certain types of other debris and process impurities which can become obstructions, among them: cooling tower fill, waste construction material, sponge rubber balls, rocks, sticks, twigs, seaweed and fresh water pollutants, any or all of which can become lodged in the tubes and will require removal. Meanwhile, experience has shown that, if appropriate procedures are followed, properly designed cleaners should not become stuck inside tubes, unless the tube is deformed.

Removal of corrosion products. When heat exchangers are equipped with copper alloy tubing, copper deposits grow continuously and the thick oxide coating or corrosion product can grow to the point where it will seriously impede heat transfer. Not only will the performance of the condenser be degraded but such deposits will also increase the potential for tube failure. When a thick outer layer of porous copper oxide is allowed to develop, it disrupts the protective inner cuprous oxide film, exposing the base metal to attack and causing under-deposit pitting to develop. Such destructive copper oxide accumulations together with any other deposits must be removed regularly.

Surface roughness. Rough tube surfaces, often the result of accumulated fouling deposits, are associated with increased friction coefficients while the reduced cooling water flow rates allow deposits to accumulate faster. It has also been found that rough tube surfaces tend to pit more easily than smooth surfaces. A tube surface rendered smooth from effective cleaning can improve condenser performance through:

- Improved heat transfer capacity and a lower water temperature rise across the heat exchanger, reducing the heat lost to the environment
- Increase in both flow volume and water velocity, often resulting in reduced pumping power
- Increased time required between cleanings, by reducing rate of re-deposition of fouling material on the tube surfaces.
- Reduced pitting from turbulence and gas bubble implosion
- Longer tube life and heat exchanger life

Fouling Tendencies of Air-Cooled Condenser

From Putman and Jaresch (2002) we know that the external surfaces of the finned tubes on air-cooled heat exchangers are very prone to fouling from pollen, dust, insects, leaves, plastic bags, bird carcasses, etc. Not only is the air flow affected but also the heat transfer coefficient: the deterioration in performance increasing unit operating costs. In severe cases, fouling can also limit the generation or production capacity of the facility or process.

To improve the heat removal capacity of an air-cooled heat exchanger under conditions of high ambient air temperature, operators will sometimes spray water on the heat exchanger to reduce surface temperature. Unfortunately, depending on the quality of water used, this sometimes leads to new scale formation on the tube fins and, again, reduces the heat transfer rate if the deposits are allowed to accumulate.

Cleaning Techniques for Air-Cooled Heat Exchangers

The three principal methods for cleaning the external surfaces of air-cooled condensers are as follows:

• Fire hose

• High pressure handlance

• Automated cleaning machine

Fire Hose. While the volume of water consumed is high, a fire hose offers only a low washing effect because of the low pressure involved. The galvanized surfaces of the tubes and fins are not damaged by this method. Unfortunately, in order to perform cleaning the plant must be taken out of service and scaffolding erected. The process may also be time and labor intensive depending on unit design and accessibility.

It has also been found that use of the fire hose only leads to small performance improvements even if the surfaces seem to be optically clean. The reason is that only a portion of the fouling material is washed off while the remainder is pressed between the fin tubes and can not be washed out by this method. Furthermore, once compressed, the fouling material not only hinders heat transfer but also obstructs air flow.

High Pressure Handlance. The high pressure handlance method offers low water consumption and a high water pressure. Unfortunately, the latter can cause the galvanized surfaces to become damaged or even cause the fins to be snapped off. Again, the plant must be taken out of service and scaffolding erected in order that cleaning can be performed. Unit accessibility will affect cleaning productivity.

As with the use of a fire hose, this procedure only leads to small performance improvements and, once the fouling material has been compressed, it hinders heat transfer and obstructs air flow.

Automated Cleaning Machine. The automated cleaning machine, an example of which is shown in Figure 8, Cleaning a Flat Cooler, uses a significant volume of water; the water pressure allows for effective surface cleaning, while avoiding damage to galvanized surfaces and fins. The main components of the system include a nozzle beam, a tracking system, and a control panel. The water contains no additives. The nozzle beam is optimally matched to the tube bundle geometry, with a constant jet angle as shown in Figure 9, Nozzle Beam. Optimizing the geometry of the nozzle beam involves determining the proper nozzle distance to the surface, the jet energy and the selection of the appropriate nozzle design. The constant jet angle also ensures that there is no damage to or snapping off of tube fins, regardless of the material from which they are fabricated. Furthermore, the carriage on which the nozzle beam is mounted moves at a constant speed and so allows the fouling to be removed effectively and uniformly across the heat exchange elements of the heat exchanger. Because the fouling material is removed, air flow is no longer obstructed.

Figure 8
Cleaning a Flat Cooler

Figure 9
Nozzle Beam

An important advantage of the automated cleaning method is that cleaning can be performed during operation while the unit is still on-line. Further, there is no need for scaffolding and labor requirements are minimized. The automated cleaning system can be applied in three principal forms:

1. Permanently installed system complete with PLC controls, one system being supplied for each side of the heat exchanger.
2. Semi-automatic system in which only the guide rails are permanently installed, the nozzle beam carriage being moved from section to section as the cleaning progresses as shown in Figure 10.
3. Portable service unit, together with a portable nozzle beam carriage and control unit. The cleaning service is performed in-house or by a qualified service provider as shown in Figure 8.

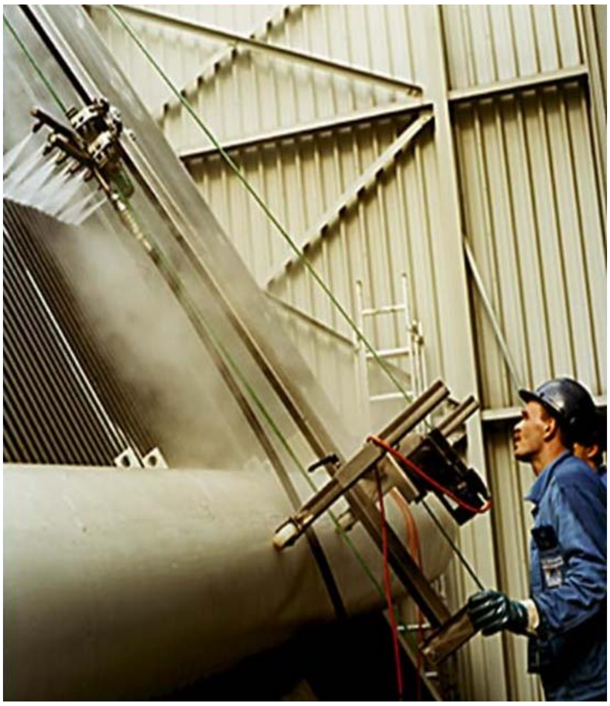

Figure 10
Semi-Automatic System

CONCLUSION

Amidst a marketplace replete with numerous cleaning and service options for every aspect of the production process, site engineers and staff must choose maintenance practices which will help to improve performance, while ensuring that the integrity of their equipment will not be compromised. Interim gains in performance can be achieved while maintaining the long-term efficacy of a respective unit, so long as the technology applied is sound and site-specific.

With regard to heat exchanger maintenance, in particular, the race to combat fouling is easily won or lost vis-à-vis the maintenance that is performed. If a heat exchanger is not cleaned at appropriate intervals, the reduction in heat transfer will impact product cost. This cost of this inefficiency impacts far further than mere machinery. Inefficient production has environmental and economic ramifications for consumers and corporations alike.

Effective, safe and affordable cleaning technologies such as mechanical cleaners, HydroDrilling and automated cleaning, have revolutionized the maintenance of plant heat exchangers.

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ACKNOWLEDGEMENTS

The authors would like to acknowledge with thanks Conco Systems, Inc. and Global Heat Exchanger Services Company for their innovative approach to the development of heat exchanger cleaning technology and for their encouragement to share their findings with others.