Energy Efficiency and O&M Cost Reduction Gained by Automatic Tube Cleaning System (ATCS) installation in Oil Refinery Plant: Case Study and Fouling Global Perspectives

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ABSTRACT

Automatic cleaning of heat exchangers and condenser tubes by means of sponge balls is well known since the early 1950s, with applications expanding from steam power plants to industrial cooling and air conditioning systems. The main benefits (bottom-lined in cost savings) are: elimination of maintenance down-time, elimination of the need for chemicals, more efficient operation of the processes and the plant and more efficient use of energy.

This paper presents the design and performance assessment of an Automatic Tube Cleaning System (ATCS) implemented in a hydrogen-sulfide retrieval and monoethanolamine treatment plant at the Paz Ashdod Refinery, one of the two refineries in Israel. Patented by CQM for its ball injection and trapping methods, the ATCS reveals unique benefits in operation, and the resulting O&M cost savings are evaluated in detail. The paper concludes by presenting the main costs of heat exchanger fouling, offering a view on fouling mitigation as a means to meet the main goals of global energy efficiency.

Keywords: energy efficiency, heat exchanger fouling, fouling mitigation, energy savings, GHG savings

1 INTRODUCTION: THE PROBLEM AND TYPICAL SOLUTIONS

The problem of fouling in heat exchangers that are cooled by cooling towers is well known. The accumulation of sediment, which deposits itself on heat-transfer surfaces in cooling towers, heat exchangers, main pipeline systems and control equipment, decreases performance and productivity. Fouling also results in higher operating and maintenance costs due to restricted flow, increased pressure, loss of throughput, equipment replacement and higher energy consumption.

The most common solution to such fouling is periodic **off-line** cleaning of the heat exchanger, either by mechanical or chemical methods, which has several drawbacks. It requires a complete process shutdown for cleaning. Immediately after cleaning, the fouling process begins again, and the accumulation gradually hampers performance until the next cleaning treatment. Moreover, the cleaning chemicals are harmful to the environment, requiring stringent safety measures and specialized disposal, as well as the ongoing use of costly chemical additives.

As much as 8% of the maintenance costs in a typical industrial plant can be attributed to fouling in heat exchangers alone. The costs of fouling and its off-line cleaning approach can be divided to four groups [1]:

- **Decreased productivity** due to escalated efficiency degradation and loss of production during shutdowns. These are the main cost of fouling.
- **Higher maintenance costs** for removing fouling deposits and for chemicals or other operating costs of antifouling devices.
- **Higher energy consumption** in many processes. Extra electricity, fuel or process steam is needed to overcome the effects of fouling. Between 1% and 5% of the energy consumed by the industrial sector is used to overcome fouling.
- **Excess heat transfer area**: The design requirements for excess surface area to compensate for fouling varies between 10% - 500%, with an average of around 30%. Such excess areas can generate additional capital costs of 25%. There are also costs of stronger foundations for heavier or redundant heat exchangers, extra space requirements and increased transportation and installation costs.

These drawbacks make the off-line cleaning methods expensive, cumbersome and inefficient for the entire industrial process. Indeed, off-line cleaning is not considered an adequate solution for the fouling problem; it is only used for lack of a better technology.

The on-line cleaning method, in contrast, is an ongoing process using mechanical means to keep the heat exchanger clean while it operates. Some cleaning systems also use chemicals (which must be carefully adapted to each process), but on-line mechanical-only cleaning is both environmentally responsible and highly cost-effective.

On-line mechanical cleaning boosts performance in two ways: it does not require a system shutdown and temporary loss of operation; and it keeps performance optimal and energy-efficient through continuous cleaning, which does not allow fouling to occur. In addition, on-line mechanical cleaning not only eliminates manhours for cleaning services, but also chemical purchase and waste disposal.

In terms of efficiency, savings and environmental safety, on-line mechanical heat-exchanger cleaning is the smartest option available.

2 THE CQM ON-LINE AUTOMATIC TUBE CLEANING SYSTEM

The CQM ATCS is installed on heat exchangers and keeps them clean without intervention. The system periodically injects into the tube soft balls that are slightly larger in diameter than the tubes themselves. The natural pressure head pushes the balls through the tube, which is thereby rubbed clean. The balls are trapped on the outlet of the heat exchanger, where they are prepared for the next cleaning cycle. The environmentally friendly ATCS results in energy conservation and reduces toxic waste, while providing cost-effective tube cleaning. It also prevents expensive downtime by keeping processes running.

The specific advantages of the CQM ATCS over other on-line automatic cleaning products (sponge balls, brushes and tube inserts) are:

- Thorough cleaning: Balls are periodically injected at a single shot carried by the fluid and reaching all tubes, both central and peripheral.
- Solid design: The system shows high reliability, rapid installation, low maintenance, and high viability for cost-sensitive markets.
- Wide range of sizes: The system is suitable for a wide variety of heat exchangers, from small condensers in air conditioning to large industrial applications.
- Better ball-trapping mechanism: In other solutions, balls are frequently lost in the system, causing damage to downstream equipment, environmental concerns and higher cleaning costs.
- Better control of the cleaning process: Cleaning periods are customizable to maintain a high level of performance, and to minimize ball wear.

CQM has installed more than 2,000 ATCS units around the world, involving the chemical / petrochemical industry, power plants and central HVAC systems. The ATCS has delivered documented value to these markets:

- Central air conditioning systems and industrial refrigeration: Up to 25% savings in energy costs, and typically saving 600 tons of GHG per 1000 T.R. per year.
- Electric power plants: Up to 4% increased annual power generation.
- Industrial processes: Significant increases in productivity and reduction of operation and maintenance costs.

3 CASE STUDY

3.1 Background

The Paz Ashdod Refinery began operating in 1973 and has the capacity to process around 4 million tons of crude oil per year. "Area A" in the refinery is the first station in the process of refining the crude oil. After the composition of the crude oil is determined, it is pumped through a series of heat exchangers, rinsed with water to remove salts, and heated to a temperature of 370° C.

The study focused on a hydrogen sulfide (H_2S) cooler in a H_2S recovery process downstream from the CDU. At the final stage of H_2S recycling, it must be cooled below 40°C in a water-cooled tube and shell heat exchanger (tagged 151-C5). During this process, the remaining water vapor in the H_2S is condensed. A cooling tower supplies the water for cooling. Our discussion below refers to this heat exchanger.

3.2 The fouling problem

Fig. 1: Clogged H_2S cooler: mud and scale.

The heat exchanger (Fig. 1) was clogged by scale and silt, and the heat exchange capacity had diminished to the point where external cooling, in the form of water spray over the condenser case, had to be used. The external cooling was only a partial remedy, and moreover it added corrosion and soiled the surroundings. The inadequate condensation phase caused many malfunctions in the sulfur recovery plant installed after the amine unit, and in extreme cases it even disrupted production.

When the heat exchanger became clogged, the effluent gas temperature climbed to above 70 °C and some water penetrated the sulfur recovery plant, which exacerbated clogging with corrosion particles and required plant shutdown. Cleaning the heat exchanger twice yearly did not

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solve the problem, as the exchanger became clogged soon after each cleaning.

Disruption of the sulfur retrieval plant cost tens of thousands of US $ per day. This cost was amplified when the crude oil had a high sulfur content.

3.3 The solution

The CQM ATCS was installed in October 2003, during plant renovation. Prior to the ATCS installation, the heat exchanger had been manually cleaned with acid and high pressure water.

Characteristics of the H_2S cooling heat exchanger were as follows: tube and shell, 4 water cooling passes, 156 tubes (0.75 inch diameter, length 6 m). The ATCS diameter is 6 inches on the heat exchanger outlet pipe, where the ball strainer is installed.

As of today, the ATCS is continuously operating, maintaining the heat exchanger tubes in a clean state and providing the benefits and savings described later.

3.4 The results

3.4.1 Introduction

It was obvious that cleaning the clogged condenser would create a significant energy savings. The complexity of the referenced process, however, made it necessary to use computational simulation tools. A process model was built with HYSYS. After several simulations using various conditions, the data was fed to the Horizontal Multipass Flow TEMA HTRI model for computing the output and other condenser data.

3.4.2 Simulation

	Fouled HX	**Cleaned HX**
Gas Flow Rate – kg/s	2,364	2,364
Gas Inlet Temp. - °C	90	90
Gas Outlet Temp. - °C	70	40
Wall Temp. min/max - °C	65/83.9	33.9/66.4
CW Inlet/Outlet Temp. - °C	32/40	32/40
CW Flow Rate – kg/s	38.8	61.0
CW Pressure Drop Coefficient	1.422	0.903 (-37%)
Effective Overall Temp. Difference - °C	44.3	24.2
Overall Heat Transfer Coefficient - kcal/m2·h·°C	123.3	352.2 (+285%)
Fouling factor – 1/U	0.003	0.0004
Cooling Capacity - kcal/h	309,600	487,000 (+157%)

Table 1: Rates of simulated improvement at the Paz Ashdod Refinery.

The simulations results are presented in Table 1, which also present a few measurements of the rate of improvement (in brackets). The simulations were based on two actual measured heat exchanger H_2S outlet temperatures:

70 °C of a clogged condenser, which was measured just before shutdown.

40 °C of a clean condenser, which was measured 156 days after the ATCS installation.

3.4.3 Water savings

Under the old system, external cooling was used 5 months per year, 12 hours per day: a total of 1,800 hours per year.

The 2-inch pipe that was providing the water has 26 holes (3 mm diameter). The measured water flow from one hole is 189 liter/hour, calculating the total sprayed water per year at 8,845,200 liters.

At the cost of water of US $1 / cubic meter, the total savings provided by the elimination of the external water cooling is US $8,845 / year.

3.4.4 Other savings

Manual cleaning (manpower costs) approx. US $2,500 per year.

Sealing: US $600 per year.

Savings due to continual operation of the sulfur retrieval plant: US $40,000 - 50,000 per year.

Condenser cleaning	2,500
Sealing	600
Continuous operation of the Sulfur Retrieval Plant	50,000
Spray water savings	8,845
Total	**$61,945**

Table 2: Total savings in US $ per year at the Paz Ashdod Refinery.

It should be emphasized that this amount does not reflect the increase in plant productivity as a result of keeping the heat exchanger constantly at its highest designed efficiency. Likewise, it does not include costs of consequential unscheduled shutdowns which had occurred a few times during the 30 years of the plant operation. Unfortunately these were not recorded.

3.4.5 Additional ATCS installations

Since the reference installation on the H_2S recovery process line, the Paz Ashdod Refinery has ordered 4 more ATCS units, each one providing substantial energy savings and cost savings.

3.5 Direct application for oil refineries

Oil refineries use massive quantities of water for cooling. The plant's central water-based cooling infrastructure includes cooling towers, pumps, piping and chemical treatment. Water cooling is used mainly for final cooling to prevent evaporation of the distillates (gasoline, diesel fuel, kerosene) and to remove pollutants.

In January 2008, CQM installed its first ATCS in a U.S. refinery in Texas. The heat exchanger in which hydrogen recycled gas is cooled by water had suffered from repeated fouling, necessitating its shutdown for manual cleaning 3 to 5 times a year. **Each shutdown was costing the plant $100,000.** The heat exchanger in question is 6 meters in length, consisting of four U-tube passes with 350 tubes per pass.

Crude oil refining suffers major losses caused by fouling, and there is a growing demand for effective measures. About half of the financial penalties due to fouling in an oil refinery are attributable to the crude distillation unit (CDU). Crude oil distillation accounts for a large percentage of the energy used in oil refining. In the USA alone, fouling just in the crude preheat trains is estimated to cost around **$1.2 billion per annum**.

Recently, by the development of unique OEM cleaning balls, CQM has been able to extend the ATCS capabilities to non-aqueous high temperature applications, such as acids, oils and chemical liquids. A cost-effective, automatic, efficient fouling mitigation method for heat exchangers in a crude preheat train has the potential to revolutionize the oil refining industry.

4 FOULING: GLOBAL PERSPECTIVES

The main cost of fouling is due to the decrease in productivity, which in the case study above accounted for 80% of the total cost. But inefficient fouling mitigation not only costs huge sums, it also pollutes the environment. Not least, it uses an enormous amount of energy resources, which necessitates more energy production and more power plants. This usage can be significantly reduced using effective fouling mitigation measures.

Energy efficiency methods aim to reduce GHG (greenhouse gases) and to increase both the potential and actual productivity of existing infrastructures (e.g. more kWh from existing power plants). Based on the above presentation, and as further illustrated in Table 3, on-line cleaning of heat exchangers should become a high priority in the effort to promote private, national and global energy efficiency interests.

REFERENCES

[1] Prof. Dr.-Ing. H. Müller-Steinhagen, Introduction, *Handbook Heat Exchanger Fouling – Mitigation and Cleaning Technologies,* 2000, pp. 24-25.

OFF-LINE Fouling Cleaning Implications	ON-LINE Fouling Cleaning Implication	Energy Efficiency Implications		
		Cost Savings	More power from existing infrastructures	Saves GHG
Productivity Decrease	Productivity increase	√	√	√
	Operation at maximum design efficiency	√	√	
	Avoiding plant shutdown	√	√	
Increase of Initial Investment	Decrease of heat transfer areas	√		√
	Eliminate of fouling monitoring equipment	√		√
Increase of O& M Costs	Decrease of energy consumption	√	√	√
	Reduce of pressure losses	√	√	√
	Reduce of O&M costs	√		
	Minimizing chemicals usage	√		√
	Decrease of managerial effort	√		
		PRIVATE Interest	STATE Interest	GLOBAL Interest

Table 3: On-line fouling mitigation implications