Investigation of Self Cleaning Action in an Evaporator Tube Using a Spring Insert

[#1]Harsh Salgaonkar, [#2]Prakash Gadhe

[#1]Department of Mechanical Engineering, Maharashtra Institute of Technology, Kothrud, Pune

Abstract— A wide variety of industrial processes involve the transfer of heat energy between fluids in process equipment. As a result of this energy exchange unwanted deposits accumulate on the exchanger surfaces creating a resistance to heattransfer. These deposits reduce the heat transfer and can restrict fluid flow in the exchanger by narrowing the flow area. Control of fouling is costly and time consuming. In most situations, fouling can be reduced but cannot be eliminated completely.

An evaporator tubewith a spring insert is evaluated in this study. The arrangement is tested for a duration of six hours and the amount of scale formation is observed for different flow velocities. Similar experimentation is performed on a plain tube (without spring). A comparison of the two arrangements is done. Using these results a cost benefit analysis has been presented for an industrial evaporator.

Keywords**:** Fouling; Springs; Heat exchanger fouling; Heat exchanger design

I. INTRODUCTION

The global heat exchanger market is estimated to top a total of $12.7 billion by 2012, with an increase of 3–5% per annum**[1]**.Despite this very positive market outlook, manufacturers are under increasing pressure to produce heat exchangers that are more efficient in terms of heat recovery and use of material, while at the same time being faced with fluids that are increasingly difficult to process. One major problem directly related to these requirements is the deposition of unwanted materials on the heat transfer surfaces, which occurs in the majority of heat exchangers**[2].**

Accumulation of scale, organic matter, corrosion products, particulates or other deposits on the heat transfer surface causes fouling and costs the industry billions of dollars each year. These deposits degrade exchanger performance over time compared with clean conditions at startup.

The fouling layer is a conductive resistance to heat transfer that must be accounted for in the design heat transfer coefficient. Fouling thickness and thermal conductivity both contribute to the resistance. Reduced cross-sectional flow area increases pressure drop in the fouled region. This additional pressure drop must be accounted for in the pump design.

According to Nesta and Bennett**[3]** fouling costs the industry billions of dollars each year.Costs due to over design, additional fuel consumption and maintenance, loss of production, etc. has been estimated at 0.25% of the GDP of industrialized nations. In addition toincreased cost due to over design, other increased capital costs are also likely. If the fouling is severe a stand by heat exchanger unit may be required to ensure continuous operation while the main heat exchanger is being cleaned. This will result in the cost jumping up by 4-8 times the cost of running the exchanger in clean condition.Kukulka et al **[4]** have studied the effect of velocity changes on plate heat exchangers. The heat exchangers were exposed to untreated lake water and observed for 45 days.

Numerous techniques have been devised over the years to combat fouling. Bott **[5]** reviews the various techniques to minimize fouling and enhance productivity.Methods of cleaning may be classified into two groups namely online and offline cleaning. Offline cleaning consists of shutting down the process and cleaning the heat exchanger tubes.Emergency shutdown of heat exchange equipment for cleaning is disruptive and expensive. Many techniques of offline cleaning have been discussed mainly manual and mechanical cleaning. Chemical cleaning is also employed. Offline cleaning is something which is inevitable since no online method can give 100% fouling mitigation. Online cleaning consists of cleaning the heat exchanger tubes without the need to stop the process. This results in continuous operation without loss of productivity. The various online cleaning techniques consist of use of tube inserts, circulating sponge balls, brush and cage systems, passage of air slugs, etc.

Klaren D et al **[6]** have explained the use of circulating metal bits to achieve self-cleaning in shell and tube heat exchangers.The author has successfully shown how the technology can be effectively used to clean modern day shell and heat exchangers handling highly corrosive fluids. The arrangements results in substantial fouling reduction. It also helps in preventing overdesign of the heat exchanger surfaces.

Scraped-surface heat exchangers **[7]** where rotating installationscontinuously keep the pipe internal surfaces free from deposits have been used in industry for many years. Their investment, operation, and maintenance cost, as well as the complex geometry and maintenance, limit this technique to applications where very severe fouling occurs.

Krueger A et al **[8]**have shown how effective fouling mitigation can be achieved through the use of springs as tube inserts. Three different arrangements of springs inside the tubes have been demonstrated. Results show that around 80% fouling reduction

© 2015, IERJ All Rights Reserved

is achievable by these methods.Benefits of these systems include energy savings, extended run lengths of exchangers, reduction in maintenance costs, production enhancement and debottlenecking. The author has talked about a spring arrangement wherein the spring is held fixed at one end and rotary motion is imparted to it. The paper doesn’t mention how the rotary motion is given.Petitjean et al**[9]** have reviewed the use of tube inserts in terms of their ability to improve heat transfer co-efficient and mitigate fouling. They have found the method to be very effective.Ebert W A et al**[10]** have analyzed ExxonMobil’s data on fouling in crude preheat trains. They have reviewed the various fouling mitigation strategies adopted by ExxonMobil.

Distillery spent wash**[11]** is usually considered as waste of distillery processes and can be classified as a dilute organic liquid fertilizer with high potassium content. Sugarcane is crushed in the sugar mills to produce sugar. Along with sugar two other by products are formed namely bagasse and molasses. The bagasse is usually used in producing paper. The molasses are used in the production of alcohol in breweries. The molasses are fermented with yeast over time to produce alcohol. A by-product of this process is the distillery spent wash. It is an environmentally polluting effluent and it can be directly disposed off. It is generally passed through evaporator tubes to remove its water content and thereby increaseit total dissolved solids concentration. Thereafter it can be used to irrigate sugarcane fields. In recent years, due to expansion of distilleries in sugar cane growing countries, the disposal of SW has become an acute problem. In India, about 15,000 million litres of spent wash is produced annually from 246 distilleries which is characterized by undesirable colour and a foul odour. The fluid is brownish in colour.

In the present paper, the effect of a spring insert in mitigating fouling in a distillery evaporator has been presented. A spring having an outer diameter a few millimeters less than the tube’s inner diameter is fixed at one end of the tube. The other end is kept free. The fluid is passed through the tube at different velocities. The resultant increased pressure drop and reduced fouling has been noted and analyzed.

Fig. 1 Spring fitted inside the experimental tube

II. EXPERIMENTAL DETAILS

2.1 Experimental Setup

A schematic diagram of the experimental setup is shown in Fig. 2. The test section consists of a smooth tube,1 m long and having an inside diameter of 25.4 mm, with a spring inserted inside it.A pin has been inserted inside the reducer with the pin’s axis perpendicular to that of the tube.The spring is attached to this pin. This ensures that the spring is kept fixed at the inlet section while the other end is free. Two springs having different wire diameters were tested and the experiment was carried out separately for each spring. The working fluid used is distillery spent wash, the waste effluent from the distillery.

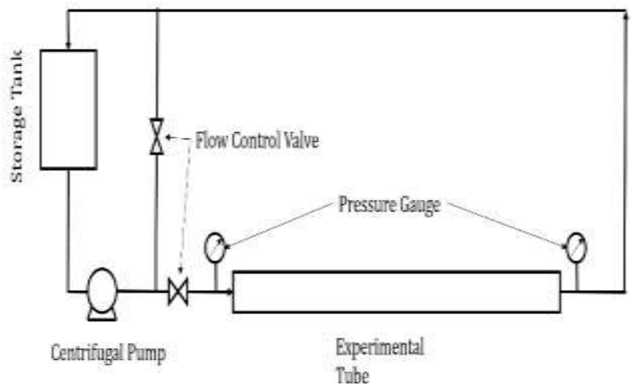

Fig.2 Experimental setup for scaling and pressure drop measurements

© 2015, IERJ All Rights Reserved

A 100 liter tank is employed to store the fluid through which it is supplied to the tube. A standard 5 HP centrifugal pump is used to circulate the fluid through the tube under pressure. Two diaphragm pressure gauges (0 to 6 kg/cm^2) were installed at the inlet and outlet sections of the tube to measure the pressure drop. The flow control valves help in getting and maintaining the required flow velocities. A rotameter (1000 liters/hr) was installed at the inlet to the tube to measure the flow velocity.

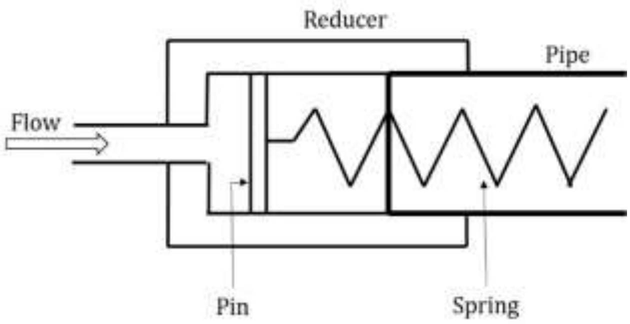

Fig.3 Schematic of spring installation

Both the springs are 1.5 m long having an outer diameter of 20 mm. This ensures a 2.5 mm radial clearance between the spring and tube surface. The wire diameters are chosen to be 1 mm and 1.2 mm. This results in the spring index (D/d) being greater than 16 which causes the spring to buckle under its own weight as well as the force of the incoming fluid.

Observations were made for four different flow velocities namely 1.5 m/s, 1.75 m/s, 2m/s and 2.25 m/s. The experimentation was performed for a duration of six hours for each spring and for each velocity. No heating was carried out during the entire process. As the fluid is passed through the tube the spring begins to vibrate laterally. This causes the spring coils to scrap the wall surface thereby removing any deposits formed. The change in the amount of scale formation due to the presence of the spring insert at different velocities has been observed. The pressure drop was noted. The scaling thickness was measured for the different velocities. Similar experimentation was done on a plain tube without any spring insert.

2.2 Spring Selection

Since the tube diameter is 25.4 mm, the outer diameter was selected to be 20 mm. This ensures a radial clearance of approximately 2.5mm. In actual working conditions, the tube will be subjected to temperatures in excess of 100°C. The spring will also have to sustain these temperatures. Also our desired action is that the spring should continuously scrap the tube walls. Thus the spring should have sufficient shearing as well as fatigue loading capacity. Considering all this the material for the spring was selected to be SS 316. The length was chosen to be 1.5 m since the spring was to be attached a little before the inlet of the tube. In this experimentation, the spring needs to buckle to achieve the scraping action. As per **[12]**, for the spring to buckle the spring index$C = \frac{D}{d} > 15$. Thus the wire diameter should be d<1.2 mm. Wires of diameters 1.2 mm and 0.8 mm were chosen. The pitch was selected to be 5 mm so that during scraping action the spring can be in contact with maximum portion of the tube surface.

III. OBSERVATIONS

As the fluid is passed through the tube the spring starts oscillating laterally. This causes the spring coils to scrub the tube wall surface thereby removing any deposits formed at an early stage. As the flow velocity is increased from 1.5 m/s to 2 m/s the scale formation reduces. This is in conformation with the theory**[13]**. For the condition of plain tube without the spring a scale thickness of 0.82 mm was observed at a velocity of 1.5 m/s. At velocity of 2.25 m/s the scale thickness was recorded to be 0.59 mm. When the spring of wire diameter 1.2 mm (Spring 1) was inserted inside the tube the scale formation reduced. For flow velocity of 1.5 m/s the scale thickness was recorded to be 0.56 mm and for flow velocity of 2.25 m/s the scale thickness was recorded to be 0.36 mm. Slightly better results were observed for the spring with wire diameter 1.8 m/s (Spring 2). Overall around 40% reduction in scale formation was achieved by the use of springs.

© 2015, IERJ All Rights Reserved

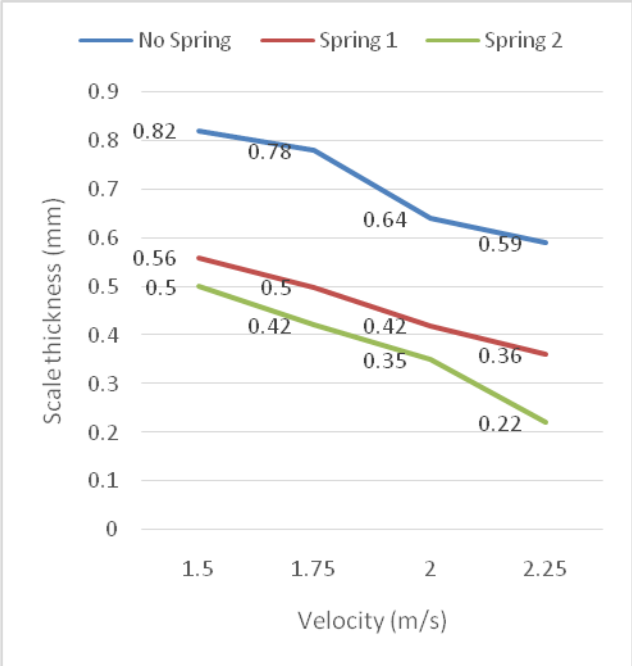

Fig.4 Scale thickness vs Velocity

The presence of spring causes an interference to the fluid flow. The spring insert causes an additional pressure drop which leads to increased pumping demand. In the case of a plain tube a net pressure drop of 0.19 kg/cm^2 was observed. With the insertion of spring 1 the net pressure drop rose by nearly 15% to 0.23kg/cm^2. Spring 2 gave a similar reading.

IV. COST BENEFIT ANALYSIS

The reduced scale thickness is accompanied by an increase in pressure drop. The economics of the proposed experimentation has been presented here. This experimentation was done in Praj Industries. The company manufactures heat transfer equipment mainly used in breweries. The fluid, distillery spent wash, is passed through evaporator tubes as a part of its treatment process to evaporate its water content and increase its total dissolved solids concentration.

For a commercial evaporator of the company which processes 1000 TPD (tonnes per day) of distillery spent wash, the total heat transfer area required is 3200m^2. This translates to a system volume of 80m^3**[14]**.The CIP process consists of cleaning the evaporator tubes with a 5% nitric and caustic solution. For normal evaporator tubes the cleaning period is every 5 days. Thus the evaporator is cleaned 6 times a month. This requires 37 tonnes of nitric acid and 49 tonnes of caustic solution per month.

Thus the cost of chemicals required to clean the tubes works out to be INR 2, 76,000. In our experimentation we found out that the scaling reduced by 40%. Based on this result we can predict that if the evaporator tubes were fitted with the spring inserts the evaporator would run for an additional 3 days. The evaporator would now require cleaning every 8 days i.e. max 4 cleanings per month. The cost of chemicals required for four cleanings would be INR 1, 84,000. That is a neat 30% savings.

	Nitric Solution	Caustic Solution
Normal Evaporator	37 TPM	49 TPM
Evaporator with Spring Insert	25 TPM	33 TPM
Net Savings	32%	33%

Table 1. Net savings in CIP chemicals

V. CONCLUSIONS

Based on the experimental work and the subsequent economic analysis the following conclusions can be drawn:

1) Scaling reduces as the flow velocity is increased in all the cases. This was expected as increased velocities result in lesser time available for the fluid particles to stick to the wall.
2) The springs result in an approximate 40 % reduction in scale formation.
3) A pressure drop increase of around 15% is observed which is acceptable considering the other benefits that can be achieved.
4) The evaporator can now run for an extended period of 3 days resulting in a continuous run time of 8 days.
5) The volume of chemicals required for cleaning the evaporator tubes can be reduced by nearly 30% per month.
6) Cleaning costs can be brought down by around 30%.

© 2015, IERJ All Rights Reserved

Further work can be done in optimizing the spring design so as to achieve even better results. Also, in this paper only one type of arrangement has been presented wherein the spring is held fixed at one end by attaching it to a pin. Other innovative configurations may be worked upon to see if they yield better results.

REFERENCES

1. Heat Exchanger: A Global Strategic Business Report, Global Industry Analysts, Inc., San Jose, CA, 2008.
2. Steinhagen, R., M¨uller-Steinhagen, H., and Maani, K., Problems and Costs Due to Heat Exchanger Fouling in New Zealand Industries, Heat Transfer Engineering, vol. 14, no. 1, pp. 19–30, 1992.
3. J. Nesta, C.A. Bennett, Fouling mitigation by design, Proc of Sixth International Conference on Heat Exchanger Fouling and Cleaning–Challenges and Opportunities, Engineering Conferences International, Kloster Irsee, Germany, p. 54.
4. D J Kukulka, Mohan Devgun (2007), Fluid temperature and velocity effect on fouling, Applied Thermal Engineering 2732–2744.
5. T.R. Bott, (1998), Fouling of Heat Exchangers, Elsevier Science & Technology Books, p. 357-405.
6. Klaren, D. G., and de Boer, E. F., (2007), Achievements and Potential of Self-Cleaning Heat Exchangers Using Untreated Natural Seawater as a Coolant, Proceedings of the ECI Conference on Heat Exchanger Fouling and Cleaning–VII, ECI Symposium Series, vol. RP5, Tomar, Portugal, p. 262–274.
7. Solano, J. P., Garc´ıa, A., Vicente, P. G., and Viedma, A. (2009),Performance Evaluation of a Zero-Fouling Reciprocating Scraped-Surface Heat Exchanger, Heat Transfer Engineering, vol. 32, p. 3–4.
8. Krueger, F. Pouponnot, (2009), Heat Exchanger Performance Improvement through the use of Tube Inserts in Refineries and Chemical Plants-Successful Applications: SPIRELF, TURBOTAL and FIXOTAL Systems, Proc of International Conference on Heat Exchanger Fouling and Cleaning VIII. p. 2-6.
9. Petitjean E., Aquino B. & Polley G.T., (2007), Observations on the Use of Tube Inserts to Suppress Fouling in Heat Exchangers,Hydrocarbon World, Ed. Touch Briefings, p. 47-51.
10. Ebert W.A. & Panchal C.B., (1997), Analysis of Exxon Crude-oil Slip Stream Data, Fouling Mitigation of Industrial Heat Exchangers, Begell House Publications, New York, p. 451-460.
11. Farid Ansari, Ajay k. Awasthi and Bhawana P. Srivastava, (2014), Physico-chemical Characterization of Distillery Effluent and its Dilution Effect at Different Levels, Applied Science Research, p. 1705-1707.
12. Bhandari V.B., (2010), Design of Machine Elements, Tata McGraw Hill Publications, p. 393-447.
13. Ramesh K. Shah and Dusan P. Sekulic, (2003), Fundamentals of Heat Exchanger Design, John Wiley and Sons, p. 867-874.
14. Praj Industries, Hinjwadi, Pune.

© 2015, IERJ All Rights Reserved