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EVAPORATOR SCALE CONTROL USING 'NON-STICK' COATED TUBES

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Abstract

Six new evaporator tubes were coated internally with food-grade 'non-stick' fluoropolymer material recommended by an international chemical company and applied by an accredited coating agent in North America. The tubes were then fitted to the fourth effect of the evaporator at UCL Co Ltd, taking special precautions to minimise damage to the coating during tube expansion.

The tubes were used for an entire season without cleaning.

Scale did accumulate at the ends of some of the tubes where the tube expander had damaged the coating, but the major tube length remained free of scale.

Based on a single season, the tube coating appears to be technically promising, although there are challenges of high cost, unknown durability and the need to develop an *in situ* coating technique.

The non-stick coated tubes have the potential to reduce or even eliminate the need to clean evaporator tubes during a crushing season. This in turn could lead to substantial reduction in maintenance downtime and cost, which in turn could lead to an increase in overall processing capacity for the season. The new coating also has the potential to eliminate reduction in heat transfer coefficient caused by scale formation between cleaning.

Keywords: scale prevention, evaporators, tube coating, fouling, non-stick, heat transfer

Introduction

The elimination of scale accumulation in evaporator tubes could bring substantial cost savings to factories processing sugarcane. The savings would include:

- Direct savings of labour and equipment or chemicals used for scale removal.
- Savings related to downtime required for cleaning. This downtime reduces the annual capacity of the entire factory, thereby increasing the capital cost per unit of cane processed.
- Savings related to not having to run evaporators that are partly scaled. This translates to a reduced capital cost because evaporators would not have to be over-designed to compensate for the effects of fouling on evaporation rate, and steam usage could be reduced because lower pressure steam would suffice in the absence of fouling.

- Savings related to prolonged tube life as a result of eliminating the tube wear caused by mechanical cleaning of tubes. Tubes represent a significant portion of the capital cost of evaporators, and their periodic replacement is a major maintenance cost.

Attempts to reduce scale formation have included (a) the use of chemical anti-scalants that affect the solubility of the scale components, (b) magnetic pre-treatment of the juice to affect the ionic behaviour of scale components and (c) use of ion exchange resins to remove scale components from the juice prior to evaporation. Success with these techniques has been variable but none of the techniques enjoys universal usage in the sugar industry. In beet factories, deionisation of the juice is able to reduce the problem considerably; however, because of different liming and pH requirements, deionisation has not proved to be economically attractive in cane factories (Davis *et al.*, 1997).

This paper describes a successful factory experiment in which scale accumulation in tubes was almost completely prevented. Attempts are made to assess the economics of the technique so as to define maximum acceptable costs for preparing ‘non-stick’ tubes.

Use of non-stick coatings by other industries

The use of non-stick and anti-corrosion coatings in heat exchangers is practised by other industries, particularly the oil refining and power generating industries. Internal coatings made from phenolic materials were developed in Germany in the 1950s. They were applied by filling, draining and rotating the tubes in a specialised facility. In the 1980s an Italian company developed a spray-on technique for applying epoxy phenolics. These coatings proved successful in reducing corrosion and fouling in large condensers, and in restoring leaking uncoated condensers.

Subsequently, numerous different coatings have been developed for various applications. Each particular application has involved considerable trial and error to optimise the coating for the particular surface, tube diameter and operating conditions involved.

In most industrial heat exchangers, the coating has the dual role of controlling corrosion and fouling. In the food industry (including sugar manufacture) corrosion is generally not a major problem, but non-stick properties are sought to prevent fouling in evaporators and to facilitate cleaning of food-handling equipment. In developing suitable coatings, the food industry has the added challenge of needing to ensure that the coating material does not present health hazards. In North America there is an active lobby questioning the safety of non-stick frying pans, although without strong scientific evidence. However, food-grade and FDA-approved coating materials are available and are used extensively. A definite hazard with fluoro-polymers is that, should they accidentally be exposed to temperatures above about 250°C, they give off a toxic vapour.

Coatings for heat exchangers include baked phenolics, epoxyphenolics, vitons, novolacs and thermal plastics. One of the best coatings for oilfield application is polyphenylene sulphide (PPS), which is also used in cookware. PPS can be combined with polytetrafloroethylene (PTFE) to create a thermally conductive, self-healing thermoplastic that can be used at 200°C continuously.

Effect of coating on heat transfer

A coated tube has a lower heat transfer coefficient (HTC) than a clean, uncoated tube. The coating is, however, much thinner than the scale that builds up in the absence of coating. If the coating prevents scale build-up then the average HTC for a coated tube for the period between cleanings is much higher than that of the uncoated tube. Perspective on this is given in Table 1 and Figure 1 which shows the dramatic effect of scale thickness on the heat transfer coefficient of a coated tube, emphasising the large effect of initial scaling. The effect of the scale overrides the effect of the coating. (Note that these calculated HTC figures ignore effects of brix and boundary layers so they cannot be compared directly with measurements made in sugar factories.)

Table 1. Perspective on heat transfer barriers of coated tubes.
(These figures cannot be compared directly with evaporator measurements because they do not account for boundary and brix effects.)

Barrier	Thermal conductivity ($W/m^2/°C/m$)	Thickness (mm)	Heat transfer coefficient ($W/m^2/°C$)
Steel tube	16	1.22	13 125
Tube coating	0.42	0.06	7 000
Evaporator scale	0.2	1	200
Tube + coat			4 565
Tube + coat + scale			191

The thermal conductivity of evaporator scale is variable, with most figures in the literature ranging between 0.1 and 0.3 $W/m^2/°C/m$. Table 1 suggests that the theoretical potential heat transfer for a clean tube is 13 125 $W/m^2/°C$ but that coating the tube brings this down to 4 565 $W/m^2/°C$. If the thermal conductivity of scale is 0.2, then a 1 mm layer of scale has a coefficient of only 200 $W/m^2/°C$, illustrating the overriding effect of scale compared to coating. Further perspective on the effect of scale thickness is illustrated in Figure 1, which highlights the effect of the initial scale formation on HTC.

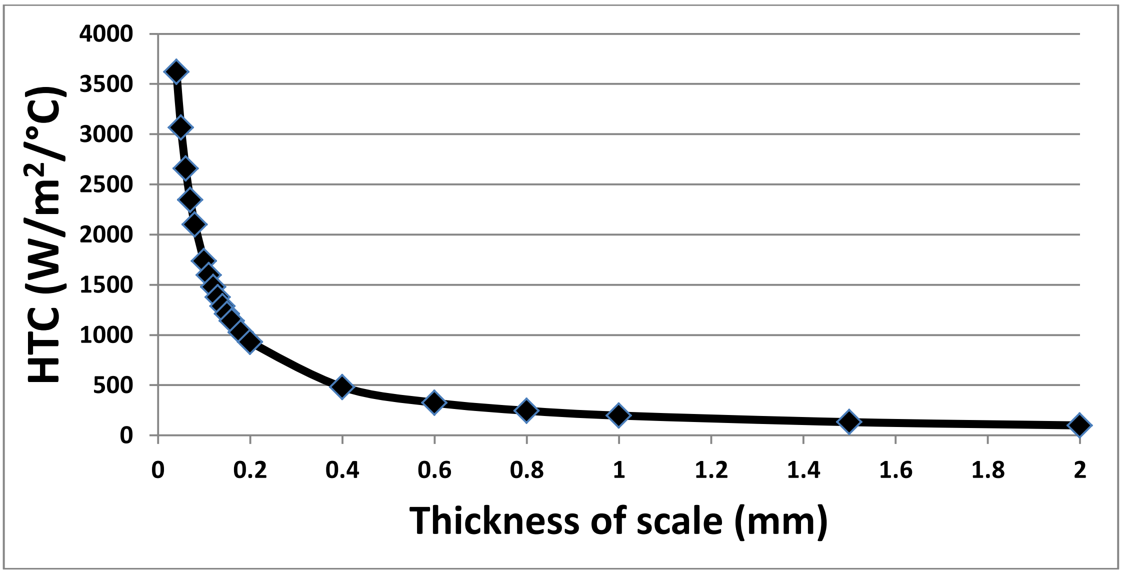

Figure 1. Perspective on the effect of scale thickness on heat transfer (assuming scale forms on a stainless steel tube with no coating – ignoring boundary and brix effects).

In addition to the prevention of scale build-up, the coating can increase HTC by reducing friction between the liquid and tube wall, thereby reducing the boundary layer. This could be particularly helpful in the latter stages of sugar factory evaporators where high viscosity causes high boundary effects.

Preparation of non-stick tubes for sugar evaporators

Batstone (1970) reported a trial in which copper tubes were coated by washing in a 1% solution of polyfluorocarbon in volatile solvent. The solvent was removed by air drying, and a $CaSO_4$ solution was then boiled to monitor scale formation. The scale adhered less strongly to coated tubes and was removed by boiling action. The results, however, were not sufficiently encouraging to promote trials in a full-scale sugar evaporator.

In the present trials the coating was sprayed onto the internal surface of the tubes using special spray equipment. This was followed by baking in a special oven at 380°C. The choice of coating material and of the accredited applicator was made by the supplier. Different thicknesses, ranging between 0.04 and 0.08 mm were applied. The material used is able to withstand cleaning with hot caustic if necessary. (Due to existing non-disclosure requirements, the name of the international chemical supply company must be withheld.)

Fitting of tubes, and experiment conditions

The six coated tubes, each 1.98 m long and 51 mm ID, were fitted to the fourth effect of the evaporator at UCL Co Ltd (UCL). This effect experiences the most severe scaling at UCL.

In an attempt to minimise damage to the coating during expansion of the tube ends, the tube expander was caused to run on shim-stock instead of directly on the surface. This was only partially successful in protecting the coating.

To prevent accidental mechanical cleaning of the tubes, permanent wire ‘pins’ were fitted across the tube openings. In addition, the tubes were covered with plastic ‘hats’ during cleaning so as to prevent flushing with water.

Observations

Although an expandable plastic scraper was constructed for gentle dislodging of any scale that attached to the tubes, this was never used. Visual observation (Figures 2 and 3) showed that, although some scale was attached to the ends of the tubes where the coating had been damaged by the tube expander, the major portion of the tubes remained free of scale throughout a complete season. The cleaning team referred to the tubes as ‘the automatic tubes’ because the team observed that the tubes seemed to clean themselves.

In an attempt to confirm the visual observation of negligible scale, the rate of heat loss of hot water in a new tube was compared with that in a coated used tube. This was done by inserting an expandable rubber plug into the tubes, adding boiling water and monitoring the rate of temperature decline. The rate of heat loss from the used tube was slightly higher than from a free-standing new tube, probably because the tube plate acted as a heat sink for the former (the water depth in the tube was only 900 mm).

The problem of coating damage at the tube ends due to the tube expansion process was anticipated at concept stage. Confirmation has been received that this problem may be overcome in a number of ways, including the use of hydraulic tube expanders, post-expansion touch-ups, or the insertion of a thin PTFE sleeve to cover the damaged area after the expansion.

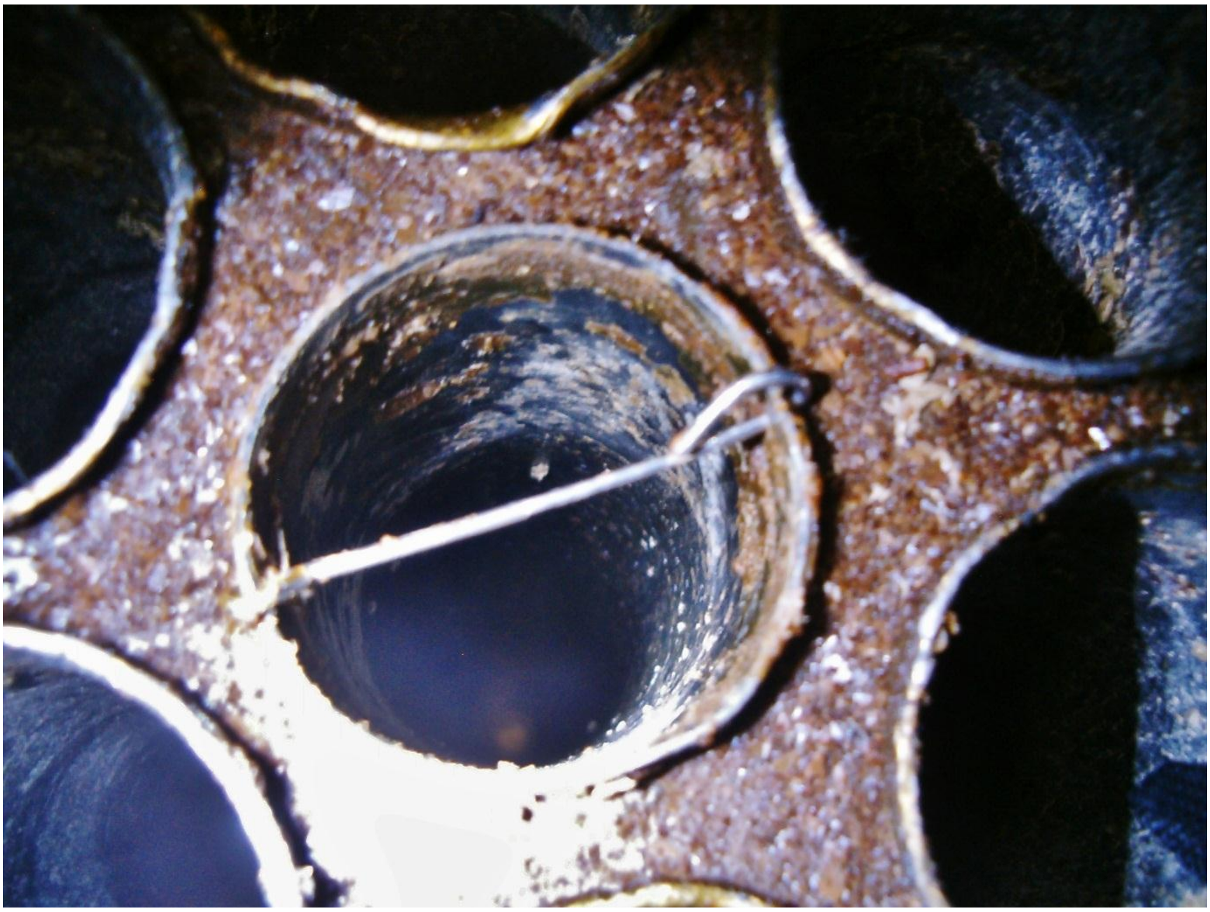

Figure 2. Mid-season view of tube showing some hard scale concentrated at the lip where the expanding tool has caused most expansion and hence damage to the coating. The zone affected by the tube expander has an abrupt ending, below which there is negligible scale.

Figure 3. Tube appearance after a complete season without cleaning. The coating is peeling where scratched by the tube expander and at the tube extremes, but scale accumulation is negligible.

Economic assessment

If tube coating could eliminate the need for evaporator cleaning then the savings shown in Table 2 could accrue to a factory crushing at a rate of 400 t cane/h (TCH) for 33 weeks per season.

Table 2. Estimated saving if evaporator cleaning could be eliminated.

Item	Cost saving (R/t cane crushed)	Comments
Labour	0.08	Includes labour cost of maintaining equipment
Equipment	0.22	Covers disposables (cutters, brushes, shafts etc)
Capital 1	1.52	Savings due to reduced factory size enabled by reduced downtime (assuming downtime due to cleaning is 8 h every two weeks)
Capital 2	0.38	Savings due to elimination of evaporator over-sizing required for operation under fouled conditions
Tube life	0.24	Savings if tube life is extended from 10 to 12 years
Total	2.44	

These estimated savings would vary widely according to circumstances, but they give some indication of the maximum cost that could be tolerated for tube coating. If the coating could completely eliminate the need for evaporator cleaning then the annualised cost savings would be R5.1 million for a 1.8 million ton crop, and the maximum attractive cost for coating at a 400 TCH factory would be about R20 million to give a four-year payback. Preliminary cost estimates from the coating suppliers are more than six times this and are equivalent to the cost of building two complete spare evaporators.

As yet, the lifespan of the coating is unknown and the particular coating used in these trials cannot be applied *in situ*. Alternative coatings that can be applied *in situ*, and which are considerably less expensive, are being sourced for testing.

Summary and Conclusions

Coating of evaporator tubes with a non-stick material has been remarkably effective in preventing fouling of the tubes in a fourth effect vessel throughout an entire season. The cost of the coating cannot, however, be justified in terms of potential savings. Initial success encourages further investigations of alternative, less costly, materials that can be applied *in situ*. The trials need to extend to Kestner vessels where high juice velocity is likely to assist in ensuring 'non-stick', thereby possibly enabling use of less expensive coating material, and to vinasse evaporators which are particularly prone to very aggressive scaling.

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