

## ALFA LAVAL EXPERIENCE WITH COATINGS TO REDUCE FOULING IN PLATE HEAT EXCHANGERS

\*O. Santos<sup>1</sup>, C. Wictor<sup>2</sup> and M. Nilsson<sup>2</sup>

<sup>1</sup> Materials Technology and Chemistry, Alfa Laval Lund AB, P.O. Box 74, SE-22100 Lund, Sweden

E-mail: [olga.santos@alfalaval.com](mailto:olga.santos@alfalaval.com)

<sup>2</sup> Business Unit GPHE R&D, Alfa Laval Lund AB, P.O. Box 74, SE-22100 Lund, Sweden

### ABSTRACT

Fouling of heat exchangers in the chemical industry, oil & gas industry, district heating, power plants, among others, results in a loss of performance which leads to production stops for cleaning and therefore increased operation costs. One approach to mitigate fouling is to alter the properties of the metal surface. A coating to be successful in any plate heat exchanger application needs to have a good adhesion to the metal but also keep the heat transfer through the metal plates as unaltered as possible. This requires a thin coating with a relatively good thermal conductivity. The plates in a plate heat exchanger are subjected to plate to plate contact point wear when in operation which also puts an extra requirement for the coating. To be suitable, the coating needs to have a good mechanical stability to resist this plate to plate wear. From the above one can see that coating plates is a much more challenging task than coating tubes (for use in shell & tube heat exchangers). A coating can be applied at larger thicknesses on tubes and are not subjected to the metal to metal wear. Alfa Laval has a long experience in coating plates for diverse applications: crude oil cooling, crude oil heating and scaling. This paper will describe the tests performed by Alfa Laval to approve a coating, results from lab fouling tests and field tests in selected applications.

### INTRODUCTION

Fouling of heat exchangers occurs in a variety of different industries. It is very detrimental to the heat exchanger performance since it leads to a loss of its thermal duty and an increase of its pressure drop. At some point the heat exchanger will need to be taken out of operation for cleaning. This will lead to production losses and increased operation costs [1]. During crude oil processing, heating and cooling are common procedures which will lead to fouling on the heat exchanger wall. During crude oil cooling, paraffin wax can crystallize at the plate wall of the heat exchanger if the temperature reaches lower values than the wax appearance temperature (ranges from 32 to 38°C, [2]). For crude oil cooling applications it was

proven by Alfa Laval that the use of coatings led to a significantly prolonged service interval (by a factor of 3) making it very economically attractive [3]. A coated heat exchanger was launched by Alfa Laval in 2015 for this application.

Different types of fouling can occur during crude oil heating: crystallization if the water fraction of the crude contains dissolve salts, particulate where clay, dirt or rust suspended in the crude deposits at the surface, and chemical fouling between the components of the crude. This last mechanism can lead to the formation of gums, coke, and polymerization of monomeric compounds. Asphaltene precipitation, especially at high temperatures, is also often the culprit of crude oil fouling. It occurs when asphaltene loses its solubility in the crude oil or when it is incompatible with the crude oil.

Scaling is the unwanted precipitation of crystals formed in a flowing medium as well as the direct crystallization at the solid surface. The most common form of scale is calcium carbonate and calcium sulfate. These salts have an inverted temperature solubility meaning that they will precipitate above a certain temperature (around 60°C). Other factors like pH, water hardness, flow rate, pressure, etc. will also influence the crystallization process. Scaling occurs in diverse applications like pulp and paper, oil production, power plants and cooling water processes [4,5, 6, 7, 8, 9]. Calcium carbonate scaling will lead to an increased pressure drop and a reduced heat transfer due to the hard insulating layer that builds-up at the metal surface (thermal conductivity of 2,9 W m<sup>-1</sup> K<sup>-1</sup> [8]). In extreme cases the scale layer will be so thick that the result is a clogged heat exchanger impossible to flush with an acidic cleaning in place (CIP). There are several approaches to mitigate scaling, like promoting turbulence (increasing the shear stress) and the use of chemical or physical additives that interfere with the crystal formation [9, 10]. Alfa Laval's approach was again the use of coatings in order to decrease crystal adhesion to the stainless steel. Alfa Laval has had some successes in reducing scaling in heat exchangers by the use of

coatings and some of the results will be presented in this paper.

While some improvements in fouling and cleaning were observed for some of the coatings, there is only, to the author's knowledge, the Alfa Laval commercially available coated plate heat exchanger for crude oil cooling application. This is due to the complexity of both the fouling mechanism and the coating properties. Besides being able to reduce foulant adhesion a coating, to be suitable to use in a heat exchanger, needs to have a decent thermal conductivity, good wear and abrasion resistance, good temperature and chemical resistance and a good adhesion to the metal substrate. Another aspect one needs to consider regarding coatings for heat exchangers is the influence the coating will have on the thermal performance of the PHE (Plate Heat Exchanger). The coating will act as a fouling layer in respect to the heat transfer, however due to the low thickness and reasonable thermal conductivity ( $\sim 2 \text{ W / m K}$ ) of the used coatings the reduction in heat transfer will be minimal. It should also be noted that an uncoated heat exchanger with a thick deposit (low heat conductivity) will result in a lower thermal performance as compared to a coated heat exchanger where only a thin fouling layer deposits.

In the following sections the tests performed by Alfa Laval to approve a coating, results from lab fouling tests and field tests in selected applications will be presented.

### LAB TESTS

To determine if a coating is suitable for use in plate heat exchangers Alfa Laval performs a set of lab tests. These tests can differ depending on the application that the coating will be used for. Below it is shortly described the most common tests.

#### *Temperature resistant test*

The coated pieces are placed in a beaker filled with boiling water for 1h. Fig. 1 shows examples of coatings that failed this test.

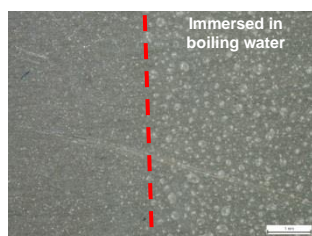


Fig. 1 Presence of blisters on the coating after being immersed 1h in boiling water.

#### *Water resistant test*

The coated pieces are placed in a bottle filled with water inside an oven at high temperature. In Fig. 2 one can see two coated coupons that have

been tested for 2 weeks, showing a pass and a fail sample.



Fig. 2 Appearance of two coated coupons after being immersed in water at high temperature for 2 weeks: a) no blisters; b) large blisters on the entire surface.

#### *Salt water resistant test*

The coated pieces are placed in a beaker filled with 3.5% NaCl solution at a temperature higher than  $60^\circ\text{C}$  with agitation. Fig. 3 shows two coated coupons that have been tested for 2 weeks, showing a pass and a fail sample.

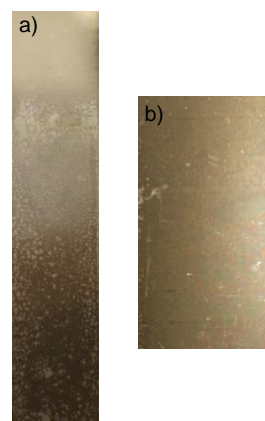


Fig. 3 Appearance of two coated coupons after being immersed in 3.5% NaCl at  $T > 60^\circ\text{C}$  for 2 weeks: a) many small blisters; b) no blisters.

#### *Chemical resistant test*

Depending on the application the resistance of the coatings can be tested with different chemicals. If the plates are subjected to cleaning in place, the coatings are also tested with diverse cleaning chemicals. This is done by dipping the coated pieces in a beaker filled with the cleaning chemical solutions for a pre-defined time at a relevant temperature with agitation. Fig. 4 shows examples of coatings that failed this test.

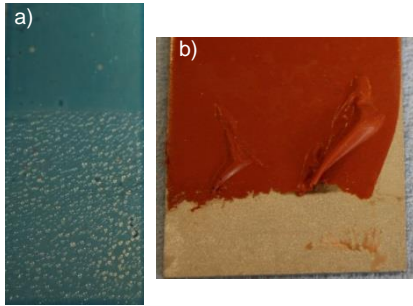


Fig. 4 Appearance of two coated coupons after being immersed in a) 5%  $\text{HNO}_3$  and b) 5%  $\text{NaOH}$  at around  $70^\circ\text{C}$  for 16 h.

#### *Abrasion resistant test*

To access how the different coatings tolerate abrasion from small particles present in the media an abrasion test was developed at Alfa Laval. The coated M3 plates to be tested are assembled in a heat exchanger. One side is connected to tap water and the other side is connected to the test rig and run with the abrasive media (water with 2% of solid plastic particles) at the maximum pump flow rate ( $4.8 \text{ m}^3 / \text{h}$ , average shear stress around 235 Pa) for 24h at room temperature. To achieve a higher temperature the water tap is closed and the test continued for another 24h. The coating is rated according to a classification from 0 to 4 where 0 is the best. Fig. 5 shows two coated M3 plates that have been tested for 2 days, showing different a rating of 1 – less than 10% of coated affected and a rating of 4 – more than 50% of the coating was abraded by the particles.

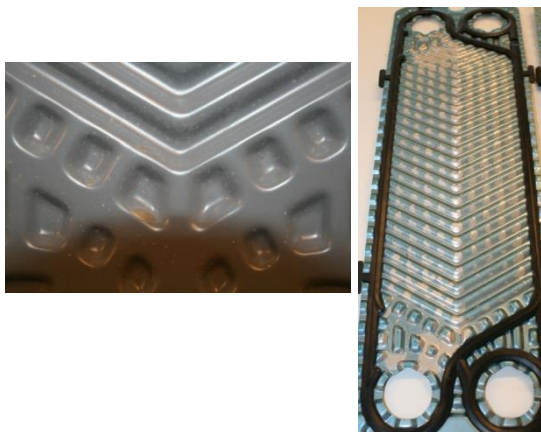


Fig. 5 Appearance of two coated M3 plates after the abrasion test: a) rating 1; b) rating 4.

#### *Wear resistant test*

A PHE contains numerous contact points where adjacent plates form metal to metal support. This makes the plate package strong and pressure resistant but creates frictional forces between individual plates and between plates and frame

parts when the unit is in operation. To evaluate the mechanical properties of the different coatings these are subjected to a pressure fatigue test. The test is conducted according to an AL Standard Method designed to accelerate the wear and friction that plate coatings would experience in a real operational PHE. The coated M3 plates are assembled in a heat exchanger which is then connected to a pressure fatigue test rig. The test is a standard 1-phase test with a water / glycol mixture on one side and the other side filled with water and unpressurized. 100.000 pressure cycles from 2-7 bars at room temperature was chosen as test conditions (average shear stress around 235 Pa). The coating is rated according to a classification from 0 to 4 where 0 is the best. Fig. 6 shows two coated M3 plates that have been wear tested, showing different a rating of 0 – no wear at the contact points and a rating of 3 – extensive wear at the contact points.



Fig. 6 Appearance of two coated M3 plates after the wear test: a) rating 0; b) rating 3

#### *Salt water / water resistant test*

To test the resistance of the coatings applied on plates to both water and salt water a test rig with M3 plates was developed. The M3 unit assembled with the coating plates is run for a total of 3 months at a time with around 2.4% salinity water from the North sea. The sea water enters the heat exchanger at a flow rate of around  $210 \text{ m}^3 / \text{h}$  and is heated up to higher than  $60^\circ\text{C}$  by circulating hot water on the adjacent channel. The sea water is flushed every two hours during working hours and kept idle at the same temperature during unmanned hours. Each flushing has a duration of 2 min. Some examples of coating failures and successes during the sea water test are shown in Fig. 7. In Fig. 7 a) one can see a coating, that was in contact with the tap water side, delaminating from the entire plate after a test period of 6 months. The most common corrosion type observed in PHEs in sea water is crevice corrosion due to the many crevices present in the PHE. Fig. 7 b) shows crevice corrosion, leading to



through holes, on a coated plate after 9 months in contact with sea water. Some of the coatings have showed a very good resistance to sea water. An example is shown in Fig. 7 c) where no corrosion is present after 27 months running time. The coating has however started suffering from wear at the plate to plate contact points.

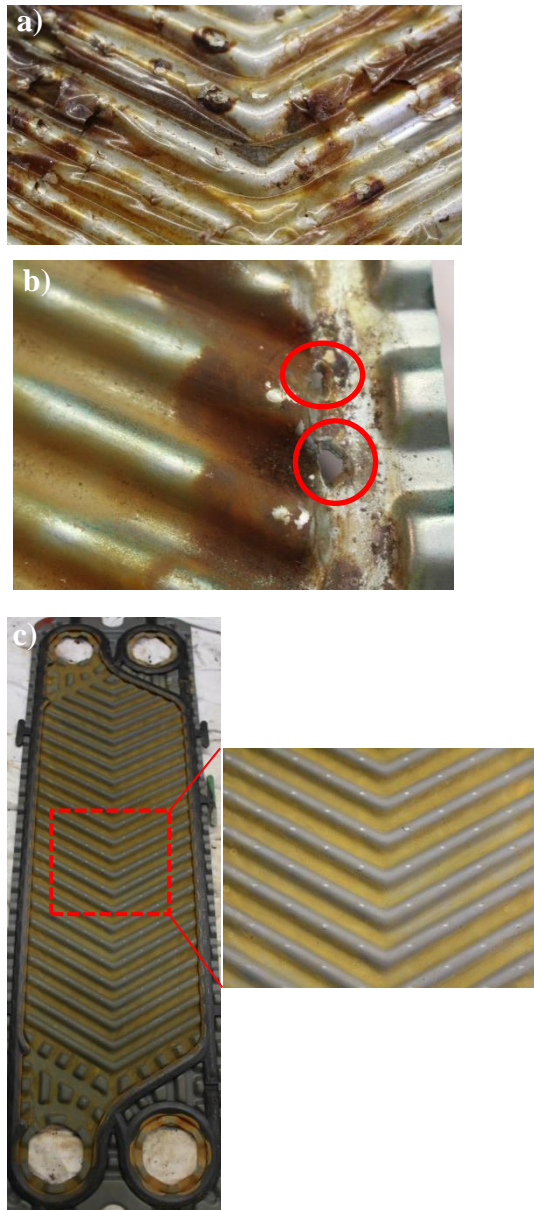


Fig. 7 Coated plates after sea water testing for: a) 6 months - coating has delaminated from the water side, b) 9 months – crevice corrosion leading to through holes and c) 27 months – no corrosion but some wear at the plate contact points.

#### Scaling test

Scaling on PHE is seen in a range of different applications using cooling water with low quality. To access if a coating is successful in reducing scaling in PHE, a scaling test rig was built

in Alfa Laval Lund. Coated HE (Heat Exchanger) plates are installed in a heat exchanger unit. The test is run with a total of 10 plates. The uncoated and coated PHE units are tested in separate runs for 7 days each. Hard well water (hardness of around 26 dH) is used to generate scaling inside the HE. The hard water enters the heat exchanger at a flow rate of around 0.6 m<sup>3</sup> / h (shear stress of 25 Pa) and is heated up to 80°C by circulating steam on the adjacent channel. The PHE is running continuously for the whole test period. As seen in Fig. 8 a larger scaling amount was observed on the uncoated plates compared to the coated ones. The plates were weighted before and after the scaling test and the results are shown in Table 1. The amount of scaling on the uncoated plates was more than three times as high as compared to the one on the coated plates.

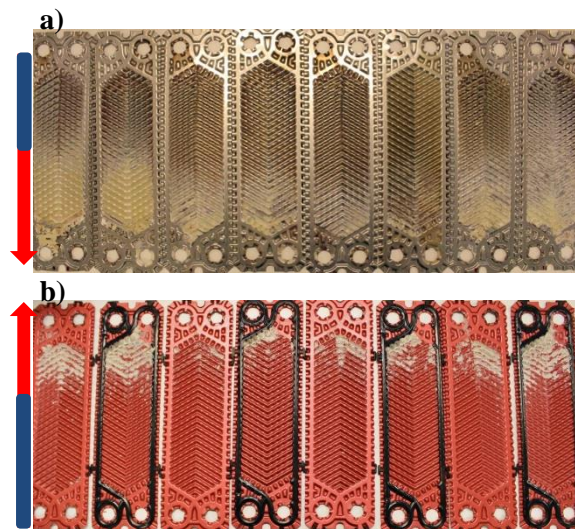


Fig. 8 Scaling on a) uncoated and b) coated plates.

Table 1. Amount of scaling on the uncoated and coated plates after the scaling test.

Plate no.	Uncoated plates (g)	Coated plates (g)
1	6.1	0.8
2	6.2	2.2
3	4.4	1.0
4	3.5	2.1
5	4.9	2.3
6	4.1	1.8
7	8.3	2.1
8	12	2.3
<b>TOTAL</b>	<b>49</b>	<b>14</b>

#### FIELD TESTS

The coatings that performed well in the lab tests are selected for further testing in the field on different applications. When testing coatings at the

customers a limited number of coated plates are installed in the plate pack. These can consist of one or different coatings. A summary of the results obtained on different applications is described below.

#### *Crude oil cooling*

The first field test was run with a partially coated plate pack in a M20 plate heat exchanger. The position of the tested heat exchanger is upstream in a typical oil production line with a dry crude cooler. From the total 349 titanium plates 15 were coated and 5 each placed in the beginning, middle and end of the plate pack. The unit was in operation for 8 months with hot runs being the only cleaning performed.

The amount of fouling on the coated plates was significantly less compared to the uncoated reference plates (Fig. 9). The uncoated plates were covered with a homogeneous wax layer whereas on the coated surfaces only small islands of wax were seen. The composition of the wax deposit is time dependent starting with a porous structure which gradually becomes denser as more wax molecules diffuses into the porous structure and oil diffuses out [11]. The denser the deposit layer the higher the impairment on the heat transfer due to the insulating effect of the wax layer (thermal conductivity of  $0.073 \text{ W / m K}$ , [12] at the surface and the more challenging the cleaning becomes. Adhesion of the wax layer to the surface was also significantly reduced compared to the uncoated plates, where it was possible to clean the coated plates only with high pressure water jet.

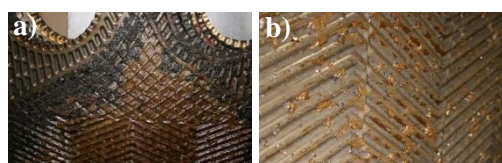


Fig. 9 Fouling appearance on the: a) uncoated plate and b) coated plate. Partially coated, 8 months operation time.

The next step was to field test two PHE's consisting of a fully coated plate pack. One of the heat exchangers was in operation for 5 months before being disassembled and the coating performance investigated. The second heat exchanger was in operation for 3 years. Fig. 10 shows that the amount of fouling on the coated plates was minimal. The adhesion of the fouling layer to the plates was also very weak where after cleaning with a dry cloth almost no fouling remained (Fig. 11).

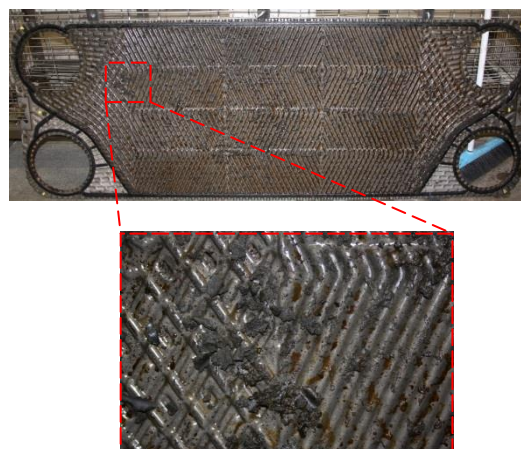


Fig. 10 Amount and appearance of the fouling on a coated plate (fully coated, after 5 months operation).



Fig. 11 Area of a coated plate cleaned with a dry cloth showing that the easy to clean and repellent properties of the coating remained intact after 5 months in operation.

No stop for reconditioning was necessary with the fully coated plate pack during the 3 years field test, leading to an increase of operating time between maintenance of more than double.

#### *Crude oil emulsion heating*

In this application the coating was applied on 64 M15 plates in stainless steel alloy 316, out of 370 plates. The heat exchanger was in operation for 5 months. Lower amounts of fouling were seen on the coated plates as compared to the uncoated plates (Fig. 12). To visualize the condition of the coating after the test, a cloth was used to clean part of the plate. The appearance of the coating is seen in Fig. 13 where no delamination or blisters were observed.





Fig. 12 Amount of fouling on the: a) uncoated and b) coated plates.

#### *2<sup>nd</sup> crude oil emulsion heating field test*

The uncoated heat exchanger at this customer suffered from severe fouling problems. After an operation time of around 6 weeks the heat exchanger needed to be cleaned. A PHE with 81 AM20 coated plates in titanium grade 1 was tested. The coated PHE was in operation for 13 months. A fouling layer, consisting of both organic and inorganic compounds, was observed on the coated plates but in a lower amount as compared to the previous run with the uncoated plates. Note that the coated plates run for 13 months while the uncoated was fouled up after 6 weeks.

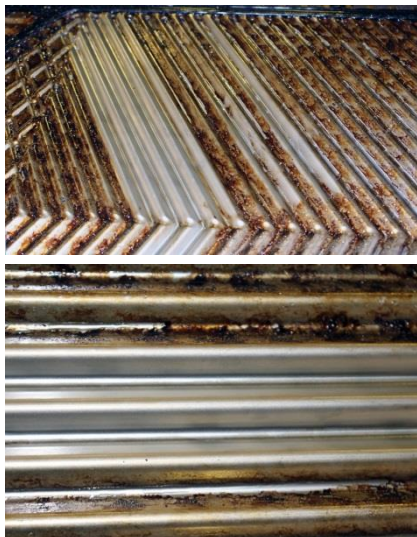


Fig. 13 Appearance of the coating after rubbing with a cloth. No coating delamination or blisters were observed.

The fouling layer was partly removed by a high pressure water jet (Fig. 14). After the test the coating was still in a good condition, no blisters or delamination was observed. The easy to clean

effect was still present on parts of the coated plates (Fig. 15).

The coated plates prolonged the operation time by a factor of 9, from 1.5 to 13 months.

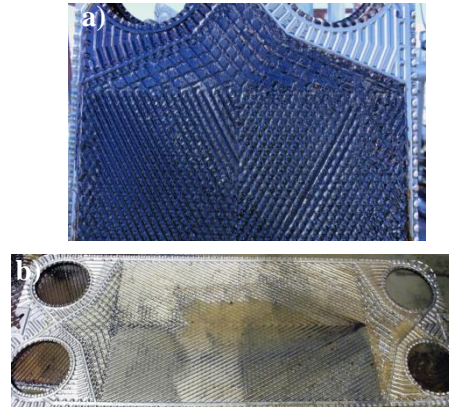


Fig. 14 a) Appearance of the fouling on coated plate; b) coated plate after high pressure water jet cleaning.

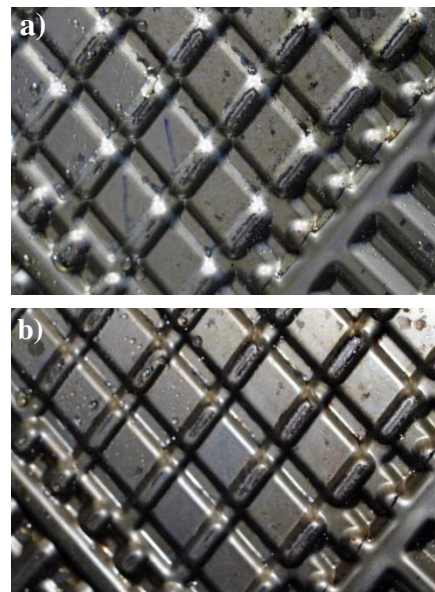


Fig. 15 Pen test on the coated plate: a) No beading effect, b) easy to clean effect.

#### *Scaling*

Calcium carbonate is a common form of scaling forming inside the HEs used in district heating. Copper brazed (CB) HEs are used in this application. A CB was coated and installed at the customer. The uncoated CB was installed in 2011 and it is cleaned 2 to 4 times a year with a descaling agent. The last cleaning had been performed around 1 month before the CB was sent to Alfa Laval for analysis. A borescope was used to image the channels near the ports of the water side of the heat exchanger. The amount of scaling on

the uncoated unit is seen in Fig. 16 from the tap water inlet and outlet. On the inlet of the tap water side no scaling was present as expected since the temperature is low (Fig. 16a). On the outlet a huge amount of scaling was present (Fig. 16b). The corresponding pictures on the coated CB are shown in Fig. 17 where as seen very little scaling was present on both tap water inlet and outlet.

Both uncoated and coated units were thermally tested to access the loss in heat transfer performance and the increase in pressure drop. The test was done using water on both sides at similar flows and inlet temperatures. The uncoated had only a 13% heat transfer performance (a reduction of almost 90% of its heat performance!), which is too low to work as a heat exchanger. The pressure drop on the tap water side also shows a large influence from the scaling formed on the units. It increased 40 times for the uncoated unit. The corresponding values for the coated CB where a reduction of 1% in heat performance and around 10% increase in pressure drop.

The units were cut open and the channels imaged with a stereo microscope. On the uncoated CB many of its channels were blocked with scaling which is in line with the thermal analysis results (Fig. 18). On the coated CB unit no scaling was present on the channels near the tap water inlet (Fig. 19 a) and little or no scaling on the channels close to the tap water outlet (Fig. 19b).

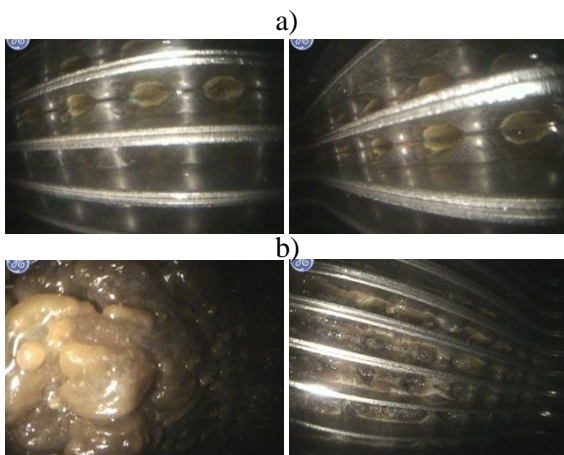


Fig. 16 Appearance of the channels near the tap water side ports. Tap water a) inlet and b) outlet.

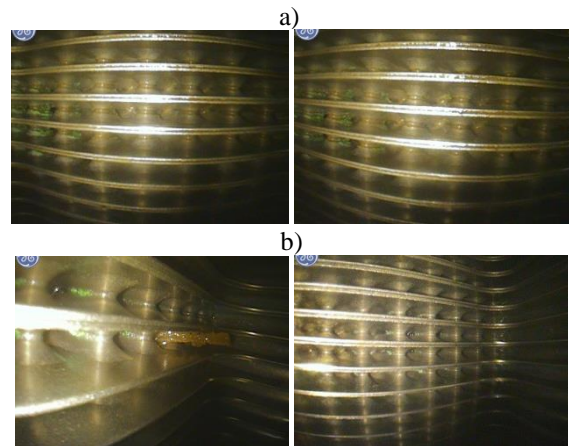


Fig. 17 Appearance of the channels near the tap water side. Tap water a) inlet and b) outlet.



Fig. 18 Appearance of the channels on the tap water outlet side.

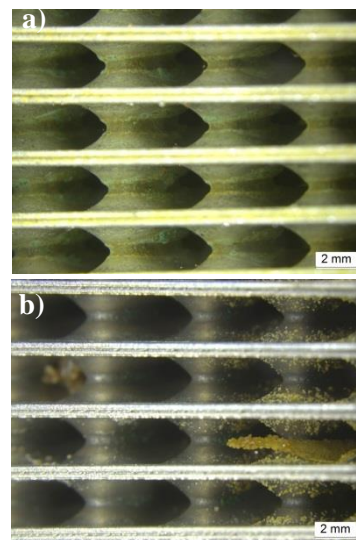


Fig. 19 Appearance of the channels on the tap water side. Close to the: a) inlet and b) outlet.

## CONCLUSION

Alfa Laval has implemented a variety of tests for coated plates in order to be able to approve a coating for further field tests. Applications such



as crude oil cooling and heating, and scaling have experienced huge savings by the use of coated plates. The use of coated heat exchangers does not require any change in the design or operating conditions.

Coatings are, since 2015, commercially available for crude oil cooling applications and more will become available in the near future for other applications.

## NOMENCLATURE

CB Copper-Brazed heat exchanger

PHE Plate Heat Exchanger

HE Heat Exchanger

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