HEAT EXCHANGER WORLD

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UNITING THE HEAT EXCHANGER SUPPLY CHAIN

Cover story:

ORANGE Cleantech Inc.'s innovative *clean-in-process* technology

Coating: a viable way to prevent shell & tube heat exchanger fouling, reduce the carbon footprint of equipment and lower CAPEX

Each year, corrosion in process equipment causes substantial financial consequences in production plants, particularly in the chemical and petrochemical industry. Increasing investments for the replacement of equipment made of alloys lead to rising operating costs, which in turn endanger profitability and sustainability. One of the causes for equipment failure and loss of performance, particularly in heat exchangers, is fouling. Practical examples have shown that SÄKAPHEN® linings applied to various heat exchangers lead to an avoidance of corrosion, significantly reduce incrustation and fouling and thus increase performance, service life, and the reliability of plant operation.

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Fouling is the deposition of organic or inorganic substances over the exchange surfaces of a heat exchanger (HE). This can proceed through one or more of the following mechanisms [2]:

(1) Crystallization of dissolved salt.
(2) Sedimentation of suspended particles.
(3) Chemical reaction within the fluid (e.g. polymerization).
(4) Corrosion, the resistance of the produced oxide is lower than other forms of fouling but higher than that of carbon steel. On the other hand, the increase in surface roughness favors the formation of other forms of fouling.
(5) Formation of organic film of micro-organisms and macro-organisms.

The loss of performance is dependent on thickness and heat conductivity. For example, calcium carbonate has a conductivity of 2.9 [W/m/K] and biofilm of 0.7 [W/m/K] [2]. As a reference carbon steel (CS) has a conductivity ranging from about 30 to 60 [W/m/K] according to its composition.

Fouling has multiple consequences. The additional thermal resistance reduces the heat exchange coefficient. The common method in which thermal resistance of fouling is estimated, is through standard values reported in the literature, such as the TEMA fouling resistance [2].

Using the standard values for the fouling coefficient in the design phase, and thus considering the reduction of heat transfer, will intuitively imply larger equipment. Larger equipment commercially implies an increase in the CAPEX both for the process unit itself but also for its installation and for its structural support as well as for operational costs, e.g. when larger pumps are needed, the result is higher power consumption. The technical consequence is a pressure drop increase as a consequence of the combination of different factors. The over-dimensioning of the HE will lead to longer tubes and therefore linearly higher pressure drops, as shown in Eq. 1:

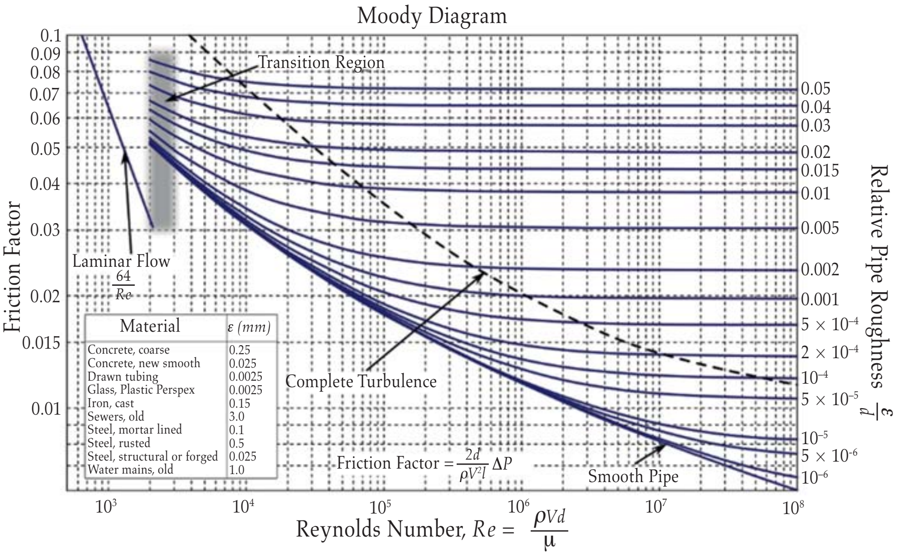
$$\Delta\ Pressure = \frac{length \times fluid\ density \times velocity^2}{Diameter \times 2} * friction\ factor\ (Re, \varepsilon)$$

Equation 1: Distributed pressure drop

The fouling deposit reduces the inner diameter of the pipes, thereby reducing the dimension of the fluid passage and eventually increasing the fluid speed. A further contribution to higher pressure drops comes from the increase in surface roughness caused by the fouling deposit. The friction factor, at high Reynolds numbers, as it can be seen in Fig 1, is only dependent on the relative roughness of the pipes. Therefore, the graph shows how easily an increase in surface roughness can result in a significant increase in pressure drops. The fact that fouling enhances localized corrosion due to differential aeration, cavitation, and erosion should also not be neglected.

Most of the fluid passing through a HE will cause fouling. The extent of fouling depends on various factors, such as the fluid speed, composition, and temperature. Some factors cannot be changed since they result from the existing plant layout and the production process.

A commonly evaluated design choice is the application of a SÄKAPHEN® coating tube side and/or shell side, depending on the process. At a first glance, the application of an additional polymeric layer over the exchange surface suggests a decrease in performance due to the additional thermal resistance. In reality, the additional resistance is small as the SÄKAPHEN® coating has a thickness of only 200 [µm] and it is compensated by the reduction in fouling, which is usually thicker and less conductive than the coating. The accumulation of fouling is reduced thanks to the lower surface roughness of the coating compared to uncoated CS as shown in Fig. 2 [1].



Material	ε (mm)
Concrete, coarse	0.25
Concrete, new smooth	0.025
Drawn tubing	0.0025
Glass, Plastic Perspex	0.0025
Iron, cast	0.15
Sewers, old	3.0
Steel, mortar lined	0.1
Steel, rusted	0.5
Steel, structural or forged	0.025
Water mains, old	1.0

Fig. 1. Moody's diagram.

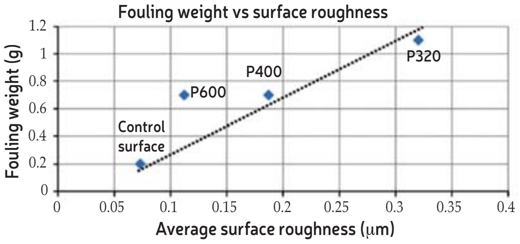


Fig. 2. Fouling as function of surface roughness [1].

Quantifying the above observations, a HE unit is examined that is coated by the Donelli Group, Italy in its ISO 9001 and 14001 qualified workshops in Voghera, Italy, for a mayor client in the oil & gas industry.

The unit is a 1:1 water-water HE with a volumetric flux of 100 [l/s] on both sides. The fluid speed is 2 [m/s] on both sides. On the hot side the inlet temperature is 100 [°C] and has an outlet temperature of 50 [°C]. The inlet temperature on the cold side is 20 [°C]. The tubes are carbon steel ¾ inch gage 14. The 'average water' fouling factor defined by TEMA (0.35 [K*m^2/kW]) is assumed on the tube side. Carbon steel conductivity is assumed with 30 [W/m/K].

Two coatings, with a dry film thickness of 200 [µm], are considered:

- SÄKAPHEN® Si 57® E 2.54 [W/m/K] (*SI57E*):
- SÄKAPHEN® Si 570 AR 4.79 [W/m/K] (*SI570AR*)

The graph hereafter shows how a fouling reduction of about 15% is sufficient to compensate the extra resistance caused by the coating. Any further reduction will result in a noticeable improvement in heat exchange coefficient.

Interestingly, the exchange coefficient λ of a newly built HE made of carbon steel protected with SÄKAPHEN® baked linings is comparable to the exchange coefficient λ offered by a newly built stainless steel HE.

Other than the stainless steel HE, the SÄKAPHEN® coated HE made of carbon steel has a significantly lower CO_2 foot print:

Based on a cooling surface of 521m² and a weight for 1.4301 grade stainless steel of 15,86 [kg/m²/2mm] vs 15,70 [kg/m²/2mm] for S235JR+AR grade carbon steel, the bundle has a weight of 8.236kg made of stainless steel and 8.180kg if made of carbon steel. Looking at the carbon dioxide equivalent per kilogram of bare metal and considering 7 [kg of CO_2 Eq/kg]

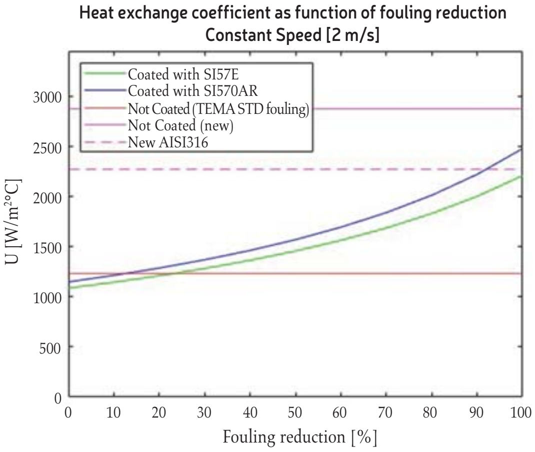


Fig. 3. Heat exchange coefficient as function of fouling reduction.

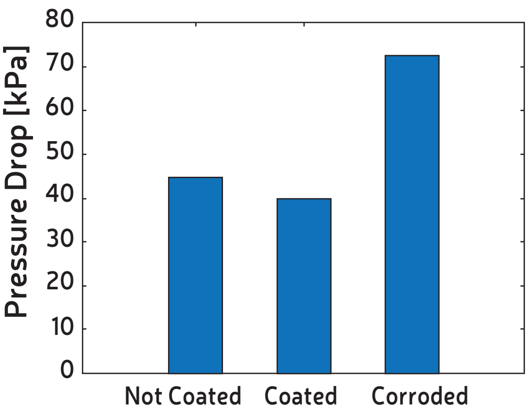


Fig. 4. Pressure drop.

for stainless steel compared to 2 kg of CO_2 Eq/kg for carbon steel the overall carbon dioxide for the bundle results in

- Stainless steel HE: 57.841 [kg of CO_2 Eq]
- Carbon steel HE: 16.359 [kg of CO_2 Eq]

Adding the CO_2 Eq for the applied coating with 4,3 kg of CO_2 Eq per kilogram of material and approx. 1,5 kg of material per m² plus the CO_2 Eq for the baking process of the coating with 2,8 kg of CO_2 Eq per cubic meter of natural gas and an average consumption 30m³ of NG for the complete baking process, the total balance looks as follows:

- Stainless steel HE: 57.841 [kg of CO_2 Eq]
- Carbon steel HE with SÄKAPHEN®: 20.476 [kg of CO_2 Eq]

The above values and calculations result in a reduced carbon dioxide equivalent of 65% up front! Looking at the reduced energy costs due to the reduced pressure drop resulting from a smoother surface of a SÄKAPHEN® coated HE compared to corroded/fouled surfaces and even new steel surfaces derived from the table in Figure 1, the following surface roughness is assumed:

- The new HE has roughness comparable to structural steel: 0.025 [mm]
- The coated HE has roughness comparable to plastic: 0.0025 [mm]**
- The corroded/fouled HE has roughness comparable to cast iron: 0.15 [mm]

*applies to both stainless steel and carbon steel
** surface profile of Si 57® E : 0,00111 [mm], Si 570 AR : 0,00194 [mm]

The different pressure drops derive only from the different roughness. As it can be seen in Fig. 4, the fouled/corroded heat exchanger will have a significant increase in pressure drop compared to the brand new unit. The difference between the coated and the brand new HE is only about 10% but the brand new uncoated HE will likely develop corrosion and fouling in a short period of time while the coated HE will be significantly less affected.

Following the above-mentioned figures, the internal coating would result in a pumping power saving of about 5 [kW], resulting in about 4.500 [€/year] saving and an emission reduction of about 50 [t Eq CO_2/year]. A further reduction in pressure drop is ensured by the coating applied on the tube plate. The high thickness coating on the tube plate allows for the creation of a purposely shaped conical pipe inlet and outlet. This configuration ensures a more gradual inlet than the sharp edge inlet of the uncoated heat exchanger. A further advantage of this inlet configuration is the reduction of erosion and cavitation phenomena.

After this numerical case study, it is clear that if coating would offer more than 15 % reduction in fouling, it would make this solution technically viable from the heat transfer point of view. No theoretical approach was found for estimating the fouling reduction ensured by coating. Therefore, some significant case studies will

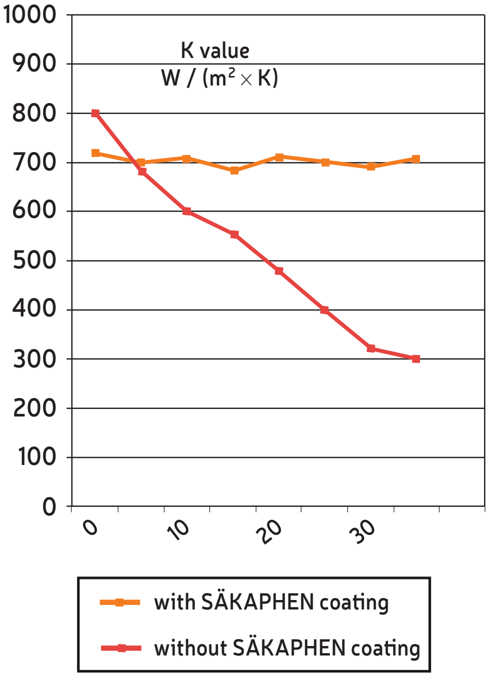


Fig. 5. First case study [5].

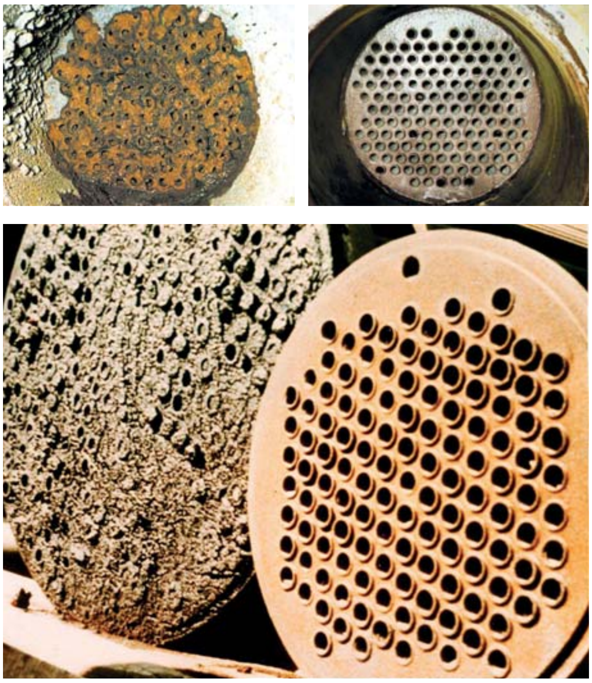


Fig. 6. *On the left an uncoated HE and a HE coated with SÄKAPHEN® Si 17 TC on the right. HE coated with SÄKAPHEN® Si S17® TC after 14 months in service during inspection after cleaning: no fouling, no deposit (yellow = touch-up paint applied by client after mounting the coated tubes).*

be reported to compare the performance of a coated HE with an uncoated one.

The first experimental case study [5] is the comparison of two identical HE operated in the Netherlands on the delta of the Rhine river, its water being used as coolant. One was coated with SÄKAPHEN® and the other was bare CS. As can be seen in Fig. 5, the coated HE has initially a slightly lower heat transfer rate compared to the uncoated HE, but its efficiency remains almost constant over time. The uncoated HE has a significant decrease in performance almost immediately. After 19 months, the uncoated HE required a cleaning procedure, and after 36 months it was decommissioned. The coated HE was cleaned after 36 months and then returned operational. Comparing the experimental measures of Fig. 5 with the theoretical estimation reported in Fig. 3, it is possible to conclude that the fouling reduction ensured by the coating, in this case study, was really high (around 90% reduction). The difference in fouling is visually visible comparing the two HE side by side as in Figure 5.

The second case study is from HE tubes internally coated for trial in a large cooler battery located inside ROGESA (former part of Dillinger Hütte/Germany) steel mill. In Figure 6 it is possible to observe a coated and an uncoated HE. On the uncoated HE, the increase in roughness and the reduction in cross section of the pipes is clearly noticeable. Therefore, the pressure drop along the uncoated HE would be significantly higher and the heat transfer rate significantly lower.

Summarizing what is explained above: coating, thanks to the significant fouling reduction, ensures multiple advantages:

- Higher heat exchange coefficient, ensuring higher efficiency and smaller exchange area.
- Lower pressure drops, allowing for lower pumping power or better heat exchange coefficient at constant pressure drop.
- Better corrosion protection, especially against aggressive environments, ensuring longer service life and less unplanned shutdowns.
- Easier, cheaper, and less frequent cleaning procedures. The fouling will be more easily removed and a more aggressive cleaning product can be employed.
- Lower power consumption, both for pumping and heating, with consequently lower CO_2 emissions.
- Significantly reduced carbon footprint.

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Martino Donelli, studied at Politecnico of Milan and at Technion (Haifa, Israel). He has a master's degree in chemical engineering. He works for the family business "Donelli Group".
Donelli Group was established in 1911, is ISO 9001 certified, and meets the most demanding anticorrosion, fireproofing and insulation needs of energy, petrochemical and chemical facilities onshore and offshore. Throughout the years, Donelli Alexo has developed extensive experience in coating and lining of heat exchangers (SÄKAPHEN® licensee) and other equipment. The reliability of the applications is also a result of running efficient and modern facilities, which have obtained ISO 14001 certification.

Christoph Fischer-Zernin, is Commercial Director of SÄKAPHEN, a 3rd generation family business renowned for its internal linings, especially for internal and external coating of heat exchangers. Christoph is mainly in charge of international sales. His professional experience reaches from international sales and technical consultancy to lining inspection and application supervision of own products. He has experience in lining related technical consultancy as well as material composition, application technologies and procedures. He is also acquainted with laboratory related testing procedures. As trained NACE CIP Level 2, he is experienced in failure analysis concerning internal linings.