Proceedings of the International Conference on Heat Exchanger Fouling and Cleaning - 2024 (Peer-reviewed)
April 21–26, 2024, Lisbon, Portugal; Editors: H.U. Zettler and E.M. Ishiyama

EXPERIENCES WITH APPLICATION OF ANTI-FOULING LOW SURFACE ENERGY COATINGS ON INDUSTRIAL HEAT EXCHANGERS

***K. S. Chunangad[1] and R. Pratt[2]**
[1] ExxonMobil Technology and Engineering Co., Spring, TX, USA, krishnan.s.chunangad@exxonmobil.com
[2] ExxonMobil Beaumont Refinery, 1795 Burt Street, Beaumont, TX 77701 USA

ABSTRACT

The world is facing the dual challenge of (a) increasing demand for energy and products to improve standard of living, and (b) reducing greenhouse gas emissions. To meet this challenge, it is imperative that all industries seek to maximize the energy efficiency of processes that produce the energy and products the society needs. One technology available is anti-fouling low surface energy coatings to minimize fouling and maximize energy efficiency of industrial process equipment.

This paper serves to share our experiences and learnings on fouling reduction and performance enhancement from the use of available modified epoxy and ceramic coatings on four different heat exchanger services. The intent of the sharing is to highlight the successes and current limitations with these coating options for different service conditions and metallurgies of industrial heat exchangers, to spur the development of new and enhanced coating or surface treatment products to lower fouling.

INTRODUCTION

Coatings have been used in the industry for over 30 years. The first-generation coatings are still being used for corrosion protection and extending the useful life of equipment. They are used on the inside diameter of tubular exchangers, mainly on carbon steel cooling water systems to mitigate corrosion and associated fouling. See the ASTM Manual [1] for the selection of coating systems for cooling water system components including heat exchangers. These coatings are typically epoxy and phenolic based and are limited by (a) maximum temperature of 300-350 F, (b) poor chemical and abrasion resistance and (c) high minimum required application thickness (8-14 mils dry film thickness). Many failures of coatings in the industry are attributed to one or more of these reasons. Point (a) precludes the use of steam-out cleaning of coated equipment. Point (b) requires the use of low hydroblast pressures for equipment cleaning. Point (c) results in some undesirable heat transfer and pressure drop impact, when used inside equipment, particularly on the tubeside of tubular exchangers. The wider availability and lower prices of corrosion resistant materials such as duplex stainless steels, have reduced the use of these coatings.

Over the last decade, there have been major strides in the development of enhanced coatings that address the above challenges. These include modified epoxy coatings, fluoro-polymer coatings, sol-gel coatings, ceramic coatings and nano-technology based surface treatments. The focus of this paper is on the anti-fouling versions of these coatings and their application. See Nakatsuka et al. [2], Bischoff et al. [3] and Ayutsede et al. [4]. These coating types differ widely in their chemistries and have addressed the challenges to different degrees, limiting their applicability to specific services. For e.g., the modified epoxy coating has enhanced the temperature limit to 400 F and can be applied in lower thicknesses compared to the 1st gen epoxy coating. Nakatsuka [2] describes the results from laboratory evaluation and field application of an omniphobic (water and oil repelling) nano-surface treatment on the produced water side of a shell-and tube heat exchanger in an upstream plant in Alaska. Bischoff [3] explains the development and lab testing results of a thin sol-gel coating for mitigating fouling on high-temperature hydrocarbon services. Ayutsede [4] presents the lab testing and field application results of a nano surface treatment to mitigate fouling in heat exchangers and other process equipment at elevated temperatures.

The above industry papers refer to the low surface energy (< 30 dyne/cm) of the surface modified with coatings or nano-surface treatment as the key parameter to indicate the low fouling propensity or ‘non-stick’ quality of the surface for water and/or hydrocarbon services. Water repelling surfaces are called ‘hydrophobic, oil-repelling surfaces are called ‘oleophobic’ and surfaces that can repel both are called ‘omniphobic’. Note that the surface energy of common fabricated materials without coating are > 700 dyne/cm. While most papers refer to low surface roughness as another important parameter, Ayutsede [4] highlights that low surface polarity (SFE_{polar}/SFE_{total}) could be a critical parameter to signify low fouling potential.

In this paper, we share our experiences and learnings on fouling reduction and performance enhancement from the use of certain modified epoxy and ceramic coatings on specific heat exchanger services in the field.

ISBN: 978-0-9984188-3-4; Published online www.heatexchanger-fouling.com

FIELD APPLICATIONS

The first application is in a vacuum overhead condenser service in the crude distillation unit of a refinery in the Gulf Coast. The cooling water on the tubeside of this shell-and-tube exchanger experienced scale-type fouling which resulted in poor performance of the vacuum tower, as it could not be cleaned on the run. A modified epoxy coating of 3-4 mils thickness was deployed on the tubeside of a new replacement bundle in Feb-2022 to mitigate this fouling. Figure 1 shows the process outlet temperature trend of this exchanger for the current run-cycle (> 600 days) of the coated bundle as compared to three previous run-cycles. The green plot shows the significantly improved performance of the coated bundle which has resulted in enhanced performance of the vacuum tower and associated margin improvement.

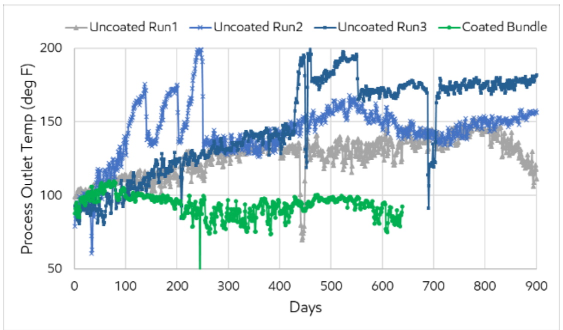

Fig. 1. Process outlet temperature trend for vacuum overhead condenser with coated & uncoated bundles

The second application is on the cooling water side (tubeside) of replacement product cooler bundles in a Gulf Coast refinery. This service consists of four shells in series on the product side with cooling water in parallel on the tubeside. Historically, all four exchangers fouled within 1-2 years, resulting in product flash giveaway and need for rental exchangers with temporary piping to be able to clean the main exchangers online due to the amount of scale-type fouling. A ceramic coating was selected and applied in 1-2 mils thickness on the tubeside of the hottest two exchangers in Apr-2022. Figures 2a and 2b show the temperature trends of the process side and cooling water side for the 2022 new coated bundles and the 2017 new uncoated bundles in the hottest two shells. The post Apr-2022 temperature trend data in Figure 2a shows the higher performance due to lower fouling rates achieved with the new coated bundle in Hot Shell 1 compared to the performance of the new uncoated bundle from Sep-2017 over the first 20 months after start-up. Figure 2b shows the continued performance of the coated and uncoated bundle in their respective time-periods in Hot Shell 2, with the temperatures showing a pinched condition in the coated bundle leaving little remaining duty to be achieved in the cold two shells.

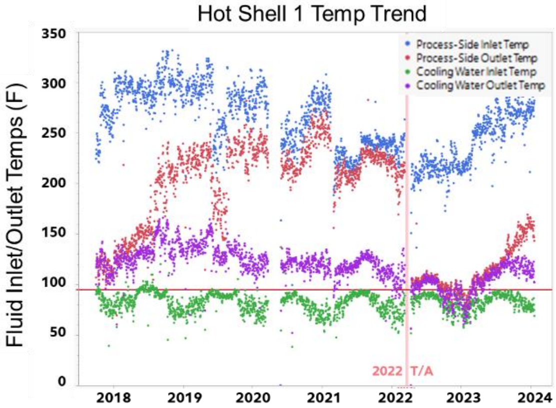

Fig. 2a. Fluid Inlet/Outlet Temps in Hot Shell 1 with 2022 coated bundle and 2017 uncoated bundle

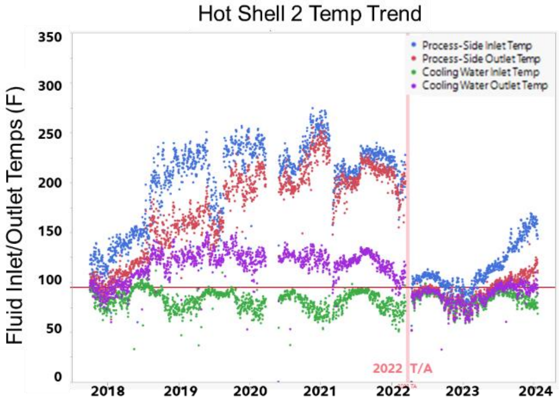

Fig. 2b. Fluid Inlet/Outlet Temps in Hot Shell 2 with 2022 coated bundle and 2017 uncoated bundle

If these two coated bundles help achieve the full 4-5 year run cycle of this exchanger without requiring rental exchangers for additional cooling, it would be considered successful.

The third application is on the crude side (tubeside) of an existing high-temperature (> 500 F) crude preheat exchanger with stainless steel tubes at a Canadian refinery. The existing exchanger fouls rapidly losing ~40% duty in ~10 months. See Fig. 3.

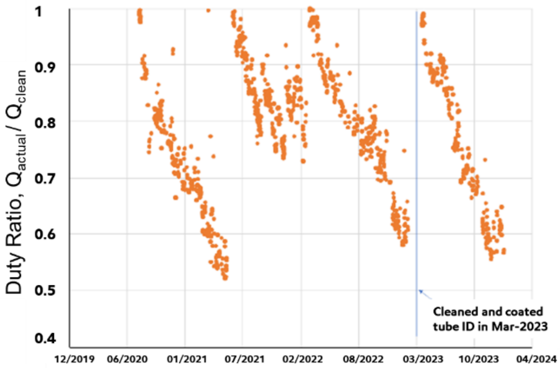

Fig. 3. Duty ratio trend of coated existing bundle and uncoated bundle in a crude preheat service

ISBN: 978-0-9984188-3-4; Published online www.heatexchanger-fouling.com

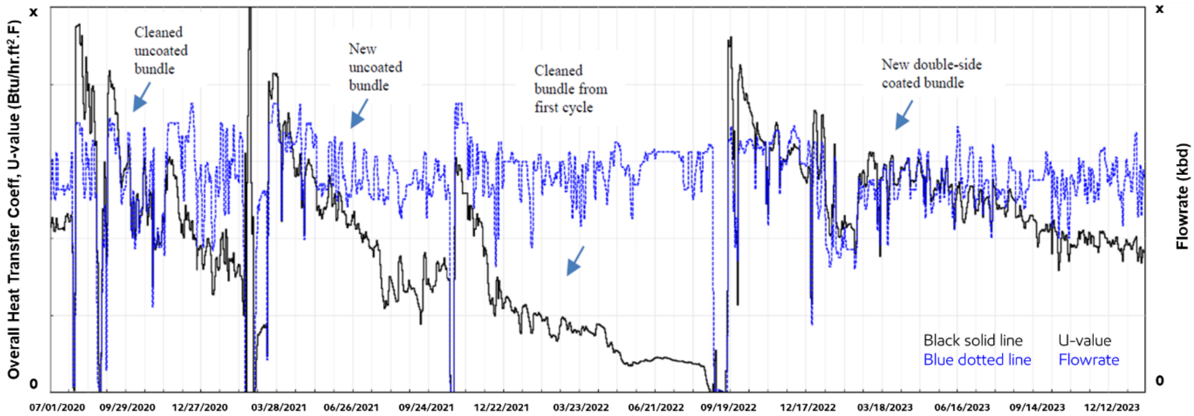

Fig. 4. U-value trend of sour water stripper feed/bottoms exchanger with coated and uncoated bundles

After thorough cleaning in Mar-2023 in an ultrasonic bath, it was coated with a ceramic coating of 1-2 mils thickness on the tubeside. Figure 3 shows the drop in the ratio of actual heat duty (Q_{actual}) to clean duty expected under similar inlet conditions (Q_{clean}) between the current run-cycle of the coated existing bundle and previous three run-cycles of the uncoated bundle. No performance improvement was observed. The reason is currently attributed to the inadequacy of the coating material for this high-temperature hydrocarbon service. Poor condition of the existing bundle and the associated limitation to achieve good adhesion of the coating material on the tubeside after surface preparation could be another reason. No unusual fouling was observed on the shellside at the next cleaning.

The fourth application is on coating both sides of a sour water stripper feed/bottoms exchanger at a refinery in the Gulf Coast. Existing exchanger fouls in ~10 months and a spare clean bundle is swapped with the fouled bundle to keep the unit running. A ceramic coating of 1-2 mils thickness was chosen to be applied on both sides of a new replacement bundle. Figure 4 shows the drop in the overall heat transfer coefficient (U-value) with time as a solid black line and the dotted line shows the flowrate variation over the same period. The first run-cycle is for a cleaned uncoated bundle. The second run-cycle is for a new uncoated replacement bundle. The third run-cycle is with the cleaned bundle from the first cycle. The fourth run-cycle is with the new double-side coated replacement bundle. The lower drop in U-value with the coated bundle shows the relative performance improvement achieved.

CONCLUSION

The above field references highlight some key successes of minimizing fouling and maximizing energy efficiency with careful application of certain modified epoxy and ceramic anti-fouling coatings. They also provided clarity on the inadequacy of the ceramic coating material for high-temperature hydrocarbon service. The key technical challenges and barriers for the use of anti-fouling coatings are: (a) understanding the niche areas of application for each coating type, (b) recognizing the field application limitations (beyond lab based limits) of the coatings with regard to the acceptable fluid chemistries (incl process fluids, chemical additives, cleaning agents, etc, - pH level), (c) mechanical handling limitations such as maximum permissible hydroblast pressures, (d) ability to determine the remaining life of existing coatings with some inspection and (e) ability to predict the fouling reduction expected with a specific coating. The desired properties of anti-fouling coatings are: (a) similar or better chemical and temperature resistance than the base surface, (b) be compatible with commonly used materials for process equipment, (c) have no impact on product quality or downstream equipment, (d) have abrasion resistance equivalent to the base material and (e) can be applied to new or existing equipment using established processes. The academic and industrial research community is requested to gather perspectives from the above sharing and seek to address the challenges raised and the properties desired with anti-fouling coating materials and application. Also, continued fundamental research is necessary to define key individual parameters or a combination of parameters (such as surface energy, surface roughness, surface polarity, interfacial energy, etc..) that truly characterize the low-fouling properties of surfaces under different process environments (oil-based, water-based, acidic, alkaline, polar, polymeric etc.).

NOMENCLATURE

mil	1/1000 in = 25 µm
SFE	Surface Free Energy, dyne/cm
T	Temperature, deg F
U	Overall Heat Transfer Coeff., Btu/hr.ft^2.F
Q	Heat Duty, Btu/hr

REFERENCES

[1] Monday, J. C., Shugart, T. B. and Tamayo, J. A., *Manual on Coating and Lining Methods for Cooling Water Systems in Power Plants,*

ASTM Manual Series MNL 28, ASTM PCN 28-028095-14, 1995.

[2] Nakatsuka, M., Thapa, S., Ventura, A., Basile, M., Pascolini, O. and Pellicciotta, L., Decarbonization and Improved Energy Efficiency Using a Novel Nanocomposite Surface Treatment, SPE-208080-MS, *Proc. Abu Dhabi International Petroleum Conference (Society of Petroleum Engineers)*, Abu Dhabi, UAE, Nov 2021.

[3] Bischoff, C., Losada, R., Poulsen, T., Jackowski, L. and Taylor, S., Development of Thin Sol-Gel Coatings for Heat Exchanger Fouling Mitigation at Elevated Temperatures, *Proc. Heat Exchanger Fouling and Cleaning 2017*, https://heatexchanger-fouling.com/wp-content/uploads/2021/09/22_Bischoff_Development-of-Thin-Sol-Gel-Coatings.pdf

[4] Ayutsede, J., Kerber, S., Curran, E., Dooley, B., Luna, I, and Jackowski, L., Novel Surface Treatment to Mitigate Fouling in Heat Exchangers and Process Equipment, *Proc. Heat Exchanger Fouling and Cleaning 2022,* https://heatexchanger-fouling.com/wp-content/uploads/2023/01/S13-1000-Friday-Ayudaste.pdf