

Coating solutions for centrifugal compressor fouling

Several options available to mitigate build up in high-use machinery in a variety of applications, environments. By **Derrick Bauer**

Corrosion and fouling of centrifugal compressors during operation are major concerns in the petrochemical industry. While the cause of an electrochemical (corrosive) attack depends on several variables, corrosion and its effects are readily visible and well understood. In most circumstances, the selection of a base material that is suitable for the process gas application will minimize a corrosion attack.

Fouling, or the buildup of solids on the compressor's internal surfaces, is a more process-dependent issue. In hydrocarbon services, foulant is caused by a polymerization reaction intrinsic to the compression process. Foulant buildup limits flow through the compressor and can alter the compressor's aerodynamics, reduce efficiency over time, increase vibration and result in an unplanned shutdown.

Many variables affect the occurrence of fouling and the exact process is not always fully understood. These factors make predicting the amount of fouling expected within a centrifugal compressor impossible

to determine with any amount of certainty. The focus, therefore, needs to be on how to best minimize the amount of foulant depositing on the aerodynamic surfaces of the compressor or, if possible, prevent fouling from forming in the first place.

Finding a solution

Polymerization has been reported to start above 194°F (90°C) (1). While this is not a steadfast law that applies to all applications, the intent of a compressor design is to keep the process temperature low throughout the compressor. Centrifugal compressor operators typically try to minimize fouling within the compressor through process control and injections. In addition to the compressor design, liquid injections of oil or water help to maintain a lower process temperature that can prevent the foulant from forming in the first place. Additionally, anti-polymerization additives can be added to the process. Despite these preventative efforts, fouling still occurs in many hydrocarbon compressors.

Hydrocarbon foulant is less likely to adhere to a smooth surface (Wang, et al). A corrosion product on any surface will increase the surface roughness and lead to increased foulant build-up. In most applications, the prevention of a general corrosion product can be controlled through

the material selection for each component. Centrifugal compressor casings and diaphragms are often manufactured from carbon steel. The rotating impellers are typically manufactured from low-alloy steel or martensitic stainless steel. When increased corrosion resistance is required, the base material selection can usually be adjusted accordingly. For example, nickel-based alloys can be used for the impellers and a compressor casing might be overlaid with stainless steel. Naturally, more highly alloyed materials result in increased costs.

Original equipment manufacturers (OEMs) look to the construction materials to prevent corrosion and fouling. Despite the OEM's best efforts to choose a suitable alloy, it is usually impossible to find a single material that is ideal for a centrifugal compressor application. This is certainly true for centrifugal compressor impellers and diaphragms where the material with optimized mechanical properties might not always resist corrosion or prevent the buildup of foulant on its surfaces. For this reason, coatings are often used to exploit the beneficial properties of two or more materials for a particular application.

While the turbomachinery industry is over 100 years old, anti-fouling coatings were first used only during the late 1970s. By the end of the 1980s, the coating systems that are still popular today were introduced. OEMs have since improved upon these systems, including Elliott Group, which developed several coating systems, including a metallic glass coating that offers increased durability.



First anti-fouling coating options developed

The first successful anti-fouling coatings made use of polytetrafluoroethylene, more commonly known by the acronym PTFE or the DuPont trade name Teflon. PTFE was widely used in numerous industrial and commercial applications for its excellent "nonstick" properties, which logically also work as an effective anti-fouling coating. To apply a material with these types of nonstick properties, it has to be mixed with a resin binder that will allow the Teflon to adhere to the complicated geometries of a centrifugal compressor flow path. (Wang, *et al*)

The application of Teflon coating directly to the surface of a component did not completely solve the issues related to corrosion within a centrifugal compressor. Teflon, by itself, is relatively chemically inert to almost any chemical or process gas. The resin binder mixed with Teflon acts as a barrier separating the base metal of the component and the process gas within the centrifugal compressor. If this barrier is compromised, corrosion of the component can still occur underneath the coating. A corrosion product under the coating can cause a release of the coating and expose a corroded surface, which is subject to foulant build-up. A pre-requisite of an effective anti-fouling coating is that it must be a corrosion-resistant coating.

To provide corrosion protection for the anti-foulant coating, a base coat was developed by Praxair (formerly Sermalon). An aluminum-filled, chromate-phosphate ceramic coating is applied directly to the base materials of the compressor's aerodynamic flow path. The chromate-phosphate ceramic is chemically inert and very durable, while the term "aluminum-filled" means that discrete aluminum particles are added. Aluminum provides sacrificial galvanic corrosion protection if the coating is compromised, meaning that the aluminum preferentially reacts with the environment to prevent a reaction with the iron-based substrate. Because aluminum is present as discrete particles, corrosion is limited to the particles that are exposed to the environment (Chow, *et al*). To limit

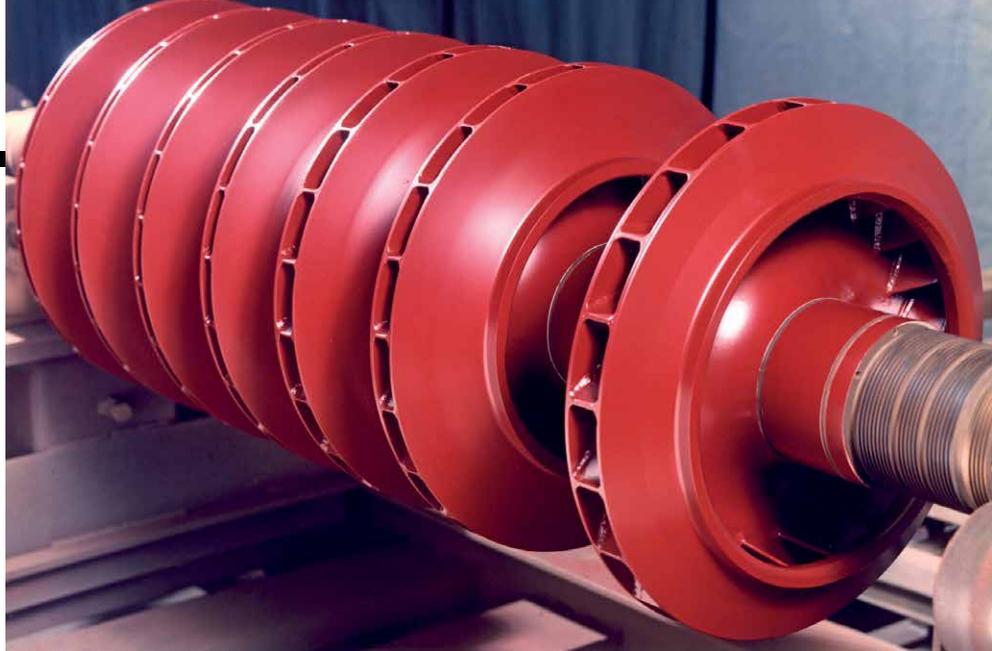
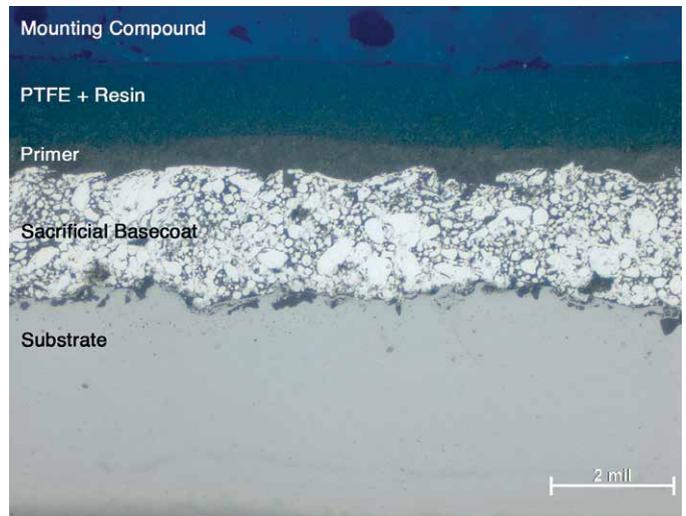


FIGURE 1
Centrifugal compressor rotor with Pos-E-Coat coating.

FIGURE 2
Cross-sectional photomicrograph of Pos-E-Coat system.



the exposure of the sacrificial basecoat to the compressor process gas environment, an additional primer is added on top of the aluminum-filled, chromate-phosphate layers. This primer also acts as a bond coat for the PTFE filled resin topcoat (Chow, *et al*).

The layered anti-fouling coating system described above was developed in the late 1980s and is still used today in specific applications. Elliott has trademarked this coating system as

Pos-E-Coat (Figure 1). The system's base layer is an aluminum-filled, chromate-phosphate coating, the intermediate coating is a protective primer and the topcoat is a PTFE-filled resin (Figure 2). Each layer is applied by a spray process and requires a heat cure after each layer is applied. The application involves coating application equipment that can reach inside the narrow internal passageways of an impeller

or diaphragm, and specially designed furnaces are necessary to avoid distortion of compressor rotors during the heat curing cycle. The Pos-E-Coat system has a proven history of use in hydrocarbon compressors.

Improved anti-fouling coatings

While the Pos-E-Coat system has worked well in centrifugal compressors in hydrocarbon service, the search was still on for coatings with even better anti-fouling properties and durability. The PTFE component is an effective anti-fouling material, however, some of its non-stick properties are minimized by mixing the PTFE powder in the resin that makes up the topcoat of the system. The durability of the resin also limits the service life of the topcoat.

To improve the anti-fouling characteristics of the coating, Elliott's materials engineering

team evaluated the components that make up the topcoat. To improve the coating's nonstick properties, fluorinated ethylene propylene (FEP) replaced PTFE. Fluorinated ethylene propylene has a similar chemical composition to PTFE, but has increased anti-stick properties that make it a more effective anti-fouling additive. The resin was changed to a harder and more durable epoxy. The epoxy topcoat allows for application directly to the sacrificial basecoat and is less permeable in comparison to resin, eliminating the need for an intermediate primer. This coating system is marketed as Pos-E-Coat

Plus (Figure 3). The cross-sectional photomicrograph in Figure 4 displays the layers that make up this anti-fouling coating system.

Non-standard coatings

While the Pos-E-Coat and Pos-E-Coat Plus coating systems have effectively minimized fouling in hydrocarbon compressors, these coating systems do not work in all applications. Compressors are expected to operate between five and seven years between turnarounds. Operators typically use liquid injections for cooling and cleaning

purposes, resulting in high-velocity liquid droplet impacts on the aerodynamic surfaces that will eventually wear away an organic topcoat of the coating system. Chemical additions to the process can either react with the epoxy or resin topcoat or permeate the topcoat and result in blistering. The push for an anti-fouling coating that can maintain compressor efficiency for a five- to seven-year operational period was the impetus to look beyond standard coating systems that rely on an organic topcoat.

Elliott's Pos-E-Coat 523 coating is different from the industry standard spray and bake type of coating (Figure 5). Pos-E-Coat 523 applies a nickel-phosphorus glass to the surface of the components being treated. Besides its anti-fouling benefits, this coating system has numerous advantages in terms of durability. The metallic glass coating has a hardness of over 40 HRC, which makes it more durable than the compressor impeller base metal, allowing the coating to withstand liquid injections. The amorphous nickel coating is relatively chemically resistant to many process gas environments and chemical applications.

Although the coating is metallic, there are no grain boundaries so the coating is not susceptible to intergranular corrosion. Electroless nickel performs very well in the presence of hydrogen sulfide and can become even more corrosion-resistant as a thin but tenacious layer of nickel sulfide, which is extremely effective at blocking additional corrosion reactions, forms at the surface.

By blocking corrosion and providing an anti-fouling surface, this coating makes the liquid injections in the compressor extremely effective in removing foulant buildup in the compressor. The coating is applied by a submersion process where the Nickel-Phosphorus reacts directly with the base material. This application process forms an extremely strong chemical bond and allows for application to complicated geometries with narrow tip openings (Figure 6).

Measuring anti-fouling benefits of centrifugal compressor coatings

The benefits achieved by the application of an anti-fouling coating are something that



FIGURE 3
Pos-E-Coat Plus coated rotor.

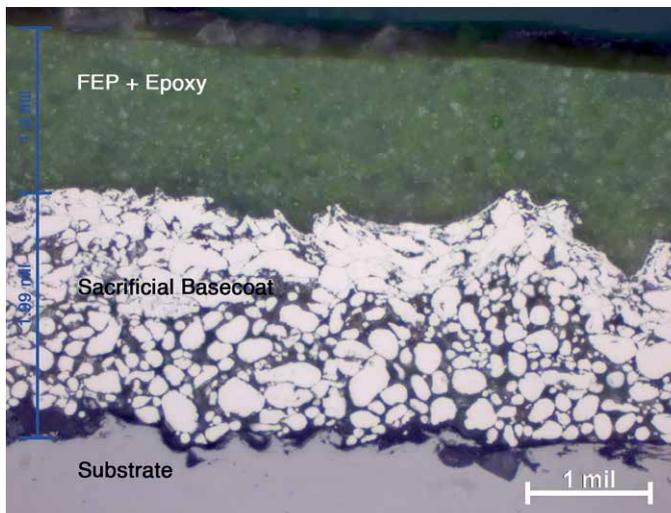


FIGURE 4
Cross-sectional photomicrograph of Pos-E-Coat Plus coating system.



FIGURE 5 Rotor coated with Pos-E-Coat 523 after six years of operation with the coating still intact.



FIGURE 6 Cross-sectional photomicrograph of Pos-E-Coat 523 system

every operator of a centrifugal compressor in hydrocarbon service would like to know. Measuring the anti-fouling benefits of a coating within a laboratory is challenging as it is not possible to simulate the exact operating conditions inside of a hydrocarbon compressor. Even if this were possible, every centrifugal compressor has a different process gas composition and temperature, the number of liquids injected can vary significantly, and chemical injections differ at each site if they are used.

One method of providing a relative ranking is to compare the foulant release abilities of the various coatings against a standard hydrocarbon foulant. Elliott used this method to test and compare the Pos-E-Coat, Pos-E-Coat Plus, and Pos-E-Coat 523 coating systems for foulant release.

The first step in the testing process is to apply a substance that can form an imitation foulant that mimics the foulant formed in hydrocarbon compressors. Elliott created and applied a proprietary imitation foulant (Figure 7) to a bare steel sample, as well as to coated samples, and baked the samples in a curing oven until a thick tar-like foulant formed on the surfaces. Each sample was then placed in a test rig that scrubbed the sample against a soft pad and the amount of foulant removed was measured by weight



FIGURE 7 Steel sample coated with proprietary imitation foulant used to test coating foulant release ability.

Proprietary imitation foulant

at set intervals. The bare steel samples did not release the imitation foulant after 2000 cycles, which demonstrates the standard problem in hydrocarbon compressors where efficiency cannot be increased regardless of the number of liquid injections intended to clean the compressor. The Pos-E-Coat and

Pos-E-Coat 523 coated samples released the imitation foulant after 1250 cycles while the Pos-E-Coat Plus system released the imitation foulant at 150 cycles. This testing demonstrates the significant anti-fouling benefits these coatings can provide.

Conclusion

The petrochemical industry faces various compressor fouling challenges and each operating condition is unique. Compressor coatings are available that can improve resistance to corrosive environments and improve foulant release abilities. The selection of the appropriate coating for the specific process conditions will help extend compressor service life and maintain optimum operational efficiency. **CT2**

FIGURE 8 Fouling release testing results for Elliott coating systems.

