

DEVELOPMENT OF ANTIFOULING AND CORROSION RESISTANT COATINGS FOR PETROCHEMICAL COMPRESSORS

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ABSTRACT

Two coatings have been developed for petrochemical compressor antifouling and corrosion resistance purposes. One is a multilayer composite coating with a modified polytetrafluoroethylene (PTFE) impregnated organic topcoat, which gives it superior antifouling performance to the similar coating that has been used by the compressor original equipment manufacturers (OEMs). The other is a high-phosphorous electroless nickel plating, which has been widely used as a corrosion resistant coating, but newly been employed by the authors' companies for antifouling purpose. Both coatings have demonstrated excellent antifouling performance, while the electroless nickel has shown to be much more forgiving to the washing and cleaning injections that have caused erosion damage and chemical attack to the composite coating. Therefore, the electroless nickel is considered as a very attractive alternative coating to the PTFE impregnated composite coating system, especially in such cases where the oil washing, water cooling, and/or chemical cleaning injections have to be carried on in the process.

INTRODUCTION

Fouling and corrosion are two long-standing problems in petrochemical compressors. Fouling refers to solid substances, usually polymers, which adhere to the internal aerodynamic surfaces of the compressors. It usually will not cause catastrophic failure, but can gradually reduce the efficiency of the compressors, or, in some worse cases, block the flow path and stop the production. Corrosion is caused by corrosive impurities in the process gases, or in many cases, by the corrosive process gas themselves, such as chlorine and hydrogen sulfide. Corrosion affects the reliability of compressors by damaging the integrity of the components, which can lead to premature retirement of the parts, or even result in catastrophic failures. Fouling and corrosion have imposed significant cost on petrochemical production.

Compressor end-users and OEMs have gone a long way to cope with fouling and corrosion. In the early days, petrochemical companies frequently shutdown their units in order to clean out the foul and restore the efficiency. For example, in ethylene manufacturing industry, cracked-gas compressors used to be shutdown every one or two years for cleaning the rotor and diaphragms. The other common practice in the industry was to inject oil or water to wash or cool the compressor internals in order to retard the fouling rate. However, these measures have not always been successful.

In the late 1980s or early 1990s, a concept of “nonstick” coating was introduced to the industry (Robichaux, et al., 1995). Applications have shown that the non-stick coating has effectively minimized the fouling problem. At certain petrochemical plants, the coating has performed so well that the costly, sometimes detrimental, washing practice has been terminated. It has also been reported that some ethylene plants have successfully lengthened their compressor overhaul interval from one or two years to three or four years (Dugas, 2000; Chow, et al., 1995), which has yielded a substantial cost saving for the companies.

However, not every coating-user’s experience has been so successful. Due to the complexity of the petrochemical processes, some plants still experience fouling problems even when the coating is used. Therefore, they still have to do oil or water injection in order to complete the function of the coating. However, the downside of the oil or water injection is that it may damage the antifouling coating by erosion or chemical attack, especially when strong detergent or solvents are employed to assist removing the fouling substance. In the last three to five years, a number of incidents have been reported by the plants who have suffered coating deterioration after the injection practices. Therefore, there is a strong desire for developing either a superior antifouling coating to reduce the demand on washing operation, or a tougher coating with improved erosion resistance and chemical stability to prolong its service life.

FOULING, CORROSION, AND COATING

Fouling Problems

Fouling is a common problem in all types of centrifugal and axial compressors. Depending on the types of compressors, fouling substances may come from outside of the machine, or be generated internally. In plant-air-compressors and gas turbine or turbocharger’s compressor sections, foulant comes from airborne salt, submicron dirt, and organic or inorganic pollution in the air. A well-maintained air filtration system usually helps to minimize this type of fouling (Meher-Homji, et al., 1989; Guinee, et al., 1995). But in petrochemical compressors, the situation becomes more complicated. For example, in ethylene cracked gas compression, fouling results from the internal polymerization reactions, which is intrinsically associated with the compression process.

Polymerization is a process of smaller organic molecules reacting and forming larger polymer chains. This reaction depends on temperature and pressure. Higher temperature and pressure favor the polymer formation. A rule-of-thumb being used in the petrochemical industry is that polymerization will likely occur when process gas temperature is above 90°C (194°F). Polymer fouling also depends on the surface condition of the compressor internals. If the surface is smooth, and/or wetted with oil, fouling rate will be low (just like food will less likely stick on oiled cookware). So a common practice at some plants is to continually inject oil into the cracked-gas compressors. However, oil-wash is an expensive practice, which can cost an ethylene plant one to two million dollars each year. Therefore, some other plants inject a cheaper medium—water. The main purpose of injecting water is to cool down the compressor internals, which to some extent helps to minimize fouling occurring in the first place. The injecting water has to be clean, usually treated boiler-feed water; otherwise, impurities and salts may build up when water vaporizes, which will cause a new fouling problem. Other problems that water injection may cause include erosion and corrosion. Today, erosion is

partially controlled by installing properly designed inline injection nozzles that atomize water and inject it to noncritical locations. However, corrosion is a more difficult problem.

Corrosion Problems

Most petrochemical process gases contain a certain amount of impurities, which may dissolve into the water and become corrosive. For example, hydrogen sulfide is a common impurity in cracked gas, while carbon dioxide may exist in natural gas. Usually these impurities are not corrosive in a dry condition. But when moisture is present, they will dissolve into the water and form a hazardous acidic vapor or droplets. In this sense, water injection may induce corrosion problems. When corrosion associates with erosion, the impeller material can be attacked at a much faster rate. The other damage that may occur on the impellers is stress corrosion cracking (SCC). However, this failure mechanism can be effectively prevented by controlling the yield strength of the impeller material, which is not a topic in this paper.

General corrosion and corrosion-erosion attacks can be minimized by applying protective coatings on the compressor internal surfaces. One of them is a galvanic sacrificial coating, which will be discussed in the following section. Another is electroless nickel, which is commonly used on impellers and diaphragms. Due to its excellent corrosion resistance, electroless nickel has been successfully used in some critical applications, such as chlorine compressors.

Multilayer Composite Coating Concept

The most commonly used coating on hydrocarbon compressors is a three-part system. The base coat consists of an aluminum-filled chromate/phosphate composite, which is commonly used as a corrosion and oxidation resistant coating for turbines and compressors. The aluminum particles embedded in the structure function as a galvanic sacrificial phase to corrode themselves and protect the base metal. In order to improve the galvanic protection, this layer is burnished after curing, which “bridges” the aluminum particles and increases the conductivity of this coat. Some coating vendors may apply an additional unburnished base coat to make a four-layer coating, but it is optional. The middle coat is an ion-reactive organic primer, which inhibits corrosion of the base coat, and, more importantly, enhances bond strength of the topcoat. The topcoat consists of a PTFE impregnated organic coat, which provides a nonstick feature as well as an impervious barrier to corrosive media. This three-part coating system is illustrated in Figure 1.

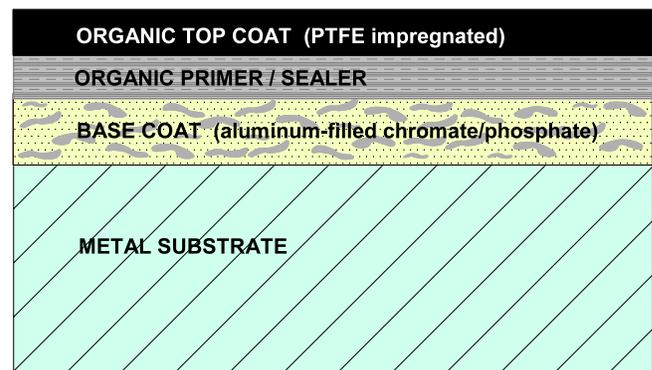


Figure 1. Illustration of Three-Part Construction of Multilayer Composite Coating.

PTFE, commercial name Teflon®, is one of the few miraculous engineering materials. One of its unique characteristics is that very few substances can stick on it. Because of this, PTFE is widely used on cookware, plastic molding, and, in recent years, on fabric. On the other hand, however, this “nonstick” feature makes PTFE

very hard to stick on other materials, which makes the coating process difficult. To solve the problem, engineers have tried to blend PTFE with some kind of binders, such as resin. Resin can dramatically improve the bonding strength, but will tradeoff some of the nonstick properties of the coating. Therefore, by selecting the right resin and optimizing the PTFE content in the topcoat, one can improve the antifouling performance of the coating.

Electroless Nickel Coating Concept

Electroless nickel (EL-Ni) combines all the desired properties and features of an antifouling and corrosion resistant coating for petrochemical compressors. It is lubricious, chemically inert, very hard, strongly bonded to a base metal, suitable for coating complicated shapes such as impellers, and relatively inexpensive. Since being commercially used in the 1950s, EL-Ni has found a very wide range of engineering applications where a corrosion or erosion resistance is needed. EL-Ni has also been extensively used on turbomachinery components for corrosion resistance, for example, on chlorine compressors since the late 1970s. However, application on cracked-gas compressors for antifouling purpose is a brand new attempt at the authors' companies.

In order to understand this coating, it is important to know its process, composition, and microstructure. EL-Ni coating is a plating process without electric current. In a series of electrochemical reactions, ionic nickel and phosphorus are reduced from the solution and codeposited on metal substrate. The phosphorus offers low friction and nonstick features of the coating. The bonding strength of the coating on alloy steels can be as high as 60 ksi (ASM Handbook, 1994). Because thrown-power is not a concern, EL-Ni can be uniformly deposited on complicated shapes, which is technically essential for impeller coating.

EL-Ni is a metallic coating, but does not have a crystal microstructure as most metals do. Instead, it has an amorphous microstructure, so called metallic glass. While very few metallic glasses are available as engineering materials, EL-Ni is one of them. This unique microstructure makes the coating much more inert than regular nickel alloys, so its corrosion resistance to most chemicals is excellent.

EL-Ni can be precipitation-hardened by a postplating heat treatment. The precipitated phase is Ni₃P. Depending on the temperature, the hardness can be as high as 1100 HV₁₀₀, which is comparable to the hard-chrome plating. However, a higher hardness leads to a lower toughness. So most applications are treated to a moderate hardness level. A typical postplating treatment is the hydrogen-relief baking at 375°F (191°C) for 18 hrs, which yields a hardness of about 700 HV₁₀₀ (HRC 49). This hardness level grants a superior liquid impingement erosion resistance to the multilayered organic coating system. Therefore, EL-Ni is much more forgiving to oil or water injections.

Although EL-Ni is a very attractive coating for petrochemical compressors, it has some disadvantages. One of them is its relatively low toughness and possible tensile residual stress, which imposes a reduction in fatigue strength of the coating as well as the base metal. However, with the well-engineered coating processes, the fatigue reduction can be minimized to about 10 percent. Another technical issue is that applying EL-Ni onto a fully assembled rotor can be challenging because of the limitation of tank sizes and the difficulty of masking all the gaps between impellers and sleeves. For these reasons, the impellers and sleeves are usually plated individually prior to the assembly. So the used rotors may have to be disassembled then reassembled, which may increase the lead-time and cost. Finally, EL-Ni repair plating is more difficult than the composite coatings.

TEST PROCEDURES

Sample Preparation

Fouling-release test samples were 2×3×1/8 inch steel panels. The panels were ground to 0.032 inch surface finish, then coated

with different coatings. Salt spray and falling sand test samples were 4×8×1/16 inch steel Q-panels coated with different coatings.

- *Three-part multilayer coating samples*—Two sets of samples were coated with three-part multilayer coatings, with thickness of 3 to 6 mils (0.08 to 0.15 mm). The first set, designated as “3P” in this paper, is the coating that most compressor OEMs have been using for antifouling and corrosion resistance. The second set, designated as “M3P” (modified 3P), has the similar base coat and primer as 3P, but a different topcoat. The difference is not discussed here because of the technical confidentiality.

- *Electroless nickel coating samples*—Two sets of panels were coated with high phosphorus EL-Ni. The coating thickness was 2 to 3 mils (0.05 to 0.08 mm). The first set was tested in “as-coated” condition, which included a hydrogen relief baking at 375°F (191°C) for 18 hrs after the plating. The second set was further baked at 550°F (288°C) for one hour prior to the testing. The reason for doing this treatment was to simulate the impeller installation process, in which the impellers are heated to 550°F (288°C) then shrink-fit installed onto the shaft. So the second set of samples were designed to evaluate the effect of the thermal treatment on antifouling performance of the coating.

- *Bare steel samples*—One set of bare steel with no coating was tested for comparison only. The sample descriptions are summarized in Table 1.

Table 1. Sample Descriptions.

Sample ID	Description
Bare Steel	Carbon steel panels with no coating
3P	Multilayer coating currently being used by compressor OEMs
M3P	Multilayer coating being developed with a modified topcoat
EL-Ni	Electroless nickel in as-coated condition
EL-Ni (550F)	Additionally baked at 550°F for one hour

Foulant-Release Test

In order to evaluate antifouling performance of different coatings, the lead author's company has designed a foulant-release test procedure. The principle of this test is to apply a specially formulated foulant (or so-called gunk) on the surfaces of a number of coated samples, then try to scrub it off. The antifouling performance is considered better if it takes fewer cycles to scrub-off the foulant. To quantify the performance, an automatic test rig has been developed, as shown in Figure 2. The device consists of three parts:

- A scrub-pad being placed in a tray filled with water and detergent;
- A sample-holder block, which holds the sample facing down on the scrub-pad;
- An electric motor, which drives the block through a rod to scrub the sample back-and-forth on the pad.

A counter is connected with the driving rod to record the number of scrub cycles. After certain cycles, the sample is removed and weighed. The weight-loss represents the extent of foulant release.

In order to standardize the test, each sample panel was masked to leave a window of 1.5×1.5 inch on one side. The foulant was sprayed onto this window. Samples were weighed during the spray process to make the initial foulant weight from sample to sample as consistent as possible. For a more accurate evaluation, each coating was tested in three samples.

The formula of the foulant is listed in Table 2. This formula was developed in the 1980s to simulate the fouling substance in natural gas compressors, in which iron carbonate was found to be the major component. The formula consists of corn oil, carbon black, carbosil, and iron oxide powder. When the mixture is heated to 300°F (149°C), it will react and form iron carbonate. The mixture

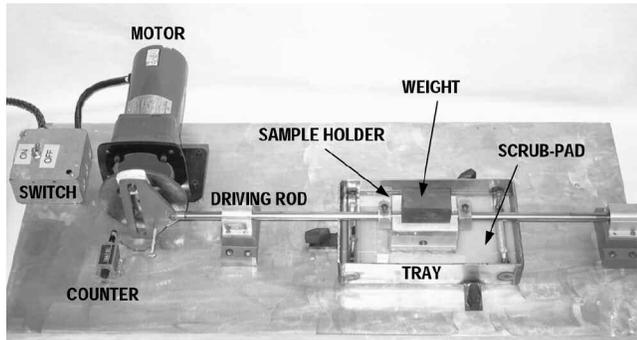


Figure 2. Foulant-Release Test Rig.

was well blended and filled in an aerosol bottle. After being sprayed and weighed, the samples were baked in an oven at 300°F (149°C) for one hour, which made the foulant become a black crust adhering to the sample surface.

Table 2. Formula of Foulant.

Ingredients	Amount
Corn Oil	50 ml
Carbon Black	2 g
Cabosil	0.4 g
Fe ₂ O ₃	10 g

Salt-Spray Test

This was a standard accelerated-corrosion test, ASTM B117. The coating on each test panel was scribed with "X" prior to being positioned in the spray chamber. The spray solution was 5 percent sodium chloride in water. The sample panels were exposed to the salt-fog and periodically evaluated for rusting (ASTM D610) and blistering (ASTM D714) at the intervals of 250, 500, 750, and 1000 hrs. Two panels for each coating, 3P and M3P, were tested, but the bare steel and EL-Ni coated panels were not tested for salt corrosion.

Falling-Sand Test

This was a standard solid particle erosion test, ASTM D968. The sand fell through a long funnel and impinged a coated panel at a 45 degree angle. The sand was continually fed until a 4 mm (0.28 inch) diameter spot of the topcoat was worn through to the base coat. The abrasion resistance, A , was calculated from the following equation:

$$A = V / T \quad (1)$$

where V was the total volume of the sand being used, and T was the thickness of the coating. The details of the testing rig and procedure are specified in ASTM D968. Only the coating 3P and M3P were tested for sand erosion, not the bare steel and EL-Ni coating.

TEST RESULTS

Fouling-Release Performance

All the coated panels showed a dramatic improvement of fouling-release capacities as compared to the bare steel panels, as shown in Table 3 and Figure 3. Among the coated samples, the coating M3P demonstrated superior fouling-release performance to the coating 3P. The coating M3P could be completely cleaned in less than 100 cycles, while it took about 1250 cycles to scrub-off the foulant on the coating 3P. In contrast, the foulant on the bare steel remained almost constant after 1500 scrub

cycles. Another interesting thing to notice is that the EL-Ni, in as-coated condition, exhibited an excellent fouling-release capacity, which was as good as that of the coating M3P. Although this capacity had been greatly decreased after the coating was baked at 550°F (288°C) for one hour, the performance was still at a comparable level to the coating 3P, and far superior to the bare steel.

Table 3. Fouling Release Capacity Measured as Number of Cycles to Obtain 50 Percent and 100 Percent Reduction in Foulant Weight (Average of Three Tests).

Sample ID	Average Cycles to 50% Clean	Average Cycles to 100% Clean
M3P	45	100
EL-Ni	50	150
3P	300	1250
EL-Ni (550F)	400	1450
Bare Steel	>3000	--

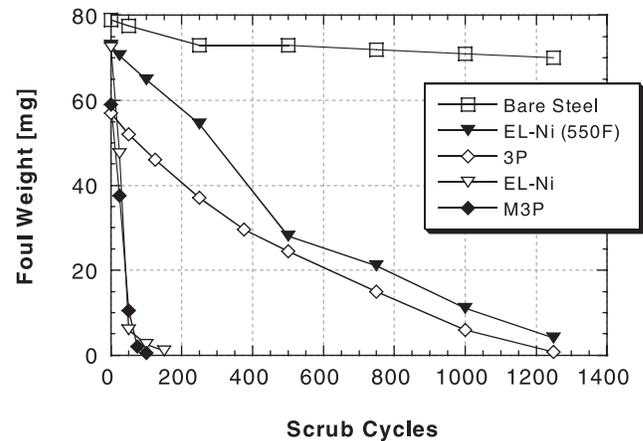


Figure 3. Comparison of Fouling-Release Performance of Bare Steel and Coated Panels.

Corrosion Resistance

Both coating 3P and M3P showed good to excellent corrosion resistance. After 1000 hrs of salt spray, the scribed marks did not show any blisters, and the rusting was minimal. Generally, the corrosion resistance of these two coatings appeared to be comparable, or 3P was slightly better than M3P.

Abrasion Resistance

The test data indicated that the abrasion resistance of M3P was about three times better than that of 3P, as shown in Table 4.

Table 4. Falling Sand Test Data.

Sample ID	Abrasion Resistance [liter/micro inch]			
	Spot #1	Spot #2	Spot #3	Average
3P	1.6	1.2	2.0	1.6
M3P	5.2	5.2	6.0	5.5

CONCLUSIONS AND DISCUSSION

The test results indicate that the modified coating M3P has a superior antifouling performance as compared to the existing

coating 3P. This improvement is attributed to the new topcoat of the coating M3P, which also makes the coating stronger and more resisting to the sand erosion than the coating 3P. The technical detail of the topcoat is not a topic in this discussion it is proprietary to the lead author's company. These two coatings have shown similar corrosion resistance in the salt spray tests, mainly because their base coats, which function as a galvanic protection layer, are similar.

The electroless nickel plating in as-coated condition has demonstrated excellent antifouling capacity, which is as good as the coating M3P. Although this capacity can be considerably reduced by a baking at 550°F (288°C), it is still comparable to that of the coating 3P, and far better than the bare steel. Considering its excellent corrosion resistance and durability against liquid erosion and chemical/solvent attacks, EL-Ni is a very attractive alternative coating to the organic composite coatings for certain applications.

The excellent antifouling performance of EL-Ni is attributed to its high phosphorus content, which makes the coating naturally lubricous with low coefficient of friction. For the same reason, when the beneficial phosphorus is oxidized, the antifouling capacity of the coating will drop. That is why the baking at 550°F (288°C) has shown a negative effect on the antifouling performance of the coating. Further examination of the baked sample confirmed that phosphorus oxide "islands" had formed at the "valleys" of the nickel nodules. It is believed that these "islands" acted as anchors to hold the foulant, which made the foulant difficult to be removed. Another preliminary test indicated that, when EL-Ni coating was cleaned with a special solution before the baking, the oxide "islands" were unlikely to show up. Thus, it is possible to develop a process in the future that will minimize the thermal effect on the antifouling performance of the coating.

CASE STUDY OF ELECTROLESS NICKEL COATING

Background

A major chemical plant in Corunna has a centrifugal compressor that used to be coated with the coating 3P for antifouling. The coating had suffered severe deterioration two times during the four-year operation since 1997. Analysis indicated that the deterioration was related to the heavy washing injection, which contained aggressive chemical additives, and steam-cleaning operation. However, the washing and cleaning were essential to the plant because of the extensive fouling and efficiency drop. In order to withstand the injections, the compressor rotor and diaphragms were recoated with EL-Ni during a plant turnaround in September 2001. The compressor has been in service since then, with satisfactory performance. This case study reviews the operation history and current status of the unit, and the previous deterioration of the coating 3P is also discussed.

Corunna Plant

The Corunna Plant is located in Ontario, Canada. The plant supplies 30 to 40 percent of Canada's total requirements for primary petrochemicals. It was the first fully integrated refinery and petrochemical complex in North America when it came on stream in 1977. This plant was originally designed to process crude oil but has been diversified through developing flexibility to process a wide range of North American and offshore feedstocks. The Corunna site produces a full range of primary petrochemicals, including ethylene, propylene, butadiene, isobutylene, n-butylene, benzene, toluene, and xylenes. Coproducts produced at the Corunna site include synthetic natural gas, gasoline components, hydrogen, isoprene, dicyclopentadiene, resin oil, diesel, and industrial fuels.

Charge Gas Compressor at Corunna Plant

Cracking heaters yields, after being cooled down and processed through a preliminary separation to knock out the heavies, are

compressed to the pressure required for the product distillation and conversion in the downstream process facilities. The compressor string is composed of five process compression stages accommodated in three axially split compressors in tandem arrangement and driven by a 64,000 hp single extraction condensing steam turbine. Figure 4 is a schematic diagram of the charge gas compressor CGC. The compressors are designed for plant operation with various feedstocks. Table 5 summarizes its design operating conditions for the light feed case.

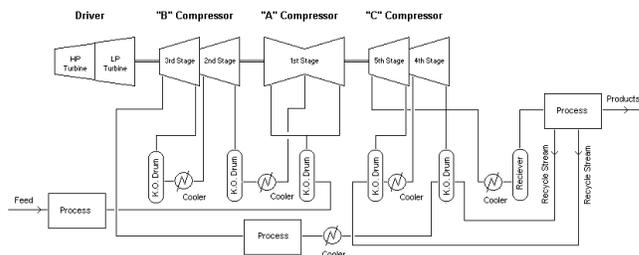


Figure 4. Schematic Diagram of CGC at Corunna Plant. ("C" compressor (fourth/fifth stage) is centrifugal compressor discussed in case study.)

Table 5. Design Operating Conditions for Light Feed Case.

Parameter	1st stage	2nd Stage	3rd Stage	4th Stage	5th Stage
Flow Rate, lb/min	10110	10051	9563	9595	9477
Gas Molecular Weight	25.6	25.6	25	24.5	24.2
Suction pressure, psig	8.3	26.6	69.1	144.5	275.6
Discharge Pressure, psig	31.4	75.6	163.5	281.8	540.3
Suction Temperature, °F	88	97	97	94	97
Discharge Temperature, °F	184	203	202	176	187

Machine Operating History

Plant turnarounds were originally scheduled for every two years up to 1991, at which time the run period was extended to three years for two periods. There was a partial plant turnaround during 1999. The last turnaround was in fall 2001. Currently the plant is expected to run for four years between turnarounds, and the next outage is scheduled for 2005. The plant turnarounds normally take 30 days with the compressor deck being the critical path of the plan.

As part of the plant production expansion to 120 percent, CGC was rerated for the first time during the plant turnaround in 1989. At the same time a wash oil injection system was provided to the CGC. Wash oil was injected to each compression stage suction piping. In 1994 CGC was rerated for the second time as part of the plant production expansion to 150 percent. The wash oil system was also upgraded to inject the oil to all compression impellers in the machine.

In spite of a thorough steam-out process before opening the compressor casing, fouling on the internals was very evident during the 1997 turnaround inspection. Compressor was suffering from poor performance and high radial vibration near the end of the run period.

During a 1997 plant turnaround the internals of CGC fourth/fifth stage compressor were coated with the coating 3P. At the same time the wash oil system was upgraded to further enhance the reliability and functionality of the system. Also, plant production was increased to 160 percent as the result of another capital project. CGC was not rerated at this time. The compressor had high radial vibration and axial thrust from the mid of the run period. For the said reasons chemical cleaning of the compressor was performed a few months prior to the end of run period.

Inspection of the compressor internals during the 1999 plant turnaround revealed that the coating 3P was badly attacked, and the

compressor internals were fouled with polymer throughout the gas path. The rotor was removed for further examination, and a spare rotor, also coated with the coating 3P, was installed. Operation data since November 1999 showed gradually increasing rotor vibration, as shown in Figure 5. Considering a possible similar coating deterioration and fouling, Corunna plant accepted the manufacturer's recommendation and had the off-line rotor cleaned and recoated with EL-Ni.

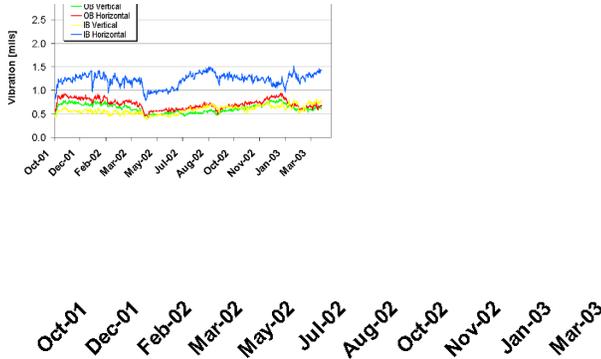


Figure 5. Vibration Trend of "C" Compressor Rotor Coated with Coating 3P and Operated from November 1999 to August 2001. ("IB" and "OB" stand for inboard (drive-end) and outboard.)

In September 2001, the compressor was shutdown for inspection. Similar coating deterioration and severe fouling as in 1999 were found on the internals. The rotor was replaced with the offline one coated with EL-Ni. During this period, all the diaphragms were also cleaned and coated with EL-Ni. The unit has been run since October 2001.

The Deterioration of Coating 3P

The analysis of the deterioration incident in 1999 revealed extensive coating blisters and peel-off throughout the compressor. Chemical attack was also observed on the impellers and diaphragms, as shown in Figure 6. It was believed that the blisters and peel-off resulted from the steam-cleaning operation, in which hot steam was purged into the compressor to remove the fouling substance prior to opening the casing. The hot steam had caused benzene, which had been absorbed by the coating and substrate during operation, rapidly evaporated, and produced the blisters. The chemical attack was probably due to the aggressive chemical additives, such as amine, that were injected to the cleaning process during the running period, or the possible caustic carryover from the upstream process. The caustic carryover could increase the pH value of the process beyond the safe range for the organic topcoat, which was four to nine, and consequently damaged the coating. This incident was a typical example to show that the organic composite coating was vulnerable to the aggressive washing and cleaning processes.

Operating Status of EL-Ni Coating

The compressor with EL-Ni coating has been successfully operated since the 2001 turnaround. The rotor vibration has been monitored at a much lower level than the previous run periods, as shown in Figure 7, which indicates that the fouling has been effectively controlled. Comparing these vibration data with the previous one shown in Figure 5, a significant improvement can be seen. This improvement is attributed to the better endurance of EL-Ni to the heavy washing operation than that of the coating 3P, because the oil washing and chemical injections have been kept in the same manner as in the previous operating periods. Although the data are preliminary, the Corunna plant feels that the EL-Ni has successfully functioned as an antifouling coating in this unit.

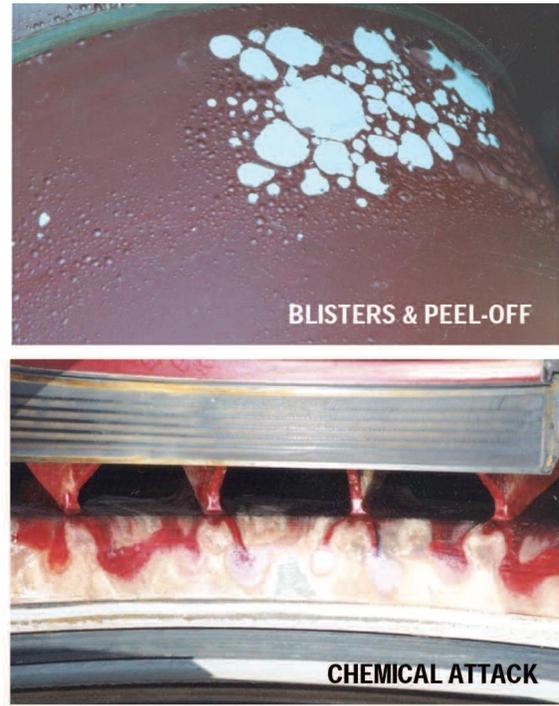


Figure 6. Deterioration of Organic Topcoat of Coating 3P with Benzene Blisters and Chemical Attack from Amine.

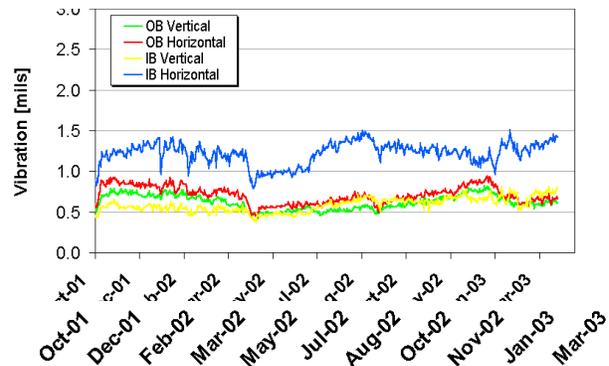


Figure 7. Vibration Trend of "C" Compressor Rotor Coated with Electroless Nickel and Operated from October 2001 to Date.

SUMMARY

The multilayered composite coating system is an innovated design. It will continue to serve the petrochemical compressors for antifouling and corrosion resistance purposes. The antifouling performance of the coating depends on its PTFE impregnated organic topcoat. By optimizing this topcoat, a new coating with superior antifouling performance has been developed, which adds a new selection to the composite coating system. The new coating's erosion resistance is also better than the existing one, while their corrosion resistance is equivalent. This new coating is presently available for further field applications.

In spite of all the merits, the composite coating system is vulnerable to aggressive washing and cleaning practices, especially when strong detergent/solvents are used. A number of field incidents have indicated that the coating can be subjected to severe deterioration due to chemical attack and erosion damage. This limitation makes electroless nickel a promising alternative coating to the composite system. The metallic electroless nickel coating not only has excellent antifouling performance and corrosion resistance, but also is resistant to liquid erosion and chemical/solvent

attacks. Therefore, it is very attractive to such applications where routine inline water/oil injections or even more aggressive washing/cleaning practices are needed. Electroless nickel has ideal application on stationary diaphragms. For impellers, the thermal effect from the shrink-fit installation may reduce the antifouling capacity to a certain extent. However, the coating is still far superior to the bare steel. A process is under development that may minimize the thermal effect in the future.

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