Simultaneous Protection against Erosion and Corrosion

Amnon Vadasz F., Ph.D., P.E., President of C.A. Tecnología Aplicada,

San Diego de Los Altos, Edo. Miranda, VENEZUELA

A coating system, applied on a component which has simultaneously some surfaces exposed to erosion and others to corrosion, has been developed and field tested.

The new coating system is comprised by a double plating of electroless nickel, where: 1) one of them, heat treated for maximum hardness, is applied on the surfaces subjected to wear due to the erosion caused by particles suspended in a fluid, and 2) another, heat treated for hydrogen relief, is applied on the surfaces subjected to corrosion due to the corrosive effect of the same fluid.

The coating system is being applied on choke valves in Venezuela, obtaining a substantial increase in their useful life time.

For more information, contact:

Ing. Amnon Vadasz F., Ph.D., P.E.

C.A. Tecnología Aplicada

Apartado 60.799

Caracas 1060A, VENEZUELA

Phones: (58) 14/321-7477 or 2/372-9046 or 283-8775

FAX: (58) 2/372-9046 or 2/284-6852

E-mail: vadasz@telcel.net.ve

Web Site: www.tecnoaplicada.com

Introduction

In practice, it has been found that most of the times, the fluids that are extracted from a reservoir (in the oil industry) or from a river (in the water treatment sector) and many other similar applications, contain a large amount of suspended particles (or solids), and at the same time most of these fluids are also corrosive.

The difficulty from the design point of view, in the selection of the fluid handling equipment, is to determine which failure mechanism predominates; in other words, whether the large amount of suspended particles will cause an early wear of the surfaces in contact with the moving fluid, due to the erosion failure mechanism, or whether the corrosion rate due to the corrosive effect of the same fluid, is the mechanism of failure that will cause the equipment to cease its operation.

It turns out in reality that when both the corrosion and erosion failure mechanisms are present simultaneously, then the failure rate is dramatically incremented. This can be understood by considering that when a microscopic portion of the substrate is removed due to the erosive effect of the particles in the fluid, then the corrosive effect of the same fluid will act immediately on the damaged area, since the substrate at that point is very active; thus the net effect, is an accelerated deterioration of the substrate.

The present paper presents a system of two electroless nickel coatings, applied separately, with different heat treatment and hardness, thus offering different properties which in combination offer an effective protection to the failure mechanisms of erosion and corrosion simultaneously.

Discussion

At the present time, there exist several types of coatings that can be applied to the surfaces that are in contact with the fluids. Most of them are designed for handling specifically either the corrosion or the erosion failure mechanisms, but not both at the same time.

Furthermore, there are other problems related to the application procedure that make some of the coatings not applicable to protect some surfaces that are complex in shape. It is easy to understand that electrolytic or metal spray processes are not easily applied to the internal surfaces of, for instance, centrifugal pump bodies, due to the impossibility of placing the electrodes or introducing the metal spray gun. Other protective coatings, like hot dip galvanizing or paints, might offer an appropriate corrosion resistance, but offer practically no erosion resistance.

The electroless nickel plating (or ENP as is better known in the oil industry) have several very interesting properties for application in fluids handling equipment, such as:

1. It copies faithfully the surface to be covered, no matter how complex its shape might be.
2. When it presents a metalographic structure with Ni_3P crystal phase, then it offers a high erosion resistance.
3. When it presents an amorphous metalographic structure, then it offers a high corrosion resistance.

4. It presents a very high adhesion to the substrate.
5. It can be applied over many different types of substrates, even over relatively low cost materials.

Based on the above properties, and most specifically due to the fact that the electroless nickel plating copies faithfully the surfaces being coated, with practically the same coating thickness, makes this plating process the best choice to coat all types of surfaces, particularly the complex shaped ones, that are in contact with the fluid.

The electroless nickel plating has different properties based on the specific heat treatment to which it is subjected; thus a high hardness, superior to 950 Vickers can be easily attained if the coating is subjected to a heat of 400 ºC for an hour. This coating, however, could suffer a shrinkage of up to 4% as it changes from the amorphous metalographic structure to a metalographic structure with Ni_3P crystal phase at about 260 ºC. When the coating is subjected to a heat treatment of about 200 ºC for 2 hours or more, the hardness is relatively low (in the order of 500 to 600 Vickers), but the metalographic structure is amorphous and free of micro cracks, thus offering an excellent corrosion resistance.

It is easily understood that a single coat of the electroless nickel plating process, can resolve the erosive effects of the fluid acting on the substrate, if it is heat treated for maximum hardness, but its corrosion resistance could be limited due to the possible presence of micro cracks as a consequence of the coat shrinkage due to the phase changes in its metalographic structure. On the other hand, if the coat of the electroless nickel plating process, is applied so that its metalographic structure is amorphous, then it will resist very well the corrosive effects of the fluid acting on the substrate, but since the hardness is relatively low, the erosion resistance will also be limited.

A novel coating system was developed and patent pending[1-2], which comprises the application of two separate coats with the electroless nickel plating process. The first one consists on a coating of about 100 microns (approximately 0.004”), heat treated to 400 ºC for one hour, with more than 8% phosphorus content. Then the surface is reactivated and coated with a second coating of about 25 to 50 microns (0.001” to 0.002”) which is heat treated to 200 ºC for at least two hours, also with more than 8% phosphorus content. The idea is that some of the second coating will cover and somewhat penetrate and/or diffuse into the micro cracks that could be present in the first coating.

In this coating system, the second coat is not expected to last very long in an erosive environment; however, since the particle size of the suspended solids in the fluids being handled are several orders of magnitude greater than the width of the micro cracks, the electroless nickel that is within the micro cracks will not be removed by the suspended solids, thus offering a surface which is very hard and corrosion resistant at the same time.

It is easy to understand that the erosion and corrosion failure mechanisms are present at the surfaces that are in contact with the moving fluid; however, there are other surfaces which are in contact with the fluid, but in this case the fluid is not moving, such as in threaded surfaces where two parts are fixed so that there is no relative motion between them, as is shown in Figure No. 1. In this case, only the corrosive effects of the fluid act on the threaded surfaces, since there is no relative motion of the fluid with respect to the mentioned threaded surfaces.

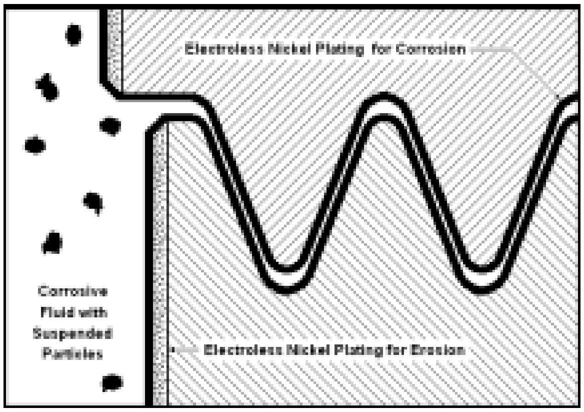

Figure No. 1 Schematic drawing of a cross section of threaded components showing the corrosion resistant coating (that covers all surfaces) and the erosion resistant coating (covering the surfaces in contact with the moving fluid).

The practical application of the double coat for components that have some surfaces subjected to erosion and corrosion failure mechanisms and at the same time have some surfaces that are only subjected to the corrosion failure mechanism, is to mask the surfaces that are never subjected to the erosion failure mechanism, while the first coat of electroless nickel is applied, then heat treat for maximum hardness, and later apply the second coat of the same electroless nickel, but this time over all the surfaces including the ones that were masked previously. Finally this second coat is heat treated for hydrogen relief and to induce diffusion into the substrate (on the areas not coated previously) and into the first coating (on the areas previously coated), thus allowing for a maximum corrosion resistance.

The above mentioned coating system was applied on choke valves used in the Venezuelan oil industry. As is well known, these valves contain different components which have threaded surfaces which only need corrosion protection; while other surfaces on the same components are subjected to the flow at high pressures (most of the time, over 3000 psi) of the fluid which contain a large amount of suspended solids (in this case sand particles), and which require erosion protection against the sand particles and corrosion protection against the corrosive effects of the fluid.

Laboratory Observations

In order to demonstrate that the coating system comprised by two coats of electroless nickel, processed and heat treated separately, will comply with the predetermined objective of offering a simultaneous resistance to both corrosion and erosion failure mechanisms, it was applied over a series of coupons which were cut and observed under a electronic microscope.

In Figure No. 2, a section of one of the coupons is presented. In this figure the first coating, heat treated at 400ºC for 1 hour, was directly applied over the substrate. The second coating, heat treated at 200ºC for over 4 hours and applied over the first coating, is presented on purpose with some Teflon particles, so that a clear distinction can be made between the two coats. It is interesting to observe in this case, that even at 1000x amplification, no micro cracks are visible in the first coat.

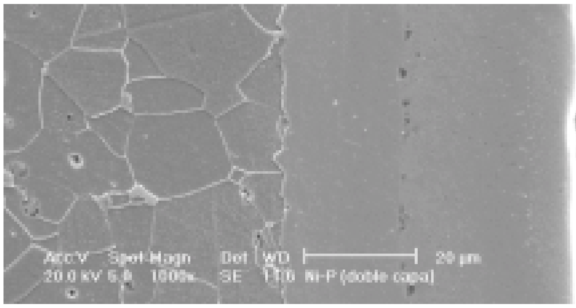

Figure No. 2 Photograph of a cross section of a coupon showing the coating system comprised of a double coating of electroless nickel.

Based on the laboratory observations, it is clear that if the micro cracks that could be present in the electroless nickel coat that was applied over the substrate, are even slightly filled with the electroless nickel corresponding to the second coat, then there is a completely sealed surface covering the substrate and thus there is no communication between the fluid and the substrate, and in consequence there is a real protection against the corrosive effects of this fluid. Furthermore, it is clear that if the softer amorphous coating wears off due to the erosive effect of the suspended solids, then the hard coating will be exposed and this one will be the one to withstand the wear due to erosion.

Field Applications

Based on the great number of problems encountered by the Venezuelan oil industry in the handling of fluids which contain a large amount of suspended solids, particularly sand particles, and at the same time is corrosive, the coating system was field tested in a very important application, specifically on choke valves that permit the fluid passage through an orifice.

As is well known a choke valve, whose schematic drawing is shown in Figure No. 3, restricts the flow of the crude oil and forces it to pass through an orifice (which can be either, fixed type: which has a set orifice area, or adjustable type: in which the orifice area is variable, allowing it to be adjusted according to the user requirements), thus maintaining the pressure of the reservoir. The high pressure crude oil comes with different amount of sand particles, thus the erosion effects on all of the components of the valve, are very damaging. Furthermore, the crude oil is typically corrosive, depending on the contents of CO_2, H_2S or formation gas and/or water.

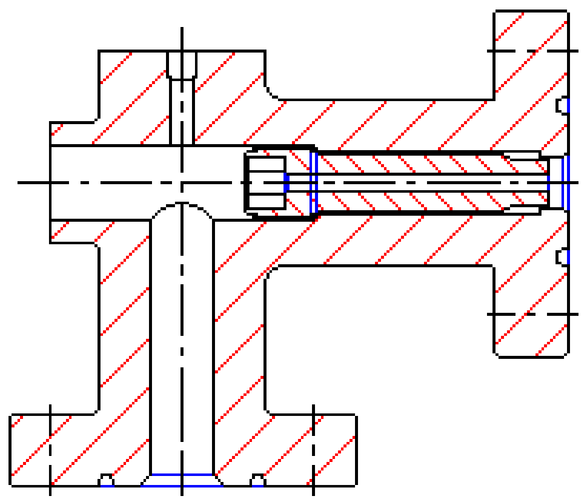

Figure No. 3 Schematic drawing of the body and the choke bean of a typical choke valve.

Due to the fact that many of the choke valves would not last even three months in operation, the R&D branch of PDVSA (Petróleos de Venezuela) and one of the field operators, proceeded to field test some electroless nickel plated valves.

For many years, the choke valves failed due to what was believed to be a typical erosion failure mechanism. Thus one valve belonging to the R&D branch of PDVSA and five other valves belonging to the operator were coated with a high hardness electroless nickel coating, in order to study its resistance to the erosion failure mechanism.

Three months later the valve belonging to the R&D branch of PDVSA was opened for observation purposes, and it was detected that there were profound corrosion pits, that did not permit the valve to be reassembled. Soon after, the other five valves belonging to the field operator, started to malfunction. Originally it was thought that there was a problem with the application of the electroless nickel plating. But as soon as the crude oil produced from the wells was analyzed, it was quickly determined that it was corrosive.

Figure No. 4, shows a picture of a failed valve, where a high wear in the inner surfaces can be observed. Knowing now that the real problem is a combination of erosion and corrosion failure mechanisms, the R&D branch of PDVSA was considering to use other alloys, some of which are several times more expensive than the present carbon steel material. We proposed to test the new coating system comprised of the two coats with the electroless nickel plating process. Based on the fact that the cost of the electroless nickel coating system is only a fraction of the cost of a carbon steel valve, the R&D branch of PDVSA decided to allow us to realize the test, but this time as C.A. Tecnología Aplicada considered best fit.

Figure No. 4 Photograph showing erosion and corrosion damage to the entrance portion of a choke valve.

The coating system was applied to a second valve belonging to the R&D branch of PDVSA, according to the patent pending[1-2] procedure briefly described in the discussion above, and the field test results were as predicted.

Once the valve belonging to the R&D branch of PDVSA lasted 1½ times the normal life time expected from a conventional choke valve at the test well, the field operator decided to install ten other choke valves, under different operating conditions.

At the present time, all of the check valves are still installed and most of them have already surpassed the normal life time under each specific operating condition.

By the time this paper was being prepared, the choke valve belonging to the R&D branch of PDVSA has been in operation for 11 months, which is more than three times the typical life time of the valve, and all of the ten choke valves installed by the field operator are also still in operation.

Conclusions

The purpose of this technical paper was to present a novel solution to a typical problem encountered in fluids handling, where there is an early wear of the components due to the simultaneous failure mechanism of corrosion and erosion, by using a coating system comprised of two coatings applied separately with the electroless nickel plating process.

Based on the field test results, it is expected that the Research and Development branch of PDVSA will write a report on the results and establish the patent pending[1-2] electroless nickel coating system, as a specification for choke valves that are subjected to erosion and corrosion effects simultaneously.

The preliminary results of the field test, was considered positive by the field operator, who decided to install other twenty choke valves.

Due to the successful field test results of the coating system, a more profound study of the possible penetration and/or diffusion of the amorphous metalographic structure coating into the crystal phase metalographic structure coating is underway.

It is believed that the coating system presented in this paper opens a whole new research area that requires further consideration and analysis, due to its potential applications in the solution of simultaneous erosion and corrosion problems and possibly simultaneous abrasion and corrosion problems.

References

1. A. Vadasz, Estrangulador o Válvula de Restricción de Flujo (“Choke Valve”), Servicio Autónomo de la Propiedad Intelectual, Planilla 19482 (Pat. Pending).

2. A. Vadasz, Sistema de Recubrimiento para la Protección de Superficies Sometidas al Desgaste y la Corrosión, Servicio Autónomo de la Propiedad Intelectual, Planilla 19483 (Pat. Pending).