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Corrosion in a Corn Milling Plant

Large and costly equipment is needed for the corn wet milling process. To protect that equipment against costly corrosion, the right materials of construction must be used. Here are some specific corrosion problems, with emphasis on the role the chemical engineer plays in the selection of materials used

At the Clinton Corn Processing Co. plant located at Clinton, Iowa, we process over 60,000 bushels of corn each 24-hour day into bulk food products such as corn sirup, refined dextrose, starches, refined edible oil, lactic acid, by-product cattle feed, and industrial starches for use in textiles, paper, and adhesives.

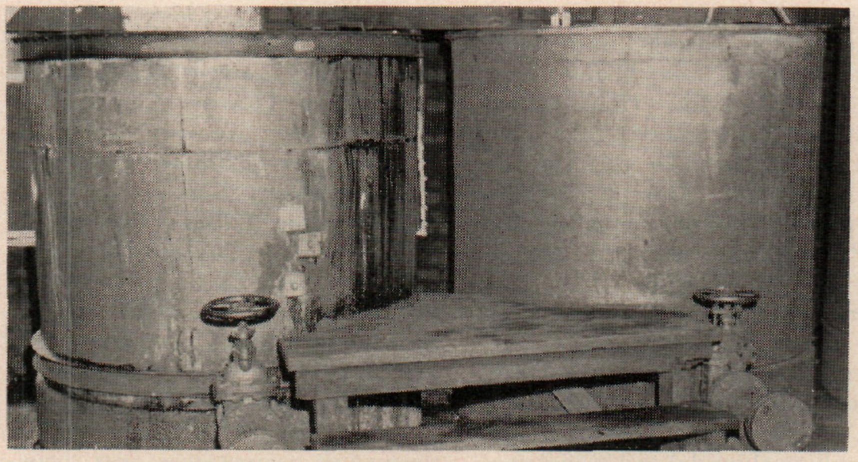
There is nothing corrosive about corn as we all know it; however, in properly separating its constituents into pure products, treating or modifying these constituents to make the many finished products, many large-scale corrosion problems are encountered. For example, the corn is steeped, ground, and separated in large volumes of water containing very corrosive SO_2, resulting in process waters containing sulfurous acid at a pH of about 4.0 and 100° to 125° F. In our refinery, starch is hydrolyzed to soluble sirups and sugars in the presence of hydrochloric acid and at a very low pH and high temperature. After hydrolysis, the partially neutralized chloride-containing liquors are handled at near-boiling temperatures and on the acid side at a pH of 4.0 to 5.0. Many of the liquors contain activated carbon, which is used as a decolorizing agent; no combination is more corrosive in our process.

The corn wet milling process is dependent upon large and costly equipment for continuous processing, and our problems are varied. The job of the chemical engineer in the development and design of processing equipment, project planning, and production trouble shooting, involves many maintenance as well as corrosion problems. Our aim in the design and specification of equipment is to minimize maintenance, obtain trouble-free and continuous operation, and justify capital expense on the basis of the benefits to be derived.

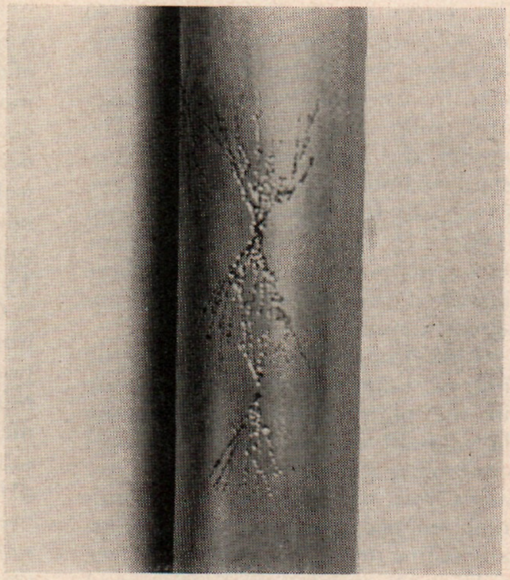
Equipment

Degerminating Mills. After corn is steeped in 125° F. water containing sulfurous acid, it is degerminated in ten large disk-type mills. The large 36-inch driven disks were formerly cast steel, to which the degerminating plates were fastened. As a result of excessive corrosion, the life of these disks was only 18 months. Replacements since 1950 have been with cast bronze disks with excellent results. It is estimated that the life of cast bronze disks should be from 10 to 15 years.

Moisture Expellers. After the starch is removed from the wet



Carbon slurry tanks for mixing hot dextrose sugar liquors and decolorizing carbon. Left tank, 316 stainless steel, failure in tank due to contact corrosion. Pitting-type corrosion with eventual complete failure of the tank. Right tank, polyester-fiber glass construction, replacement for 316 stainless steel tank



Evaporator tube failure caused by stress corrosion. Tube is 16 gage, 304 stainless steel. Heavy corn sirup product in contact has pH of 4 to 5 and temperature of 135° F.

Pit-type corrosion of exterior of a tank exposed to hydrochloric acid fumes in corn sirup refinery

coarse fiber which is a feed constituent, it is first dewatered with the use of many high-pressure continuous expellers or screw presses. The combination of abrasion and corrosion resulted in a service life of 8 months of conventional cast steel (or iron) screws. In this application, Type 316 stainless steel screws were first used in 1946 and are still giving service today.

Screw Conveyors for Wet Feed. In the manufacture of several feed by-products, a large number of 9- to 16-inch screw conveyors are used. To convey wet feeds (containing 40 to 60% moisture, SO_2, and lactic acid from steepwater) it was customary to use wood conveyor boxes and mild steel conveyors. The screws and gudgeons required constant maintenance. We now have from 3 to 10 years' experience with Type 316 stainless steel conveyor boxes, screws, and gudgeons; there is little if any corrosion and they are almost maintenance-free.

Link-Type Conveyors. Many link or chain-type conveyors operate in the plant. One unit handling hot, humid, expelled corn germ meal containing some SO_2 and free fatty acids from the oil required constant maintenance, the steel casing actually failing in about 7 months. Here a Type 316 stainless steel casing used as a replacement has been trouble-free for 21 months. There are still years of service life remaining.

Evaporators. The production of large volumes of sirups, sugars, and steepwater requires a large number of single- and multiple-effect evaporators. We have many evaporators with 3000 to 10,500 sq. feet of heating surface. Until about 10 years ago, evaporators were constructed essentially of cast iron with copper tubes. As a result of high repair costs and the availability of the corrosion-resistant alloys, cast iron has been gradually replaced by stainless steel.

Steepwater Evaporators. Steepwater—the protein-containing water in which the corn is steeped (or soaked)—has a pH of 3.5 to 4.5 and is concentrated from 7% to 50% solids for use in animal feeds and for antibiotic production. Steepwater contains SO_2 and lactic acid. This combination was very corrosive to cast iron evaporators and sections were eroding and corroding to failure in 5 to 10 years. Solid Type 316 stainless steel used in this service for 5 to 10 years shows no appreciable wear.

Refined Dextrose Sugar Evaporator. In the early evaluation of the stainless steels, a double-effect heavy sugar evaporator was installed, constructed of solid Type 304 stainless steel. Here sugar liquor at 53% solids is concentrated to 77% solids prior to crystallization to dextrose. This liquor contains about 1.3% salt (sodium chloride) and has a pH of 4.5 to 5.0.

After 11 years of operation there is no noticeable corrosion in the bulk of the surface and it should give many more years of service. However, we do experience a small degree of weld decay or intergranular corrosion in weld boundaries. Later experiences now prove that even better service can be expected with the use of Type 316 stainless steel.

Corn Sirup Evaporators. Cast iron finishing evaporators have proved unsatisfactory and have been replaced with higher-alloyed equipment. Corn sirup contains some salt (sodium chloride) and is acid at a pH of 4.0 to 5.0. In this evaporation, sirup is concentrated from 52% solids to 81% solids, and is then a very viscous sirup at 135° F. Cast iron was decayed and left a surface of graphitelike carbon, which could not be kept out of the product. This problem has been corrected by replacing cast iron units with a nickel-clad evaporator and one made of Type 316 stainless clad steel.

The nickel-clad evaporator has given 17 years of satisfactory service, with some evidence now of weld decay. The stainless clad evaporator has given 3 years of satisfactory service with no evidence of corrosion, and 20 to 30 years of service is expected.

Lactic Acid Evaporators. Lactic acid ($CH_3CHOHCOOH$) is a strong organic, colorless, viscous acid made from starch by converting the starch to sugar and the sugar to acid by controlled fermentation. In the past, many corrosion problems were experienced with evaporators used to concentrate the acid. With a substantial chloride level, there was much equipment failure.

An evaporator body built of Type 347 stainless steel failed completely in 4 years. Nickel construction failed in less than 3 years.

A rubber-lined steel evaporator body failed in 5 years, owing to a failure of the bond with the steel.

A glass lined steel body served well for about 10 years, with complete failure in 13 years.

Several years ago, because of a significant change in processing, the chlorides were eliminated from the process. At that time an evaporator body of Type 318 stainless steel was installed and after 6 years of service there is little or no evidence of corrosion. A second body of Type 318 stainless steel has just been installed. On the basis of 6 years of service, it is predicted that we can expect 20 years or more of trouble-free service from this construction.

Evaporator Tubes. Previous to about 10 to 12 years ago, all evaporator tubes used for the processing of steepwater, sirup, or sugar were of copper construction. All tubes were $1^1/_4$ and $1^1/_2$ inches o.d. by 10 to 12 feet long and all were 14 gage.

Service life of copper tubes in steepwater evaporators was poor, from 3 to 6 years, resulting in frequent replacements and considerable loss of production. The use of stainless steel tubes was indicated.

The first lot of tubes constructed of No. 430 stainless steel failed completely within a year, owing to weld failures only. A similar experience was had with some of the early Type 304 stainless steel tubes, which had not been welded or annealed properly by the supplier. One present set of 10,500 sq. feet of properly annealed and welded 16 gage, Type 304 stainless steel tubes has served well for 11 years with no failures. There are still many years of trouble-free service to be had with these tubes. Our present specification for tubes for steepwater service calls for properly annealed, welded Type 304 stainless steel.

In addition to the improvement in service life over copper, the most significant benefit is in longer service between boilouts and better heat transfer. This is due to less fouling with steepwater protein on the heated stainless steel surfaces than on the copper.

Lactic Acid Tank. Concentrated lactic acid at 50 and 80% is very corrosive, and in-plant tank storage presents a problem. A rubber-lined steel tank had to be replaced, not because of rubber failure, but the failure of the outside steel bottom caused by spillage from the tank. Several grades of polyesters were evaluated and finally a complete tank was specified.

This polyester tank has now served satisfactorily for 2 years with no evidence of failure and will continue as a test application.

Carbon Slurry Tanks. In the process of the decolorization of dextrose sugar and corn sirup, pulverized, activated, vegetable carbon is used in contact with the liquors. Failures of several small Type 316 stainless steel carbon slurry tanks became a problem. In these tanks, dry carbon was slurried at high concentration with hot sugar or sirup for use in larger carbon contact tanks. Because of some build-up of wet carbon on the tank walls at the liquid interface and some settling to the bottom, contact corrosion in the form of pin holes resulted in failure of the stainless steel.

Two such tanks have now been successfully replaced with polyester resin tanks, and these appear to be in excellent condition after about 2 years of service.

Wet Carbon Cake Hoppers. In one dextrose sugar liquor operation, vegetable carbon was filtered on continuous precoat filters, and the wet sugar-containing carbon was dropped into a Type 316 stainless steel collecting hopper for disposal. Here again the build-up of corrosive, wet carbon resulted in pinhole-type corrosion. About 3 years ago a complete lining of glass-reinforced polyester resin was applied to this hopper and it has proved satisfactory for this particular application.

Hydrochloric Acid Tank. A small rubber-lined steel tank used for the storage of hydrochloric acid had failed and needed replacement. Here again, this was not a rubber failure, but a failure of the outside steel due to acid fumes and spillage.

A tank constructed of the proper type polyester resin was installed on this application about 4 years ago and is completely satisfactory to date.

Corrosion-Resistant Valves. We have had experiences with many types of valves constructed of bronze, Type 316 stainless steel, and No. 20 alloy. Here are several specific applications. In many applications of 4- to 6-inch valves for starch processing lines where erosion and corrosion are factors, corrosion-resistant bronze valves with rubber diaphragms have been used with complete success in place of gate and globe valves. Complete success has been had during a 2-year period with the use of the ball-type corrosion-resistant valves in pipelines around starch processing tanks, where starch slurries are treated with hydrochloric acid or sodium hydrochlorite.

Tank Car Coatings. Most of our corn sirup is used for food, and a large volume is shipped from our plant in insulated and noninsulated 8000-gallon railroad tank cars. To avoid contamination of the water-white pure sirup with scale and rust from the interior of the steel cars, these must be internally lined with a resistant coating. Most of our large fleet of tank cars have been lined with a paint-type aluminum pigmented varnish. This has been satisfactory; however, service life is only about 2 to 3 years, after which time they must be recoated at a cost of about $350.

We have investigated and specified

an internal lining of a baked-on phenolic coating which has now been applied to eight sirup cars. It will be applied to about a dozen test cars for evaluation. This is a much more resistant coating, will not peel, has higher temperature-resistance, and service during the first $2^1/_2$ to 3-year test period has been entirely satisfactory.

The cost of the baked-on phenolic lining is $550 per car and we anticipate about 10 years of useful life from this coating.

Stainless Steels—General

Based on over-all general improved service life, stainless steels are now well established in our plant. Only in one application do we specify Type 304 stainless steel and this is a tube application where we can specify and be assured of proper annealing to ensure maximum corrosion-resistance.

General process conditions are such that we have experienced a minimum amount of weld decay or intergranular corrosion in field-welded Type 316 stainless steel. This grade has been specified for large tanks, and other process equipment where field welding is necessary.

In the past few years still a better Type 316 stainless steel has been developed for general use—the L or extra low cost carbon grade. The standard grade of Type 316 stainless steel contains 0.08% carbon (max.) and under certain conditions will exhibit weld decay or intergranular corrosion due to carbide precipitation in the unannealed weld areas. To minimize this type of failure we now specify the extra low carbon grade of Type 316 stainless steel for all tanks and large process equipment which cannot be annealed after fabrication. The ELC grade costs but a few cents per pound more for material and the increase in over-all cost is generally not over a few hundred dollars per tank. This improved grade of stainless steel gives improved corrosion-resistance in weld areas as a result of controlled, reduced carbon content—a maximum of 0.03%.

Information and background material for this month's corrosion column came from the text of an address by Mr. Pelton at the 8th Plant Maintenance and Engineering show held in Cleveland early this year.