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Failure cases related to material issues in wet-process phosphoric acid plant

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A B S T R A C T

The present paper describes three failure cases of metallic components handling wet-process phosphoric acid at ambient temperatures in a phosphate fertilizer plant. All the three cases of failure were related not directly to the corrosive environment rather to wrong selection or inferior quality of materials. In the first case, pipeline of stainless steel 316L failed due to inferior quality of material used in the elbow region. The elbow material was not a low carbon grade stainless steel and was also in heavily sensitized condition which led to intergranular corrosion and intergranular cracking. The other two cases were related to failures of pump sleeves made up of cast alloys equivalent to stainless steel 316 and Hastelloy C-276 respectively. SS 316 showed through-wall pitting and cracking while Hastelloy C-276 had undergone extensive corrosion along the interdendritic boundaries. Both the materials contained high carbon content which led to heavy precipitation of carbides (Cr-rich carbides in SS 316 and Mo-rich carbides in C-276) along inter-dendritic boundaries during solidification of the casting reducing their corrosion resistance. Recommendations to avoid such failures are also suggested.

1. Introduction

Phosphoric acid is used in various industries such as chemical, fertilizer, mineral leaching, water purification, petroleum refining, food, and metal production. One of its important uses is in fertilizer industry for manufacturing of phosphatic fertilizers. More than 95% of world production of phosphoric acid is obtained by wet-process phosphoric acid (WPA) [1] that involves leaching phosphate rocks rich in calcium phosphate minerals such as apatite, $Ca_{10}(PO_4)_6(F,OH)_2$ with sulphuric acid (H_2SO_4) [2]. The composition and purity of phosphoric acid produced by these processes is determined by the chemical composition of the raw mineral, i.e., phosphate rock and the acid used. Phosphate rock contain many impurities: fluoride (F^-), chloride (Cl^-), iron oxide (Fe_2O_3), aluminium oxide (Al_2O_3), pyrites (ferrous sulfide, FeS), and fossilized organic matter. These impurities impair the quality of phosphoric acid, and enhance corrosion and deterioration of materials of construction used for equipment during production of phosphoric acid [2–4]. Otherwise, pure phosphoric acid is much less corrosive than other acids such as sulphuric and hydrochloric acids. It has no effective oxidizing power and is classified as a non-oxidizing acid [3]. However, WPA is treated as an oxidizing acid due to the presence of oxidizing impurities, e.g., Fe^{3+} and Al^{3+} ions.

As reported in literature, the sulphate and fluoride concentration of WPAs are in the range of 0.8–5% and 0.1–1.3%, respectively [4]. The chloride concentration is generally lower than 500 ppm, but concentrations up to 1500 ppm have also been reported [4]. The

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Table 1
Composition of WPA used in the fertilizer plant.

Parameter	Concentration
P_2O_5 (%w/w)	26.6
SO_4^{2-} (g/l)	46.1
F^- (g/l)	27.8
Cl^- (g/l)	1.1
NO_3^- (g/l)	0.6
SiO_2 (g/l)	16.5
Al (g/l)	1.4
Fe (g/l)	2.6
Mg (g/l)	1.5
Ca (g/l)	0.6
Na (g/l)	0.6

impurities particularly chloride and fluoride in WPA are severely corrosive to the alloys. Several corrosion failures of metallic components handling WPA have been reported in literature [4–6]. Severe corrosive conditions exist in the reaction tanks (erosion corrosion of agitators), evaporators and during transport and storage of acid. Stainless steel (SS) particularly type 316 is reported to have suffered severe corrosion during transportation of WPA [4]. The corrosion attack is reported to have occurred as general corrosion or as pitting attacks concentrated mainly to tank bottoms, especially under gypsum deposits and on surfaces exposed to the vapour phase at the top of the tanks.

In the present study, three failure cases of metallic components handling WPA in a phosphate fertilizer plant are analysed. All the three cases of failure were related not directly to the corrosive environment rather to wrong selection or inferior quality of materials.

2. Case study # 1: failure analysis of SS 316L piping

2.1. Background

A pipeline made of SS 316L handling WPA in the fertilizer plant failed at the elbow region after five years of operation. The pipe was 4.2 mm thick with an outer diameter (OD) of 51 mm. The vertical pipeline was handling liquid at an ambient temperature (40 °C maximum) with a flow of 12 m^3/h (maximum) at an operating pressure of 5 kg/cm^2 (maximum). The failure was observed as hairline cracks in the 90° elbow which was installed on this vertical pipeline. Table 1 shows the typical composition of WPA that flowed inside the pipeline. The other two failed components reported below were also exposed to the same composition of the WPA. Table 2 presents the chemical composition of phosphate rock used as the raw material in the fertilizer plant.

2.2. Visual examination

The hairline crack is visible on the OD side of the failed elbow in Fig. 1(a). The weld between the elbow and the straight portion of the pipe is also visible and the crack is present close to the weld. The elbow was cut into two halves to observe the inner diameter (ID) surface of the pipe and is shown in Fig. 1(b). Welds between the elbow and the straight section of the pipes are visible near both the ends. The bend region (falling within the two welds in Fig. 1(b)) appears grey in colour in contrast to the bright metallic appearance of the straight section of the elbow. This indicates that the bend region had undergone heavy corrosion during service, while the straight section of the pipe was relatively unaffected. Regions up to 3 mm from both the welds in the elbow also showed metallic bright colour and appeared to be unaffected from corrosion (Fig. 1(b)). At the bottom of the image in Fig. 1(b), it is seen that the corroded layers are removed as flakes leading to reduction in the pipe thickness. A black region is seen on top right corner of the elbow which corresponds to the failed region observed on the OD surface in Fig. 1(a).

2.3. Surface examination

The ID and OD surfaces of the SS 316L elbow in the as-corroded condition were examined at higher magnifications using a stereo microscope. Fine multiple cracks are seen on the OD surface at about 4 mm from the weld (Fig. 2(a)). All the cracks are inclined along the circumferential direction of the elbow. Fig. 2(b) shows the ID surface of the elbow in the as-corroded condition as observed by a scanning electron microscope (SEM). Heavy intergranular corrosion (IGC), grain droppings and several intergranular (IG) cracks are evident on the corroded surface (Fig. 2(b)).

Table 2
Composition (%w/w) of major constituents of phosphate rock used in the fertilizer plant.

P_2O_5	CaO	Al_2O_3	Fe_2O_3	MgO	SiO_2	F	Cl	Moisture
30.69	48.34	0.86	0.57	0.36	3.0	4.5	0.02	3.74