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Slurry erosion-corrosion of 90° AISI 1018 steel elbow in saturated potash brine containing abrasive silica particles

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ABSTRACT

Erosion-corrosion is frequently encountered in pipelines used in potash processing equipment and it may be a severe problem, causing rapid material degradation if the slurry flow velocity and solid concentration are high. In this study, the interaction between erosion and corrosion of 1018 steel 90° elbows (2.54 cm schedule 40 - long radius) was investigated in a continuous flow loop. Experiments were conducted using a slurry consisting of saturated potash brine and silica sand. The effects of solid concentration and flow velocity on erosion-corrosion damage of the steel elbow were investigated. The results indicated that increasing flow velocity and solid concentration increased the mechanical effects of particles on the tested elbows and hence increased the erosion-corrosion rates of the elbows. It was observed that there was a 56% synergy between erosion and corrosion at 2.5 m/s, but the synergy level decreased to 11% at 4.0 m/s.

1. Introduction

Severe degradation of pipelines occurs frequently in the mineral processing industry, such as potash processing plants, due to erosion-corrosion, which is a conjoint action of mechanical erosion and corrosion. Failure of pipelines results in rapid plant degradation leading to environmental pollution, decreased productivity and increased maintenance costs. In conventional potash mining, potash ores are usually mixed with water to form slurries which are then transported through steel pipelines. Therefore, these pipelines are prone to erosion due to high velocity and turbulence leading to the impingement of solid particles on equipment. Erosion-corrosion damage is very pronounced at fittings where there is sudden change in fluid flow direction such as pumps, bends, joints, valves and elbows [1,2]. Several researchers have reported that the total material loss due to synergism in erosion-corrosion was higher than the sum of the material losses experienced when mechanical erosion and corrosion act separately [3–9].

The synergistic effect of erosion-corrosion can be determined according to ASTM G119-09 standard [10]. It is done by separating the total mass loss rate, T, into mechanical erosion rate in the absence of corrosion (E_o) and corrosion rate in the absence of erosion (C_o). The synergism (S) is determined using Eqs. (1) and (2):

$$T = E_o + C_o + S \tag{1}$$

where S is given as:

$$S = \Delta E_c + \Delta C_e \tag{2}$$

ΔE_c is the difference in erosion rate due to corrosion (corrosion-enhanced erosion) and ΔC_e is the difference in corrosion rate due to erosion (erosion-enhanced corrosion).

Postlethwaite [11] and Hu *et al.* [12] reported that the erosion rate of metals is enhanced by corrosion during erosion-corrosion through roughening of the metal surface which degrades the exposed surface. Similarly, Aminul *et al.* [13] investigated the synergistic effect of erosion and corrosion on API X-70 pipeline steel and found that erosion degraded thin layers of protective corrosion product and created subsurface cracks on the steel surface, thereby increasing the surface roughness of the specimen. Malka *et al.* [14] studied the synergistic erosion-corrosion performance of AISI 1018 carbon steel in 1 wt% sodium chloride solution containing silica sand which was sparged with CO_2. They reported that erosion and corrosion made considerable contribution to the synergistic effect by either enhancement of corrosion by erosion and/or enhancement of erosion by corrosion.

Despite the numerous erosion-corrosion research investigations carried out in the past, the problem of erosion-corrosion continues to plague the potash processing plants where damage to pipelines transporting potash brine slurries stands out very clearly amongst other forms of corrosion attack. Therefore, the main goal of the work reported

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Table 1
Chemical composition of AISI 1018 steel in wt%.

Fe	C	Mn	P	S	Si	Cr	Mo
Balance	0.19–0.21	0.42–0.45	0.012–0.018	0.005–0.01	0.2–0.22	0.03–0.04	0.001

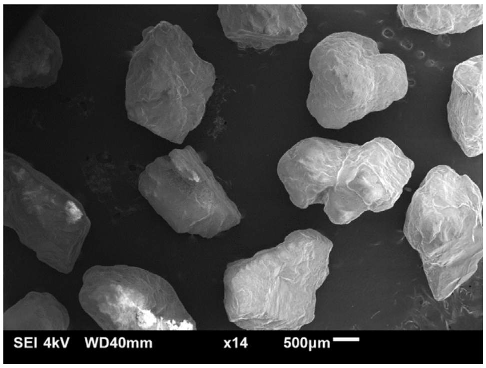

Fig. 1. SEM micrograph of as-received silica sand particles.

herein is to investigate the erosion-corrosion behavior of 1018 steel 90° elbows in potash slurry environment using an erosion-corrosion flow loop.

2. Materials and methods

2.54 cm nominal diameter schedule 40 standard long radius AISI 1018 steel elbows and saturated potash brine containing silica sand particles were used in the present study. The chemical composition range of the AISI 1018 steel is presented in Table 1. A typical micrograph of the silica sand particles acquired using a JEOL JSM-6010LA scanning electron microscope (SEM) is presented in Fig. 1. The average size of the silica sand is 1.56 mm.

The specimen for metallographic observation was sectioned from one of the as-received 1018 steel elbows. It was ground using different grades of SiC emery papers (320, 400, 600, 800, 1200 grit sizes), followed by polishing with 3 μm MD-Dac and 1 μm MD-Nap polishing cloths. It was finally etched for 20 s using a Nital solution (2 vol% nitric acid and 98 vol% ethanol) and the microstructure was examined using a Nikon Eclipse MA-100 inverted optical microscope interfaced with a PAX-it image analysis software. A typical micrograph of the specimen is shown in Fig. 2. The microstructure consists of about 82% ferrite and 18% pearlite. It can also be seen that the grains are elongated along the rolling direction.

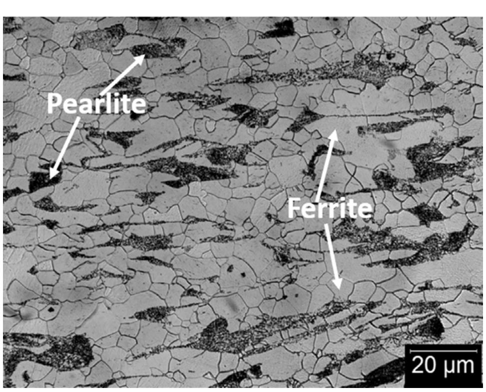

Fig. 2. Optical micrograph of a typical AISI 1018 steel elbow.

2.1. Experimental flow loop and test procedure

Fig. 3 shows a schematic diagram of the laboratory-scale flow loop used to investigate the erosion-corrosion, corrosion and erosion behavior of four elbows at different locations. Its main parts include a Verderflex Dura 55 peristaltic hose pump, a Blacoh pulsation dampener, test elbows, a pressure gauge, a flow calibration tank, a slurry tank, a heat exchanger and polyvinyl chloride (PVC) tubing with an internal diameter of 2.54 cm. Test elbows 1 and 2 are located vertically above the pump, while elbows 3 and 4 are located vertically on a pipe that runs parallel to the axis of the exit pipe from the pump. The pump moves the slurry through the pipes by compressing a flexible hose fitted inside the pump with the help of shoes (rollers) attached to the motor of the pump. The pulsation dampener is connected to the discharge manifold of the pump to dissipate system shocks and reduce pipe vibration, pressure fluctuations and fluid hammer. A Van Waters and Rogers (VWR) refrigerated/heated circulating bath pumped water through the heat exchanger coil which was placed in the slurry tank to control the fluid temperature.

The erosion-corrosion test on the steel elbows was conducted according to ASTM G119-09. The slurry was made up of saturated potash brine and silica sand. The size range of the silica sand was 0.85 – 2.00 mm, which corresponds to a mesh size of 10 – 20 (NSF/ANSI 61). The slurry flow velocity and solid concentration ranged between 2.5 m/s and 4.0 m/s and 10 – 30 wt% respectively. The erosion-corrosion test using a slurry consisting of 30 wt% sand particles and a flow velocity of 2.5 m/s was conducted three times in order to obtain the repeatability of the experiment. The standard deviation obtained from the repeated erosion-corrosion test at elbow locations 1, 2, 3, and 4 are ± 0.31 g/m^2h, ± 0.31 g/m^2h, ± 0.62 g/m^2h and ± 0.32 g/m^2h, respectively. Corrosion only test was conducted using saturated potash brine without any abrasive particles. Pure erosion test was conducted in a slurry containing deoxygenated saturated potash brine (DSPB) and silica sand. The loop was continually deoxygenated throughout the test by purging with high-purity nitrogen gas (N_2) at a flow rate of 0.5 L/min to reduce the dissolved oxygen saturation. The slurry tank was sealed during the pure erosion test to prevent air intake. Table 2 shows a summary of the operating parameters used for the investigation.

The mass loss experienced by the elbows was determined from the difference between the initial weight before testing and the final weight after testing. The weight measurement was carried out using an OHAUS Adventurer® electronic weighing balance with an accuracy of ± 0.1 mg. All scale/rust was removed from the tested elbows by first immersing in diluted Micro-90® cleaning solution for 20 s followed by soft brushing. The cleaning solution dissolves and remove the potash and clay slimes attached to the elbow surface. Each elbow was then rinsed with reverse osmosis water and ethanol and finally dried using a Powerfist 8259210 heat gun. The erosion-corrosion, erosion and corrosion rates presented in this study under different operating conditions are averages of the four elbows placed at the indicated four corners of the flow loop.

2.2. Wear surface characterization

To investigate the internal surface morphology of an elbow before and after testing, specimens were cut from its entry and exist sections