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TEST INSTALLATION FOR STUDYING EROSION-CORROSION OF METALS FOR COAL WASHING PLANTS

G.R. HOEY, W. DINGLEY AND C.T. WILES

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TEST INSTALLATION FOR STUDYING EROSION-CORROSION OF METALS FOR COAL WASHING PLANTS

by

G.R. Hoey*, W. Dingley** and C.T. Wiles**

ABSTRACT

A test installation was constructed for investigating erosion-corrosion of metals by coal-water slurries. Erosion-corrosion tests of mild steel panels were conducted using slurries of alundum, quartz, washed coal and coal refuse. Wear rates were found to depend on type of abrasive, particle size and water conductivity and were reduced by cathodic protection and inhibitors. Cathodic protection of mild steel in coal slurries containing sulphate ion reduced wear by 90% and 86% for stationary and rotating panels, respectively. This study has demonstrated that the successful application of corrosion control techniques would reduce metal wastage in coal washing plants. The test installation is considered suitable for developing the techniques.

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MONTAGE D'ESSAI POUR L'ETUDE DE L'EROSION-CORROSION DES METAUX POUR LES USINES DE LAVAGE DU CHARBON

par

G.R. Hoey*, W. Dingley** et C.T. Wiles**

RESUME

Un montage d'essai a été mis en place pour effectuer des essais d'érosion-corrosion des métaux par des suspensions de charbon et d'eau. Ces essais ont été effectués sur des panneaux d'acier doux avec des suspensions d'alundon, de quartz, de charbon lavé et de rebut de charbon. On a découvert que les taux d'usure dépendent du genre de matériau abrasif, de la granulométrie et de la conductivité de l'eau; ces taux ont été réduits par la protection cathodique et les inhibiteurs. La protection cathodique de l'acier doux dans les suspensions de charbon contenant des ions sulfate a réduit l'usure de 90% dans le cas de panneaux fixes et de 86% pour les panneaux en rotation. Cette étude a démontré que l'application menée à bonne fin des techniques de prévention de la corrosion réduirait le gaspillage de métal dans les usines de lavage du charbon. On considère que ce montage d'essai est acceptable pour le perfectionnement des techniques.

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INTRODUCTION

Canadian coal washing plants are subjected to erosion-corrosion, which causes premature failure of equipment and is a major maintenance problem in coal processing (1,2). A bibliography of corrosion and erosion-corrosion in coal washing plants shows that this problem is universal (3).

The most extensive research in this field was conducted by Zelders, who developed an erosion-corrosion test installation in which steel specimens were rotated in coal slurries in a horizontal plane (4). This was done to simulate conditions which cause severe wear of the blades of flotation agitators. The test results were compared with those from plant flotation cells through which coal was being processed. The resulting information enabled Zelders to demonstrate that the wear rate in flotation cells could be substantially reduced by lowering the conductivity of the slurry.

Wear problems in Canadian coal washing plants prompted the Physical Sciences Laboratory of CANMET to construct a test installation for comparing erosion-corrosion properties of various coals and for selecting suitable materials for use in these plants.

EXPERIMENTAL

Specimens in Zelders' installation were rotated horizontally at 167.5 rad/s (1600 rpm), and at an angle of 15° (4). The velocity of the specimen varied with the distance from the centre and reached a maximum of 6.81 m/s at the tip. This variation in velocity would cause differences in wear rate across the surface of the specimens, which would be most severe at the tips. The equipment constructed for the coal slurry experiments at CANMET was designed to avoid this variation by locating flat panels at the ends of rotating arms so that specimen surfaces were all in the region of maximum velocity.

After several preliminary experiments conducted in small laboratory slurry-mixing containers, 180° mm in diam by 200 mm deep, containing approximately 1 L of slurry it was decided that a larger container was required. A large polyethylene container 260 mm in diam by 250 mm in which 11 L of slurry was easily contained was fabricated and mounted in a steel support frame (Fig. 1). The bottom of the container sloped to a 20 mm diam outlet in the centre, originally connected to the inlet side of a Vanton polypropylene pump. This was done to facilitate removal of deposited slurry from the bottom and return it to a location just below the upper surface of the slurry. However, due to severe erosion of the pump lining, the pump was replaced with air agitation. An air line was attached to the container outlet, and air under pressure monitored by a flowmeter was bubbled through the slurry to keep the heavier material circulating and to prevent settling on the bottom. Although not as efficient as the pumping system, this method was used to obtain most of the information reported.

Four lucite baffles, 50 mm by 280 mm by 3 mm, were placed equidistant around the inside surface of the cell and immersed about 130 mm in the slurry (Fig. 1, 2). The baffles served to impede the vortex effect caused by a centrally located rotating sample rack, and to aid in mixing the slurry more thoroughly. A direct current motor and suitable controls were mounted above the cell to rotate the rack. The shaft of the motor was equipped with a 12.7 mm (0.5-in.) chuck to provide a suitable means of holding and releasing the rack.

The rack was constructed from cold-rolled mild steel and the main support shaft was 10.3 mm in diam by 330 mm long with four arms, each 4.76 mm in diam by 70 mm long (Fig. 3). The arms were joined at right angles to the main shaft. One pair of diametrically opposite arms, LA1 and LA2, was attached to the main shaft 30 mm from the bottom end and the other pair, UA3 and UA4, was attached at 45.0 mm. Steel surfaces were covered with polyethylene tubing and the joints were sealed with rubber cement except for 30 mm at the top of the main shaft and 10 mm at the outer end of each arm. The outer ends were

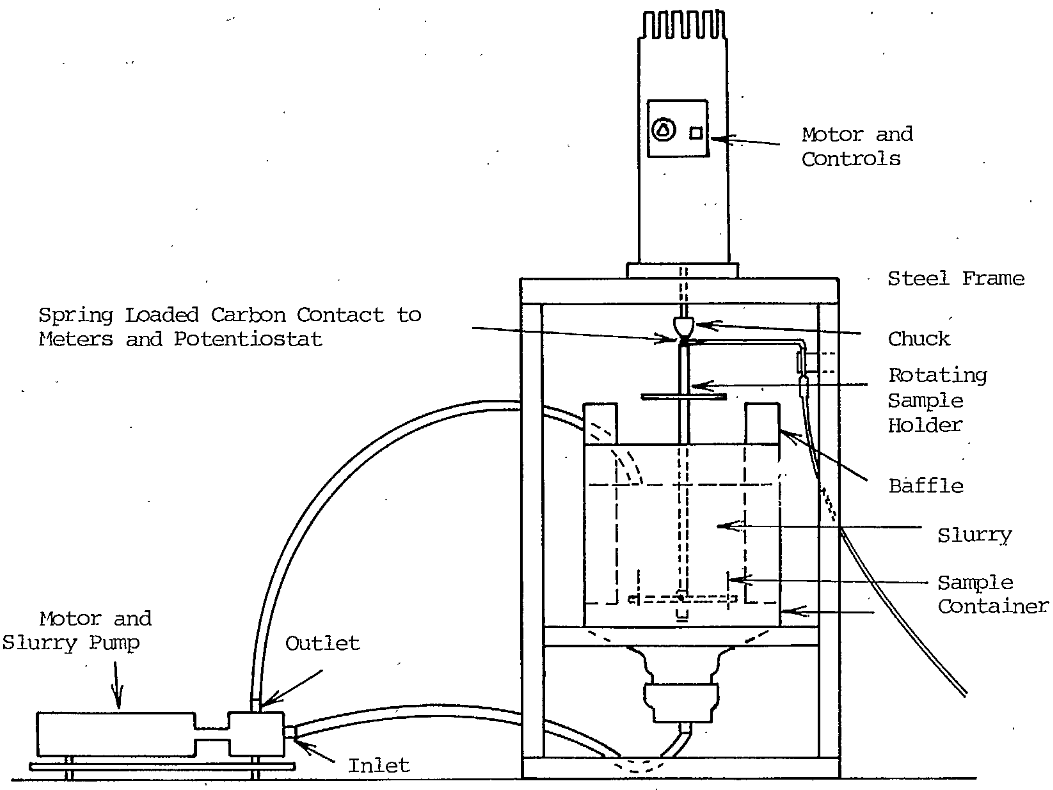

Fig. 1 - Erosion-corrosion test installation

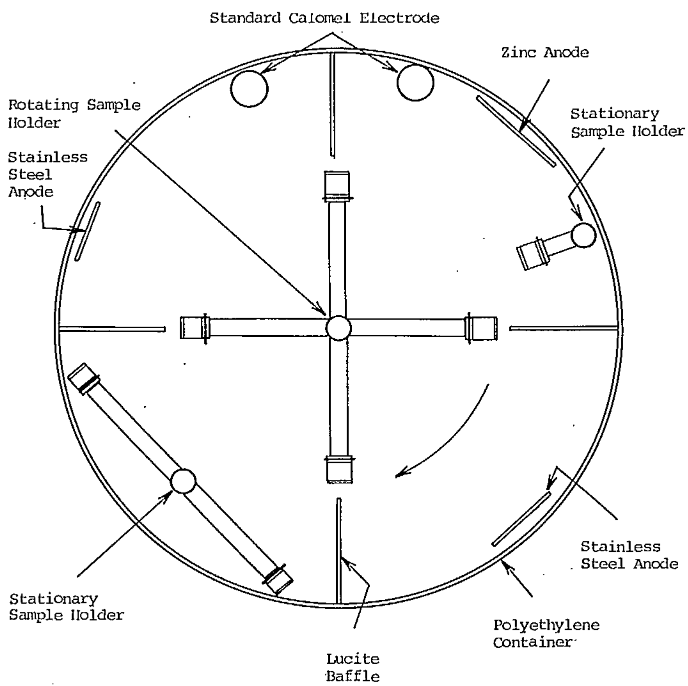

Fig. 2 - Panel racks and electrode assembly

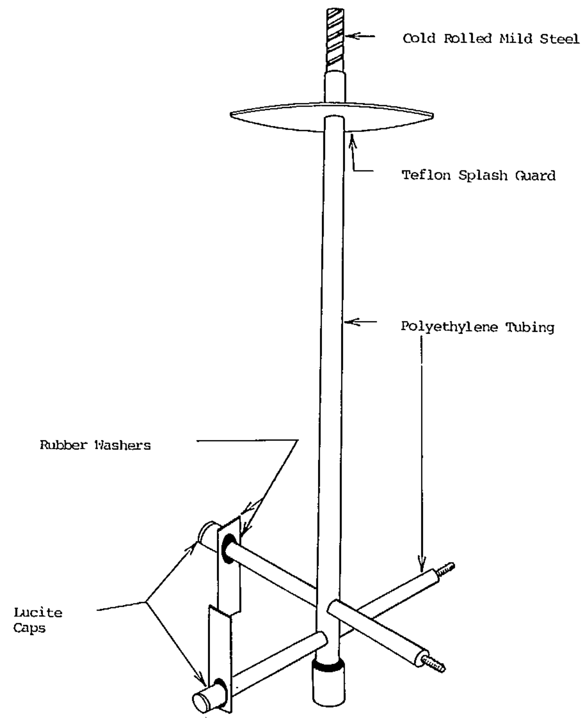

Fig. 3 - Panel rack for erosion-corrosion tests

threaded with a 10NF32 die, and equipped with two flat rubber washers 12.7 mm in diam and a threaded lucite cap to seal and secure each panel to the rack. The exposed top of the main shaft was partially placed in the chuck and the remaining exposed area provided a convenient surface for a spring-loaded sliding electrical carbon contact. The rack was rotated at 52.3 rad/s (500 rpm) in the cell producing a velocity of 3.66 m/s at the panel surfaces. This velocity could be increased or decreased as required.

Two smaller racks, one with a single arm, SA1, and the other with two, SA2 and SA3, were similarly constructed to support stationary panels in the cell outside of the periphery of the rotating panels (Fig. 1,2).

Panels, 12.7 mm by 50.8 mm by 7.66 mm, were sheared from cold-rolled steel sheet (AISI C1020) and a hole was drilled through each one at a point midway in the width and 6.35 mm from one end. Panels designated for electrical contact with the rack were drilled with a 4-mm bit and threaded with a 10NF32 tap. Other panels were drilled with a 6.75-mm bit and fitted with a Teflon insulating ring. Each panel was numbered adjacent to the hole, deburred, cleaned and weighed. Following this, a strip of Paklon plastic tape 19.0 mm wide was wrapped around the numbered end of each panel leaving an exposed area of 404 mm^2 on each side. The plastic covering the holes was removed. Care was taken not to touch the cleaned exposed metal surfaces during masking and assembly on the rack. Three uninsulated and four insulated panels were used during each experiment unless otherwise stated. They were racked as follows (Fig. 3):

uninsulated - one panel extending up on LA1 and one extending down on UA3 and SA1 respectively.

insulated - three panels extending up on LA2, SA2, SA3, respectively, and one extending down on UA4.

During each experiment the potentials of the uninsulated panels were continuously measured against standard calomel electrodes (SCE) immersed in the slurry. Measurements were made with Hewlett Packard 410C and Wenking PPT 70 voltmeters and were indicated on Hewlett Packard Moseley 7100B strip chart recorder. When required, the uninsulated panels could be electrically connected to anodes of either stainless steel or zinc to provide cathodic protection. A Wenking potentiostat Model 70HC3 was used to supply and control the impressed cathodic current applied to the uninsulated panels on the rotating rack. The stainless steel anode was used with these panels. The uninsulated stationary panel was cathodically protected by being connected electrically to a pure zinc sacrificial anode.

Before being subjected to the erosion-corrosion test, panel surfaces were prepared by one of the following two procedures:

1. Surfaces were dry grit blasted with Techline aluminum oxide at 112 µm (150 mesh) and 448 kPa (65 psi), degreased in tricholorethylene and pickled in 1N hydrochloric acid for 1 min at 22 ± 2°C with ultrasonics. They were then rinsed in distilled water, washed in ethanol and dried in a forced hot air stream.
2. Surfaces were degreased in trichlorethylene with ultrasonics, pickled in 18 vol % hydrochloric acid at 22 ± 2°C for 1 min with ulstrasonics and 4 min without. They were rinsed and dried as in procedure 1.

After an erosion-corrosion test, panels were thoroughly rinsed with distilled water, dried in a forced hot air stream and the plastic tape was removed. They were immersed in 1N hydrochloric acid width ulstrasonics for 1 min at 22 ± 2°C to remove the corrosion products and were rinsed and dried as in procedure 1.

All panels were weighed on a Mettler analytical balance before taping and after removing the corrosion products. The cleaned corroded surfaces were examined at various magnifications with a Zeiss metallurgical microscope.

RESULTS AND DISCUSSION

The efficiency of the erosion-corrosion testing apparatus was determined by a series of experiments using the following abrasive materials: aluminum oxide, quartz, Canmore washed coal and Coleman coal refuse.

ALUMINUM OXIDE SERIES

Five slurries containing 2.0 kg aluminum oxide (Al_2O_3) at 112 µm (150 mesh) and 11 L of aqueous solution were used in this series. Each slurry was placed in the cell and four test panels, cleaned by procedure 1, were rotated at 3.66 m/s for approximately 5 h at 25 ± 5°C. The composition of each, and the pH and conductivity of the resulting slurry are shown in Table 1. The number of experiments performed with each type of slurry and the average wear rate obtained from the panels are also shown.

Adding 1% sodium sulphate (Na_2SO_4) to the slurry accelerated corrosion. On the other hand, adding 1% sodium nitrite ($NaNO_2$) and 1% Borax ($Na_2B_4O_7.10H_2O$) inhibited corrosion. Ottawa tap water was used in all slurries except where indicated.

Results of two experiments using 11.6 L of solution without abrasive, are given in Table 1 for comparison. A circulating pump was used to improve slurry mixing.

The results obtained show that:

1. Adding 1% Na_2SO_4 to tap water alone increased the wear rate by 475%, and 84% if Al_2O_3 is present.
2. Adding 1% $NaNO_2$ and 1% Borax to slurries containing tap water and Al_2O_3, and to tap water, Al_2O_3 and 1% Na_2SO_4 reduced the wear rate by 66 and 86%, respectively.
3. The wear rates obtained in inhibited tap water slurries containing Al_2O_3, and Al_2O_3 with 1% Na_2SO_4 were lower than those obtained in the low conductivity slurry by 24 and 41%, respectively.
4. The corrosion was characterized by several pits scattered over the surfaces and by crev-

Table 1 - Results of erosion-corrosion experiments with aluminum oxide slurries

Solution composition	Number of tests	Al_2O_3 abrasive	Average slurry pH	Average slurry conductivity ($10^{-6}\Omega^{-1}cm^{-1}$)	Average wear rate
Tap water	1	No	8.0	152	373
Tap water 1% $NaNO_2$	1	No	8.1	13900	2136
Distilled water*	1	Yes**	6.5	10.5	835
Tap water	5	Yes	7.8	210	1884
Tap water 1% Na_2SO_4 1% Borax	2	Yes	9.1	16400	635
Tap water 1% Na_2SO_4	2	Yes	7.8	13200	3476
Tap water 1% Na_2SO_4 1% $NaNO_2$ 1% Borax	2	Yes	9.0	25000	491

* Low conductivity experiment

** Al_2O_3 was thoroughly washed

*** mdd, i.e., $mg/dm^2/d$

ice corrosion at the interface of the steel and plastic tape. The size and depth of the pits and crevices were proportional to the wear rate, some being surprisingly deep.

QUARTZ SERIES

High-grade crushed quartz was used in the second series. It was screened through Tyler sieves to obtain the following fractions: -0.104 to 0.074 mm, -0.208 to 0.147 mm, 0.295 to 0.208 mm and -0.425 to 0.295 mm. Each slurry contained 2.0 kg of one of these fractions and 11 L of aqueous solution.

In addition to the four rotating panels previously mentioned in the Al_2O_3 series, three stationary panels were included. Unless otherwise specified panels were cleaned by procedure 1. In some experiments cathodic protection was applied to both a rotating panel and a stationary panel by means of sacrificial pure zinc anodes. In others, impressed current controlled at 2 V with a potentiostat was applied to the rotating panel, and the stationary panel was connected to a zinc anode.

Cathodic protection was removed from the panels in other experiments and panels were rotated in uninhibited slurry or in slurry inhibited with 1% $NaNO_2$ and 1% Borax.

To determine the effect of panel surface preparation on the wear rate, some were cleaned by procedure 1 and others by 2. Each panel type was then tested under identical conditions in the container. Air agitation was used to improve slurry mixing.

Table 2 shows composition of each solution, the fraction of quartz used in each slurry and the type of corrosion control applied. Average wear rates and reductions obtained with inhibition and cathodic protection are also shown.

The results obtained from the quartz series show that:

1. crushed quartz at -0.104 to 0.074 mm has a

Table 2 - Results of erosion-corrosion experiments with quartz slurries

Solution composition	Quartz fraction (mm)	Corrosion control (type)	Average wear rate of rotating panels (mdd): Without protection	Average wear rate of rotating panels (mdd): With protection	Reduction in wear (%)	Average wear rate of stationary panels (mdd): Without protection	Average wear rate of stationary panels (mdd): With protection	Reduction in wear (%)
Tap water *	-0.104 to 0.074	Inhibited with	701	294	58	553	27	95
Tap water *	-0.208 to 0.147	1% $NaNO_2$ and	1649	1136	31	419	93	78
Tap water * 0.25% Na_2SO_4	-0.425 to 0.295	1% Borax	3114	1560	50	153	42	72
Tap water * 0.25% Na_2SO_4	-0.208 to 0.147	Sacrificial zinc anode	2878	1224	57	1359	191	86
Tap water * 0.25% Na_2SO_4	-0.208 to 0.147	Cathodic protection with	2878	921	68	see above	see above	see above
Tap water * 0.25% Na_2SO_4	-0.295 to 0.208	impressed current	3449	1535	55	906	173***	81
Tap water ** 0.25% Na_2SO_4	-0.295 to 0.208		1184	745	37	146	53***	64
Tap water ** 0.25% Na_2SO_4	-0.425 to 0.295		3114	1519	51	see above	43***	72

* Panels were grit blasted with Al_2O_3 at 112 µm (150 mesh)

** Panels were pickled in 18% HCl for 5 min

*** A sacrificial zinc anode was used

substantially lower wear rate than Al_2O_3;

2. adding 1% $NaNO_2$ and 1% Borax to tap water slurries containing quartz, and to quartz slurries with 0.25% Na_2SO_4 reduced the wear rate on rotating panels by 58 and 50% respectively, and on stationary panels, 95 and 72% respectively;
3. applying cathodic protection with sacrifical zinc anodes in tap water slurries containing quartz with 0.25% Na_2SO_4 reduced the wear rate by 57% on rotating panels and from 64 to 86% on stationary panels;
4. applying cathodic protection with impressed current in slurries containing tap water, quartz and 0.25% Na_2SO_4 reduced the wear rate by up to 68% on rotating panels;
5. wear rates obtained from panels cleaned by grit blasting with Al_2O_3 were substantially higher than those produced on panels cleaned by pickling in a solution of 18 vol % hydrochloric acid;
6. the corrosion pattern was similar to that obtained in the Al_2O_3 series.

COAL AND COAL REFUSE SERIES

Washed Canmore coal and Coleman coal refuse were used in the third series. The coal and coal refuse were crushed and screened to obtain -2.36- to 0.295-mm material. Each slurry contained 2.0 kg of either coal, refuse, or 50% coal and 50% refuse in 10 L of tap water. It was necessary to reduce the liquid content in each slurry because a thick froth developed on the top. Details on panels, their arrangement in the cell and corrosion control procedures were the same as described in the quartz series except they were cleaned by procedure 2. Air agitation was also used in these experiments.

The composition of each slurry and the type of corrosion control applied are shown in Table 3. Average wear rates produced and the reductions obtained with cathodic protection are also listed.

The wear rates obtained from the coal and coal refuse series show that:

1. the wear rate produced on rotating panels with Canmore coal and tap water slurry was 28% less than that with Coleman refuse;
2. in tap water solution the wear rate produced on stationary panels with Canmore coal slurry was 59% greater than with Coleman refuse;
3. adding 2082 mg/kg (2082 ppm) SO_4^{-2} to the Canmore coal slurry increased the wear rate of the rotating and stationary panels by 461 and 968%, respectively;
4. adding 400 mg/kg SO_4^{-2} to the 50% coal and 50% refuse slurry increased the wear rate of the rotating and stationary panels by 159 and 513%, respectively;
5. adding 1550 mg/kg Cl^- to the 50% coal and 50% refuse slurry increased the wear rate of the rotating and stationary panels by 67 and 196%, respectively;
6. wear rates produced in the various coal and

Table 3 - Results of erosion-corrosion experiments with slurries of Canmore washed coal and Coleman refuse

Slurry composition	Average wear rate of rotating panels (mdd) Without protection	With protection	Reduction in wear (%)	Average wear rate of stationary panels (mmd) Without protection	With protectyion	Reduction in wear (%)
Coal and tap water	236			73		
Coal, tap water and 2082 ppm SO_4^{-2}	1343	180*	86	780	53**	93
Refuse and tap water	331			46		
50% coal 50% refuse tap water	354			55		
50% coal 50% refuse Tap water 400 ppm SO_4^{-2}	918	286*	69	337	35**	90
50% coal 50% refuse tap water 1550 ppm Cl^-	590	310*	47	163	75**	54

* Cathodic protection by impressed current

** Cathodic protection by sacrificial zinc anode refuse slurries were substantially reduced when cathodic protection was applied by either impressed current or sacrificial zinc anode (Table 3);

7. cathodic protection appeared to be more effective in reducing the wear rates in slurries containing SO_4^{-2} than in those containing Cl^-;
8. corrosion pattern was similar to the Al_2O_3 and quartz series, however, the abrasion marks were larger and deeper.

CONCLUSIONS

The test installation was found to be suitable for:

1. classifying the erosion-corrosion properties of various slurries including those containing coal and coal refuse;
2. comparing the wear rate of different materials when subjected to the same slurry conditions;
3. determining the effect of various ions in the slurry on the wear rate of metallic materials used in coal washing plants;
4. determining the effect of abrasive grain size on the wear rate of various metallic materials;
5. determining the effectiveness of corrosion inhibitors and cathodic protection in controlling corrosion in coal washing plants.

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