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EXPERIMENTAL MEASUREMENT OF ACCELERATED EROSION IN A SLURRY POT TESTER

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EXPERIMENTAL MEASUREMENT OF ACCELERATED EROSION  
IN A SLURRY POT TESTER

W. Tsai, J.A.C. Humphrey, I. Cornet and A. Levy

April 1980

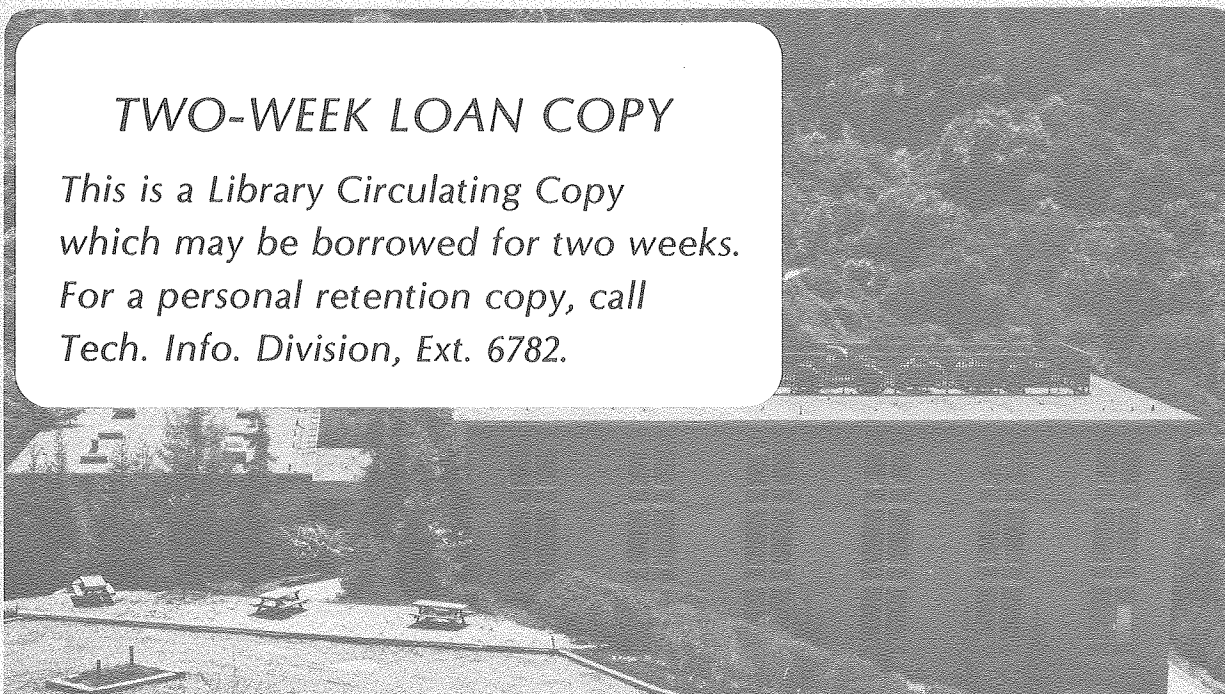
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## EXPERIMENTAL MEASUREMENT OF ACCELERATED EROSION IN A SLURRY POT TESTER

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## ABSTRACT

An apparatus is described and experimental measurements are reported for the accelerated erosion of three steel alloys by coal and silicon carbide suspensions in kerosene. The measurements are correlated on the basis of dimensional analysis considerations with empirical constants in the correlation determined through least squares polynomial regression of the data. The high speed nature of the tests yields results which are essentially independent of viscous effects in the present configuration. Various observations related to the fluid mechanics, temperature and water content of the starting coal in the particle suspension are discussed. Recommendations are made for the construction of an improved apparatus for standardized accelerated erosion testing of ductile materials.

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## NOMENCLATURE

C	Concentration ( $\text{gr}/\text{cm}^3$ )
$dC_S/dt$	Rate of erosive wear ( $\text{gr}/\text{cm}^2\text{-sec}$ )
D	Equivalent diameter (cm)
S	Yield stress or hardness ( $\text{dynes}/\text{cm}^2$ )
t	Time (sec)
V	Velocity (cm/sec)
$\delta$	Characteristic viscous layer thickness (cm)
$\Delta$	Weight loss per unit area ( $\text{gr}/\text{cm}^2$ )
$\mu$	Viscosity ( $\text{gr}/\text{cm}^2\text{-sec}$ )
$\rho$	Mass density ( $\text{gr}/\text{cm}^3$ )
$R_C$	Reynolds number and test cylinder

## SUPERSCRIPTS

*	Denotes relative to liquid phase velocity
---	---

## SUBSCRIPTS

F	Refers to liquid phase
P	Refers to solid particle phase
S	Refers to eroded metal sample

## ACCELERATED EROSION TESTING

### The Need

Slurry transport is a necessary part of coal liquefaction processes. However, the motion of suspended coal particles and various associated solid contaminants in non-aqueous liquids can be the cause for significant erosive wear in flow components such as contractions, valves, bends and tee junctions in piping and related pumping and slurry processing equipment. Although the problem of erosive wear is of considerable industrial importance there is a lack of appropriate, reliable and consistent experimental data to assist in the design and optimization of slurry transport equipment for coal liquefaction processes.

The parameters governing erosion phenomena are numerous and their relative importance in systems undergoing erosive wear varies depending on the different flow configurations and their physical characteristics. This accounts, in part, for the difficulties encountered in attempting to establish useful experiments which will simulate conditions of practical interest and also yield meaningful and reproducible data. The situation is further aggravated by the low rates at which erosive wear generally takes place in practice, requiring lengthy tests or, to reduce time of test duration for equally precise measurements, the imposition of unduly accelerated erosion conditions.

Testing under conditions of accelerated erosion is desirable because it allows the rapid accumulation of experimental results. However, in conceiving an accelerated erosion experiment care must be taken to ensure that the data derived from the experiment relates to the system of practical interest. If in some way the experiment has constraints which limit the applicability and, therefore, usefulness of the measurements, these must be known and understood.

#### Pitfalls

Various pitfalls, which are not readily obvious, beset the development of a useful accelerated erosion experiment. These relate to the question of whether or not geometrical and dynamical similarity exist between the experimental configuration and the full scale system it purports to model. A simple but significant example will clarify this point. Consider an industrial slurry flow component in which there exists a fluid layer near the component wall where viscous effects strongly influence the structure and speed of the liquid and particle motions. The thickness of this viscous layer could well be of the order of  $\delta = 100 D_p$ , where  $D_p$  is an equivalent particle diameter in the slurry flow. Under conditions of accelerated erosion in a laboratory test a geometrically similar flow component might yield  $\delta = D_p$  by retaining the original particle size distribution in the reduced scale model. In the laboratory experiment one would find that the rate of erosion is independent of  $\delta/D_p$  and, therefore, that viscous effects in the region of the eroded wall are not mitigating erosive wear significantly. It is clear that this and related results



derived from such a laboratory model really correspond to a large scale flow component in which  $\delta \approx D_p$  and not  $100 D_p$  as postulated above for the industrial component. The laboratory results then would not necessarily relate to the phenomena arising in the industrial flow component originally conceived and a more appropriate reduced scale model would be required.

#### Standardization

In conceiving an accelerated erosion experiment it must be ensured that appropriate and sufficiently accurate control is exercised over all variables affecting the experiment. For example, if small amounts of water in the starting pulverized coal strongly influence the erosive characteristics of coal particles, then accurate knowledge and control of the particle water content is imperative for a meaningful interpretation of measured results. Likewise, temperature, particle concentration and size distribution, viscosity, and particle and fluid phase velocities are important. Because the purpose of an accelerated erosion device is to force erosive wear at an accelerated rate, inadequate control of variables affecting the experiment can lead to serious measurement errors and erroneous interpretation of data. Thus, it is of utmost importance that standardization of equipment and experimental procedure be impressed upon present and, especially future, experimentation. Given the number of variables influencing erosion and the variety of complex situations where the problem arises, it is obvious that standardization of equipment and methodology can not readily nor uniformly be achieved.

The present investigation stems from the need to provide experimental information of practical value which, at the same time, will bear on some of the fundamental issues affecting erosion phenomena. The study is the result of one of several ongoing research projects presently being conducted by the Coal Liquefaction Alloy Test Program Group at the Lawrence Berkeley Laboratory and involves the experimental determination of material wear under conditions of accelerated erosion. One of the purposes of this paper, therefore, is to describe a material wear testing device that has shown considerable promise to produce data of general applicability from experiments that can be performed under standardized and carefully controlled conditions.

#### Earlier Work

There is an abundant literature on erosion-corrosion of metals by aqueous slurries. Test devices include loops (1-3) and slurry pot systems (4-6). Test loops are attractive because they include components such as pumps, valves, bends and piping which are important in process systems. Accelerated wear tests, say in 24 hours, can be obtained by means of radioactive inserts, but this technique can be hard to interpret and may be prohibitively expensive (1). More commonly, tests may require 1000 hours or more. Wear may be measured by ultrasonic thickness gage, radioactive pickup, by micrometer thickness measurements, by weighing components or inserts, by chemical analysis of the slurry, and by electrical resistance tests (on probes).

Pot tests are made in a flask or beaker in which a slurry is agitated by a propeller stirrer. Test specimens may be the stirring propeller or a small flat metal specimen placed tangent to the rotating slurry. Since these studies have generally been in aqueous systems at ambient temperatures, the corrosion component of wear has been pronounced, and corrosion behavior is often the main purpose of the test. In many pot studies the fluid mechanics are poorly defined, but this is generally recognized and improved systems have been used (7). Thus, slurry pot tests have been useful in studying corrosion-erosion of aqueous coal slurries, indicating the importance of deaeration and effectiveness and concentration of inhibitors. In fact, slurry pot tests correlate better than loop tests with field performance in coal-water slurry pipelines.

## DESCRIPTION OF THE SLURRY POT TESTER AND EXPERIMENTAL METHODOLOGY

Slurry Pot Tester

In the present work accelerated erosion conditions were attained in the 2 liter capacity slurry pot tester depicted schematically in Figure 1-a and photographically in Figure 1-b. The tester consists of a brass cylindrical tank with detachable lid of dimensions and characteristics shown in the Figures. A non-aqueous slurry of initially known physical properties was contained in the tester. It was fluidized by rotating propeller blades attached to a steel shaft aligned along the cylinder axis of symmetry. Two tubular metal samples 2" long and 1/8" o.d. (5.08 cm, 0.318 cm) were separately attached to symmetrically positioned flat side arms extending horizontally from the steel shaft. The shaft was made to rotate at a fixed r.p.m. by a 3/4 hp motor equipped with variable speed regulator. A ten tooth gear mounted on the shaft allowed measurement of shaft rotation (to within  $\pm 1$  count) by means of a magnetic pick-up connected to a digital counter. Steel baffles attached to the inside walls of the cylinder ensured good mixing of the slurry by opposing the vortical motion induced by the rotating samples and the shaft-propeller assembly.

Temperature within the tester was kept constant at  $25^{\circ}\text{C} \pm 1^{\circ}\text{C}$  by electric blanket heating combined with the flow of coolant water through a coil resting on the bottom wall of the tester. Temperature was monitored at one point in the flow by inserting a thermocouple protected by a stainless steel sheath through the tester lid.

### Experimental Methodology

Coal and silicon carbide particles were sieved on Tyler testing sieves in a Ro-tap machine to obtain the size ranges of interest in the experiment. Particle samples were dried in flat pans in an electric oven through which Argon gas flowed, for 2-4 hours at 85-95°C. A dried particle sample was immediately used to prepare the slurry mixture for an experimental run.

Two tubular metal samples were washed with acetone, dried in compressed air and weighed to within  $\pm 0.1$  mg prior to securing them between the flat side arms one on each side of the center shaft. The two samples in each test were of the same material. The shaft was then placed in the freshly cleaned tester and filled to within 1" (2.54 cm) from the tester top with a room temperature kerosene slurry of known wt% particle (solid) phase concentration. The lid was fastened to the tester and nitrogen gas was immediately made to flow over the free surface of the slurry. Seals on the lid and around the shaft, together with the injected nitrogen gas, helped to minimize corrosive effects due to the possible presence of air and humidity.

Variables controlled in the experiment were: initial particle concentration and mean particle size, type of metal sample, metal sample speed of rotation and slurry temperature. Rates of erosion were determined by measuring and averaging the weight loss of both metal tubes at periodic intervals during the course of an experimental run. These periodic interruptions were carried out carefully and with a minimum disturbance to the system. Prior to weighing the samples they were always washed in acetone and dried with compressed air.

Tests were conducted for various combinations of speed of rotation, type of steel sample, particle concentration and mean particle size and water content of the starting coal. Table 1 lists the physical properties of interest. All experiments were performed at 25<sup>0</sup>C with kerosene as the liquid phase since at higher temperatures (of more practical interest) the viscosities of the solvent refined coal process solvents and creosote oils actually used as carrier fluids in coal liquefaction processes are close to that of kerosene at 25<sup>0</sup>C.

## RESULTS AND DISCUSSION

Measurements of erosive wear in units of test sample weight loss per one-half of surface area of the test sample (the portion that the slurry particles impact) are plotted as a function of time in Figures 2-8. Results of the slurry erosion by coal particles in kerosene of 304SS, 316SS and A-53 mild steel are shown in Figures 2-4. Similar data for silicon carbide particles is shown in Figure 5. Typical results denoting the influence of particle water content, temperature and fluid mechanic behavior of the slurry in the present work are plotted in Figures 6-8, respectively.

All the erosive wear curves show similar characteristic features. While erosion increases with time the rate at which it does so decreases, indicating that the phenomenon tends to an asymptotic value. This is explained partly by the comminution of particles as they repeatedly strike the rotating test sample, the propeller blades and the walls and baffles within the container; partly by the change in specimen geometry as it erodes and partly by the possibility of work hardening of the surface. Because of these effects and the possibility of nitrogen gas inclusion in the liquid phase, it is more appropriate to use the slope of an erosion curve at  $t = 0$  as the measure for the rate of erosive wear. In actual fact a chord joining  $t = 0$  to the first data point on an erosive wear curve may be determined more precisely than the tangent at  $t = 0$  and is, therefore, a more reliable measure of the rate of erosion. This practice was followed in the correlation of empirical results discussed further below.

Figures 2-4 show erosive wear of the three steel compositions for two levels of coal concentration with a mean particle size of approximately 24  $\mu\text{m}$  at several speeds of rotation. Within this range of concentration, erosion is seen to increase with particle concentration and more non-linearly with velocity. The rates of erosion (of the three steels are nearly the same in this test series. Results for silicon carbide particles of mean size 150  $\mu\text{m}$  are given in Figure 5 for the erosion of A-53 mild steel and 304SS. The latter results are in the same pattern as the data for coal but show rates of erosion which are 40 to 100 times larger and a somewhat higher rate for the A53 mild steel. The substantial increase in erosion for the case of silicon carbide is not only due to an increase in particle size, hardness and angularity but also to an increase in density relative to coal. At equal velocities a particle of silicon carbide has more kinetic energy than one of coal of equal size and is, therefore, capable of producing greater rates of erosion. The significant increase in erosion rate at 40fps compared to 20 and 30fps for all three materials tested in coal slurries is due to a fluid mechanics effect in the slurry pot which will be discussed below.

Figure 6 shows the effect of coal particle water content on the erosive wear of A-53 mild steel and 316SS. The data indicates clearly that as little as 1 percent by weight of water in the coal particles is sufficient to reduce erosion by a factor of about 2 relative to an equivalent dry coal particle slurry. The large reduction in erosive wear may be due to cushioning or lubrication-like properties of thin



water films enveloping the coal particles. Additional and more extensive experimentation will be necessary to help understand this phenomenon.

The effect of temperature on erosion of A-53 steel is shown in Figure 7. Surprisingly, the curves indicate decreasing erosion with increasing temperature. As will be shown below, the decrease in slurry viscosity with temperature did not increase erosion. Decreased erosion with increasing temperature may be due to a surface tension effect. Reductions in slurry surface tension at higher temperature would facilitate the gradual inclusion of nitrogen gas bubbles in the slurry from the stirring action in the pot. The gas in suspension could act to "cushion" the impact of particles on the test sample, thus resulting in smaller rates of erosion. Further tests are presently under way to determine accurately whether erosion can be substantially reduced by suspending inert gas bubbles in a slurry flow.

The result of running the slurry pot tester with one and two test samples respectively in the holders is shown in Figure 8 for coal particles. Similar results were also obtained for silicon carbide particles. At 20 and 30 ft/sec (6.1 and 9.14 m/sec) Figure 8 shows small but increasing differences in the rates of erosion. The difference becomes considerable at a speed of rotation of 40 ft/sec (12.2 m/sec) and indicates a fluid-mechanical dependent phenomenon in the experiment at high velocities. This could be in the nature of vortex shedding interaction effects between sample tubes when they are present simultaneously in the pot tester. The possibility of a high

speed "cavity-induced-resonance-effect" in the slurry flow cannot be ruled out. This is not, however, in the nature of a cavitation effect since pressure reductions due to test specimen rotation were never sufficient to flash kerosene at 25<sup>0</sup>C. It is clear that additional experimentation in slurry pot testers with differing internal geometries is necessary to establish an optimized tester design.

## EMPIRICAL CORRELATION OF THE RESULTS

The experimental data of this work was correlated by reference to dimensional analysis considerations followed by least squares polynomial regression. A list of the variables considered to be of importance in determining rates of erosion in the present experiment is given in Table 2. Using dimensional analysis these variables may be combined as follows to yield a dimensionless rate of erosive wear:

$$\frac{dC_S/dt}{V_P C_P} = f \left( \frac{D_P \rho_F V_P^*}{\mu_F}, \frac{\delta}{D_P}, \frac{\rho_P}{\rho_F}, \frac{V_P^*}{V_P}, \frac{C_P}{\rho_P}, \frac{S_S}{\rho_P V_P^2}, \frac{S_P}{S_S} \right) \quad (1)$$

(1)                      (2)              (3)              (4)      (5)      (6)              (7)              (8)

In equation (1) the dimensionless groups have the physical interpretation given in Table 3.

There is evidence to suggest (11) that in liquids, for the particle ranges considered here and for fluid velocities less than about 10 m/sec, the difference between particle and fluid phase mean velocity is small, especially if  $\rho_P/\rho_F \approx 1$ . Thus, neglecting slip velocity ( $V_P^* = 0$ ;  $V_P = V$ , the fluid velocity) equation (1) reduces to:

$$\frac{dC_S/dt}{V C_P} = f \left( \frac{\delta}{D_P}, \frac{\rho_P}{\rho_F}, \frac{C_P}{\rho_P}, \frac{S_S}{\rho_P V^2}, \frac{S_P}{S_S} \right) \quad (2)$$

Further simplification of equation (2) comes as a result of noting that  $\delta/D_p \approx 1$  for the lowest velocity in the present work (3.05 m/sec). This result<sup>1</sup> suggests that viscous effects, tending to "cushion" particle impact on the surface undergoing erosion, were negligible in the present investigation. Indeed, correlations performed retaining the "impact-cushioning" number yielded worse agreement with experimental results than correlations without it. The simplest form of equation (2) excluding  $\delta/D_p$  is:

$$\frac{dC_S/dt}{V C_P} = A \left( \frac{\rho_P}{\rho_F} \right)^a \left( \frac{C_P}{\rho_P} \right)^b \left( \frac{S_S}{\rho_P V^2} \right)^c \left( 13.8 \frac{S_P}{S_S} \right)^d \quad (3)$$

The values A, a, b, c and d determined from least squares polynomial regression are given in Table 4 together with the parameter ranges covered by the experimental results. Figure 9 provides a relative indication of the goodness of fit of the regressed equation. Thus data clustered about 9.5 in the figure, corresponding to coal, has an

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<sup>1</sup>The estimate is made by taking  $\delta = C_1 (\nu R/\nu)^{1/2}$  from reference 12 where R is the sample tube radius,  $\nu$  the kinematic viscosity and  $C_1$  a constant of order unity.

<sup>2</sup>The constant 13.8 in equation (3) is a "conversion factor" between Brinell and Mohs hardness scales derived from data for gold in references 8 and 9. It is included here to ensure "dimensional" consistency. Strictly, the conversion factor is nonlinear but a more accurate determination of this parameter requires the availability of data tabulated for various materials in Brinell and Mohs units of hardness. Such data does not appear to exist.

average error of 19.4 percent while that clustered about 7.25, corresponding to silicon carbide, has an average error of 14.3 percent.

Note that  $S_S$  in

$$\frac{S}{\rho_p V^2}$$

is taken in units of dynes/cm<sup>2</sup> while it is taken in Brinell units of hardness in

$$13.8 \frac{S_p}{S_S}.$$

The coefficients in Table 4 show that the rate of erosive wear increases with  $\rho_p$ ,  $C_p$  and  $V$  increasing and with  $S_S$  and  $S_p$  decreasing. The last result is explained, in part, by the fact that hard mineral particles tend to be brittle and upon impact with a solid surface a substantial portion of their kinetic energy can go into particle comminution rather than erosive wear. It would appear that this was the case in the present work.

## CONCLUSIONS AND RECOMMENDATIONS

An experimental apparatus for the determination of accelerated erosive wear of ductile materials by solid particles has been described. The system has been used to investigate the accelerated erosion of A-53, 304SS and 316SS steels by coal and silicon carbide suspensions in kerosene at 25°C. The various effects of particle velocity, density, concentration and hardness on erosive wear were determined quantitatively. The experimental results were correlated using dimensional analysis considerations followed by least squares polynomial regression. The average predictive error of the empirical fit was found to be about 14 percent at higher rates of erosion and 19 percent at lower rates. Particle angle of attack and its influence on erosion were not considered in the study, although by virtue of the experiment, the effect is included in an integrated sense.

Relatively large changes in rates of erosion occur in the experiment as a function of particle water content, variation in temperature and fluid mechanical phenomena at high rotational velocities. These indicate clearly the need for rigorous and systematic control of all relevant experimental variables in any experiment.

It is obvious that a standardization of experimental equipment and of experimental methodologies for determining erosive wear are required. The present system, although imperfect, represents a step towards this goal. The apparatus described is in the process of being

perfected for additional and more penetrating analyses of problems related to erosive wear. Modifications include constructing a larger test chamber in which larger diameter test samples may be rotated, thus ensuring, if required, a viscous layer effect. Also considered in the improved design is the possibility of injecting measured amounts of an inert gas in the slurry to investigate its effect on erosive wear.

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Table 1. Estimated Physical Properties at 25°C.

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	Density (gr/cm <sup>3</sup> )	Average Hardness (Mohs Scale)	Equivalent Diameter (μm)
PARTICLES			
Coal	1.5	3.8*	24
SiC	3.22	9.5	150
METALS (9)			
	Average Hardness (Brinell Scale)	Average Yield Stress PSI	
A-53 (mild steel)	133	48,000 psi	
316SS	150	35,000 psi	
304SS	150	35,000 psi	
Solvent	Density	Viscosity	
KEROSENE	0.816 gr/cm <sup>3</sup>	0.816 gr/cm <sup>3</sup>	

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\*Property estimated on a wt% basis for Illinois #6 coal with the following composition: carbon 62%, SiO<sub>2</sub> 17%, Al<sub>2</sub>O<sub>3</sub> 6%, Fe<sub>2</sub>O<sub>3</sub> 6%, additional miscellaneous components including CaO and MgO amounting to 9%.

Table 2. Principle variables affecting erosive wear.

Variable	Dimensions	Units	Description
$C_p$	$M L^{-3}$	$\frac{g}{cm^3}$	Concentration of eroding particles per volume of fluid phase.
$dC_S/dt$	$M L^{-2} T^{-1}$	$\frac{g}{cm^2 \text{ sec}}$	Rate of erosive wear per unit area of eroded surface.
$\delta$	$L$	cm	Characteristic thickness of fluid layer near eroded material surface where viscous effects are important.
$D_p$	$L$	cm	Eroding particle diameter.
$S_S$	$M L^{-1} T^{-2}$	$\frac{\text{dynes}}{cm^2}$	Eroded material yield stress or Brinell hardness for metals.
$S_p$	$M L^{-1} T^{-2}$	$\frac{\text{dynes}}{cm^2}$	Eroding particle yield stress or Mohs' hardness for minerals.
$V_p^*$	$L T^{-1}$	$\frac{cm}{sec}$	Mean particle velocity relative to carrier-fluid velocity.
$V_p$	$L T^{-1}$	$\frac{cm}{sec}$	Surface normal component of mean particle velocity relative to eroded material surface.
$\rho_F$	$M L^{-3}$	$\frac{g}{cm^3}$	Mass density of fluid phase.
$\rho_p$	$M L^{-3}$	$\frac{g}{cm^3}$	Mass density of eroding particle phase.
$\mu_F$	$M L^{-1} T^{-1}$	$\frac{\text{dynes sec}}{cm^2}$	Fluid viscosity.

Table 3. Description of dimensionless parameters in equation 1.

Term	Name*	Physical Meaning
(1)	"Erosion rate" number	Mass eroded from the surface per particle impact.
(2)	Particle Reynolds number	Relative measure of inertial to viscous effects for the particles in suspension.
(3)	"Impact-cushioning" number	Argued to be a measure of the extent to which viscous effects "cushion" particle impact on the eroded surface.
(4)	"Particle inertia" number	Relative measure of particle to fluid phase density (characterizes relative inertial effects of the two phases).
(5)	"Slip" number	Ratio of particle relative velocities (characterizes slip-velocity effects).
(6)	"Energy-dilution" number	Argued to be a measure of the extent to which the fluid phase dilutes the kinetic energy content of the particle phase in suspension.
(7)	"Barrier" number	Relative measure of the "energy barrier" which suspended particles must overcome upon impact to yield conditions propitious for erosion.
(8)	"Disorder" number	Postulated as an indication of the "tendency" for erosion to occur upon impact of particles with sufficient energy to cause erosion.

\* Names in quotes have been coined by reference to physical interpretation of the respective dimensionless groups.

Table 4. Fitted coefficients and parameter ranges for equation (11).

Coefficients

$$A = 0.20 \cdot 10^{-11}$$

$$a = 6.74$$

$$b = -0.55$$

$$c = -0.36$$

$$d = -0.65$$

Parameter Ranges

$$1.79 \times 10^{-10} < \frac{dC_S/dt}{V C_p} < 9.33 \cdot 10^{-8}$$

$$1.84 < \frac{\rho_P}{\rho_F} < 3.95$$

$$9.80 \cdot 10^{-2} < \frac{C_p}{\rho_p} < 54.4 \cdot 10^{-2}$$

$$0.19 < 13.8 \frac{S_p}{S_S} < 0.99$$

$$1.08 \times 10^3 < \frac{S_S}{\rho_p V^2} < 6.19 \times 10^3$$

and

$$\frac{\delta}{D_p} \lesssim 1, \frac{D_p \rho_F V_p^*}{\mu_F} \approx 0, \frac{V_p^*}{V_p} \approx 0$$

## FIGURE CAPTIONS

Figure 1a. Slurry pot tester dimensions and characteristics.

Figure 1b. Photographic view of slurry pot tester.

Figure 2. Effect of particle concentration and rotational speed on erosion of 304SS in kerosene at 15°C;  $D_p = 24 \mu\text{m}$ .

Figure 3. Effect of particle concentration and rotational speed on erosion of 316SS in kerosene at 15°C;  $D_p = 24 \mu\text{m}$ .

Figure 4. Effect of particle concentration and rotational speed on erosion of A-53 mild steel in kerosene at 15°C;  $D_p = 24 \mu\text{m}$ .

Figure 5. Effect of particle concentration on erosion of A-53 mild steel and 304SS in kerosene, 30 wt% SiC, at 25°C at a rotational speed of 20 ft/sec (6.1 m/sec).  $D_p = 150 \mu\text{m}$ .

Figure 6. Effect of water content in coal on erosion of A-53 and 304SS in kerosene at 15°C and at a rotational speed of 20 ft/sec (6.1 m/sec). Coal 30 wt,  $D_p = 24 \mu\text{m}$ .

Figure 7. Effect of temperature on erosion of A-53 mild steel in kerosene at a rotational speed of 20 ft/sec (6.1 m/sec). Coal 30 wt%,  $D_p = 24 \mu\text{m}$ .

Figure 8. Fluid mechanic dependence of erosion on number of test specimens of 316SS in the flow; Coal 30 wt%,  $D_p = 24 \mu\text{m}$ .

Figure 9. Comparison of measured and calculated erosive wear using equation (3).

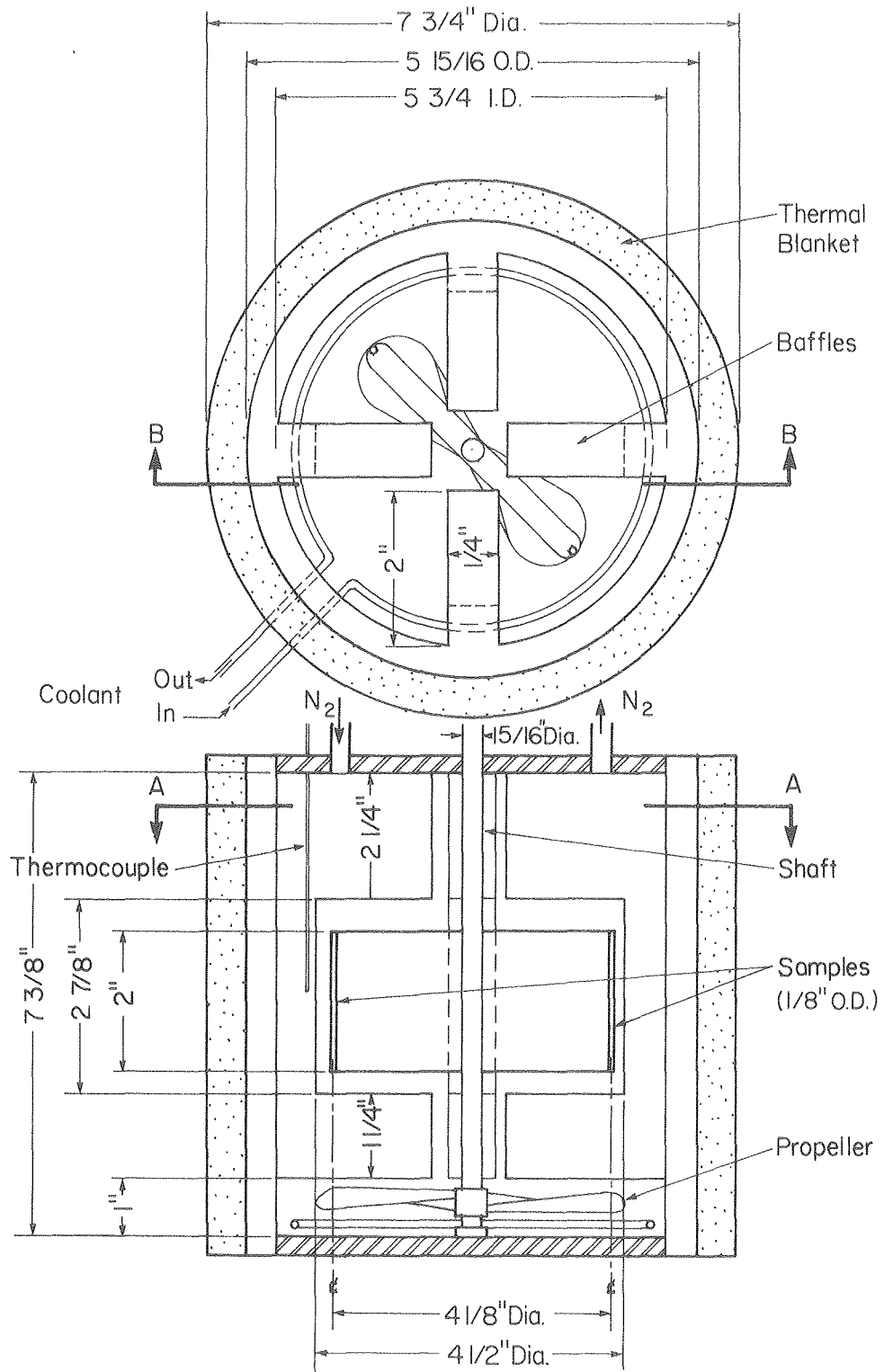


Fig. 1A

XBL 803-8458



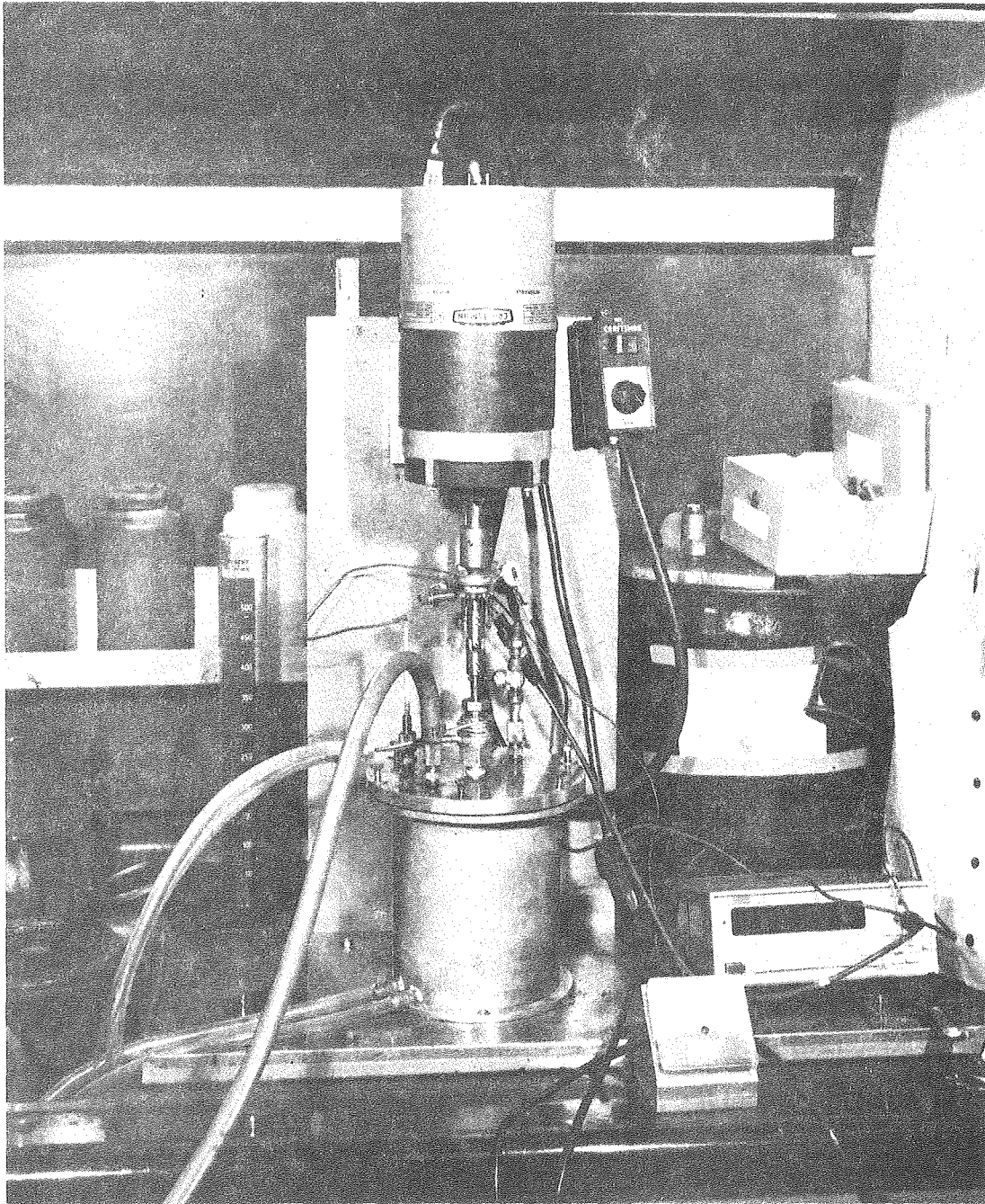


Fig. 1B

CBB 788-10553

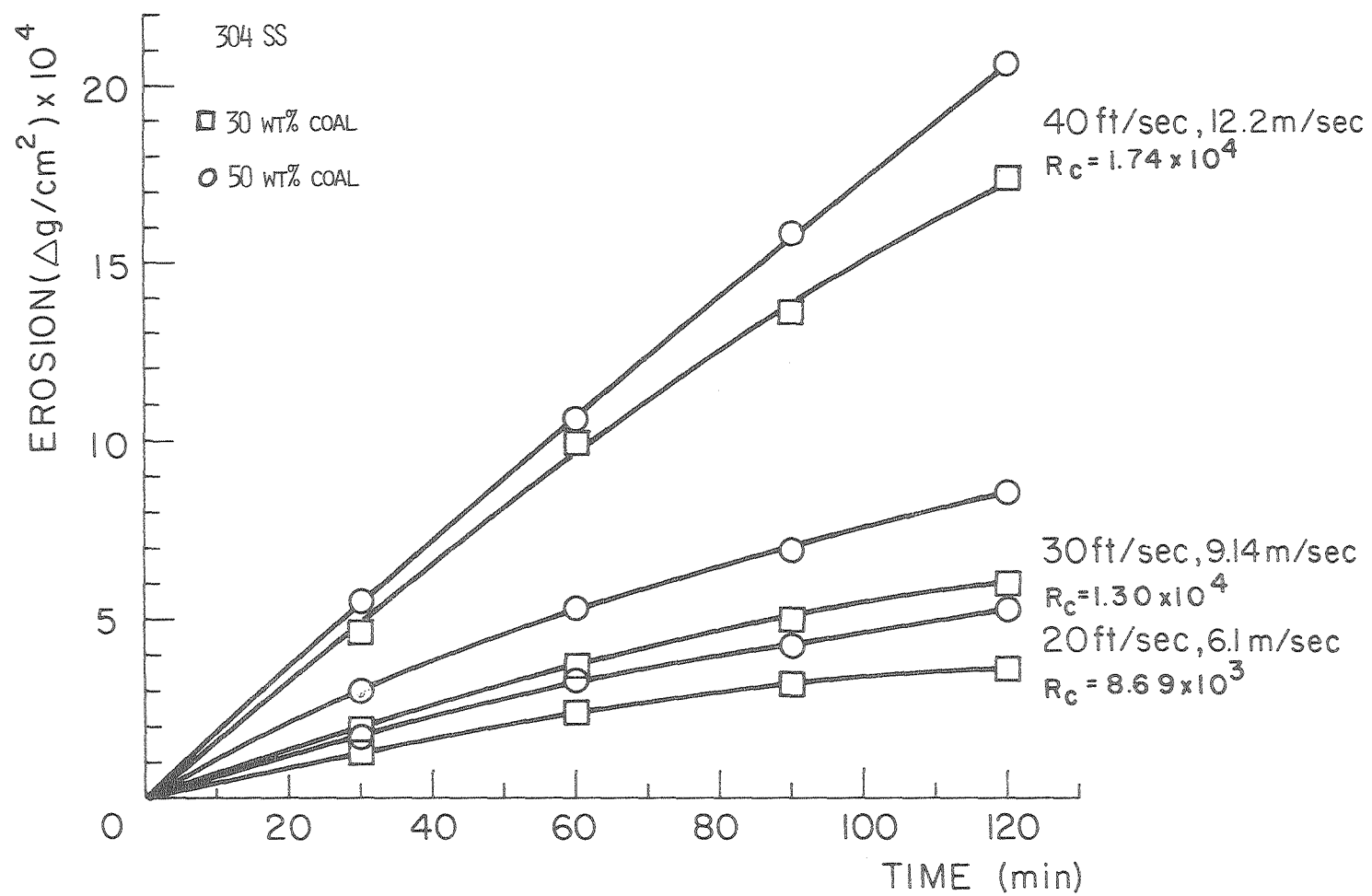


Fig. 2

XBL 803-8459

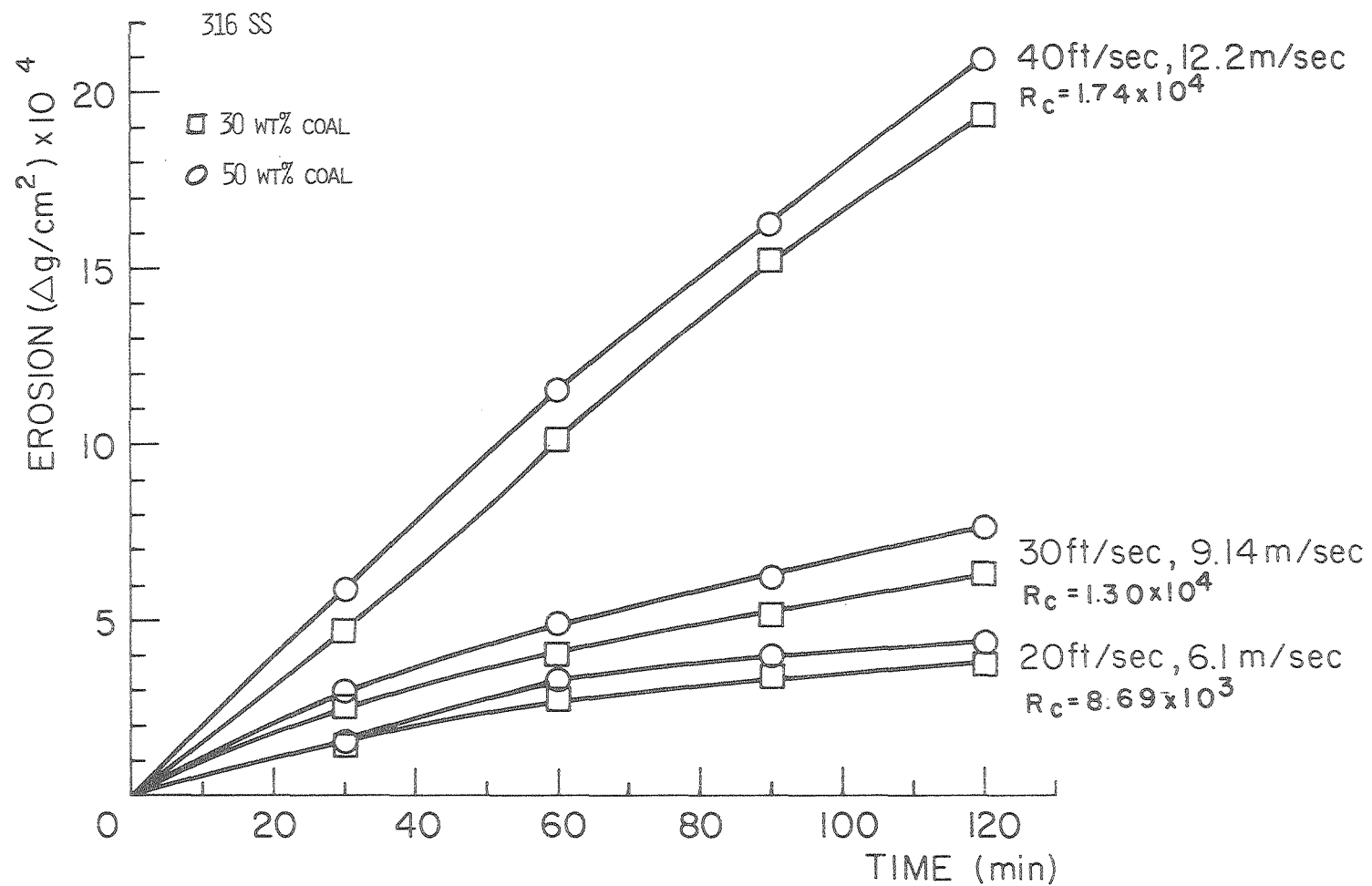


Fig. 3

XBL 803-8463

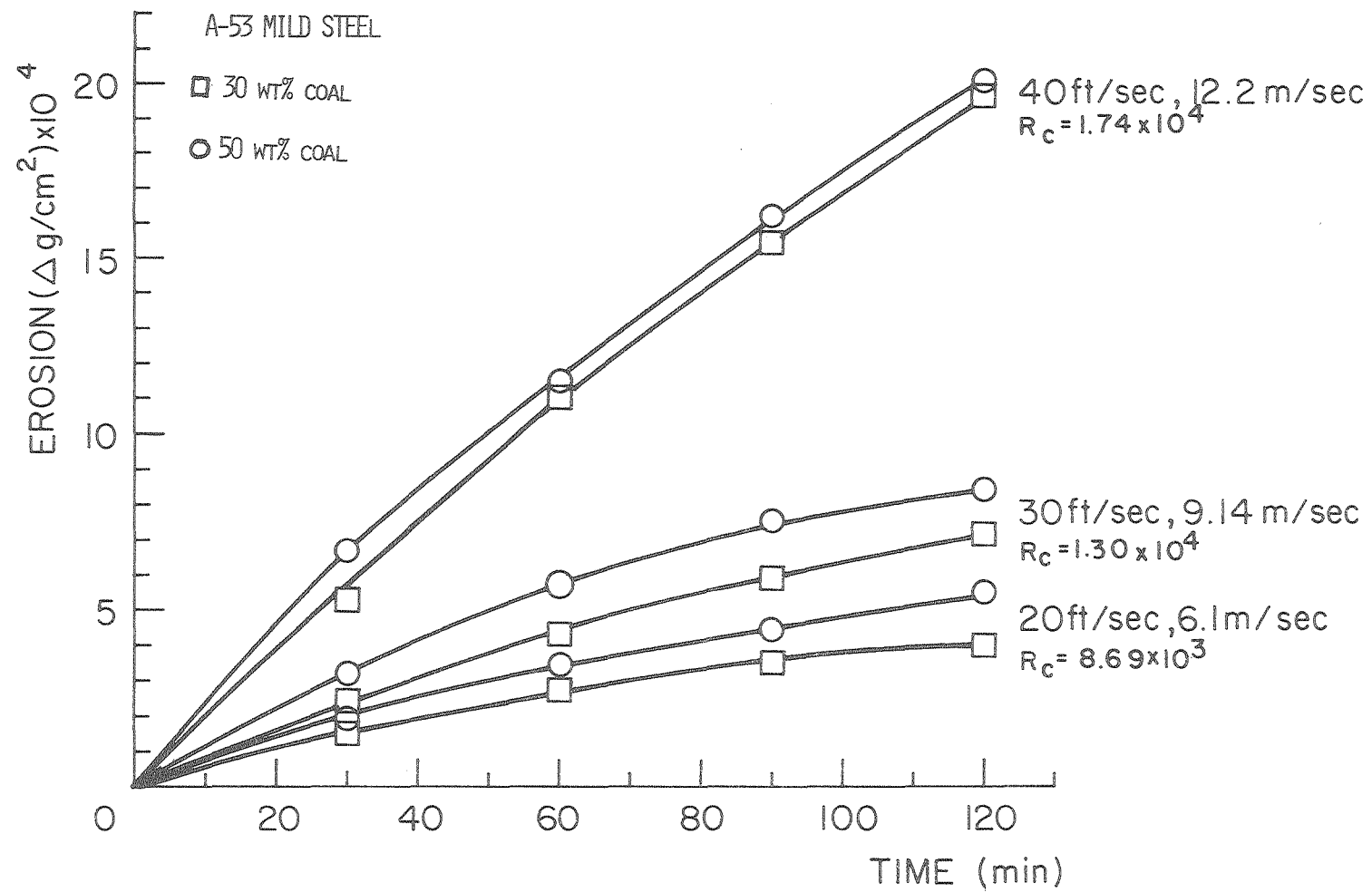


Fig. 4

XBL 803-8465

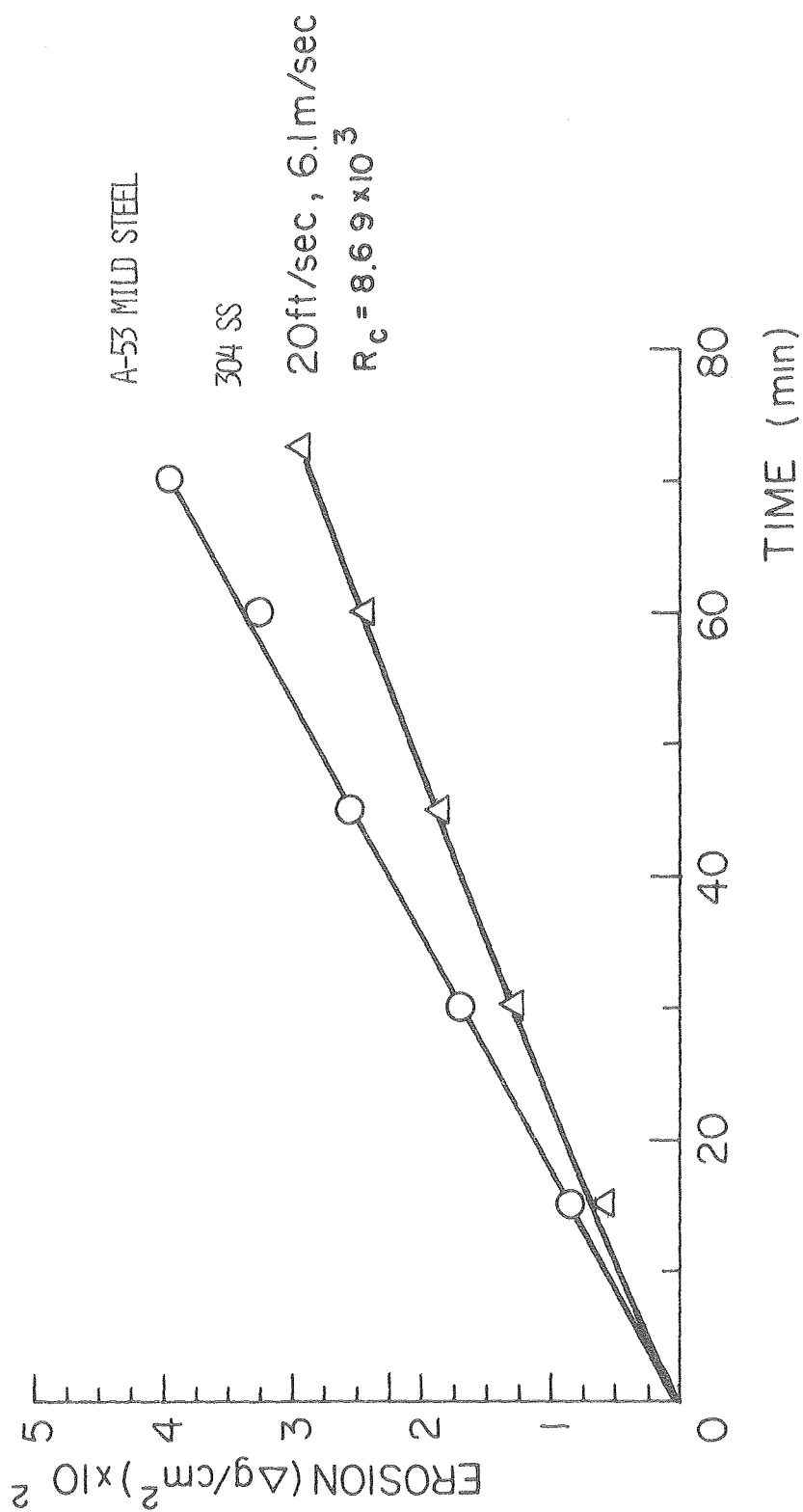


Fig. 5

XBL 803-8464

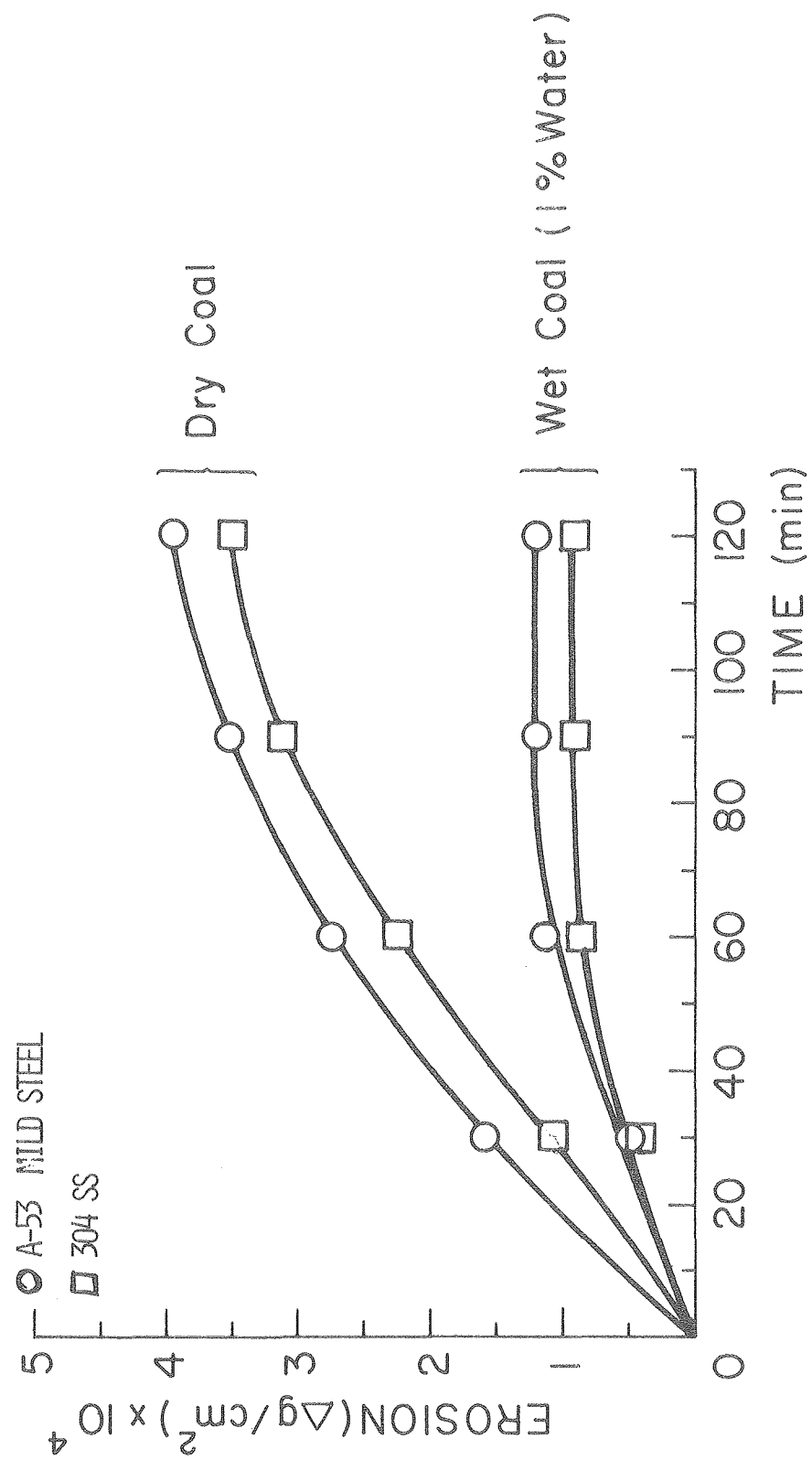
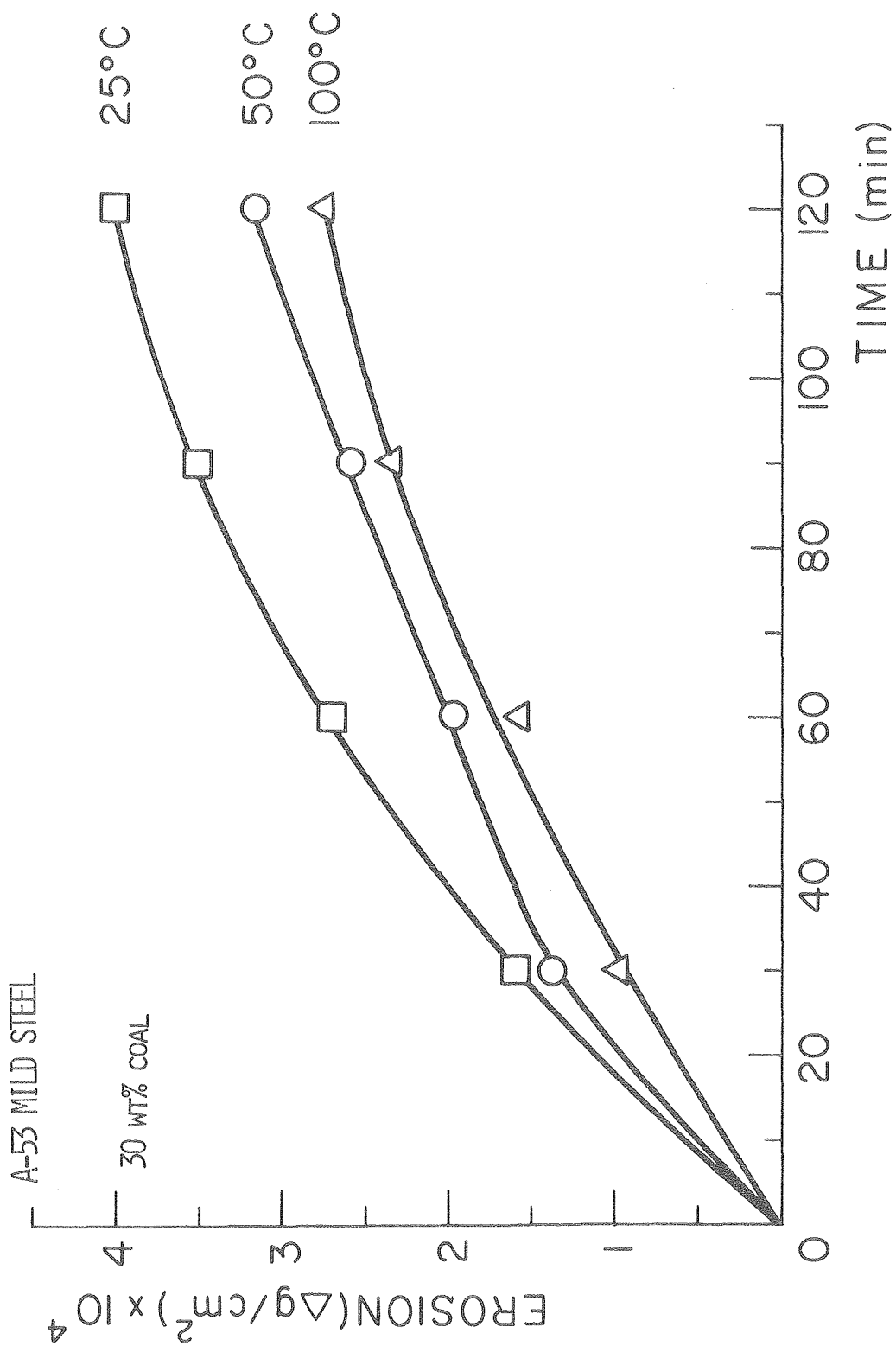


Fig. 6

XBL 803-8462



XBL 803-8466

Fig. 7

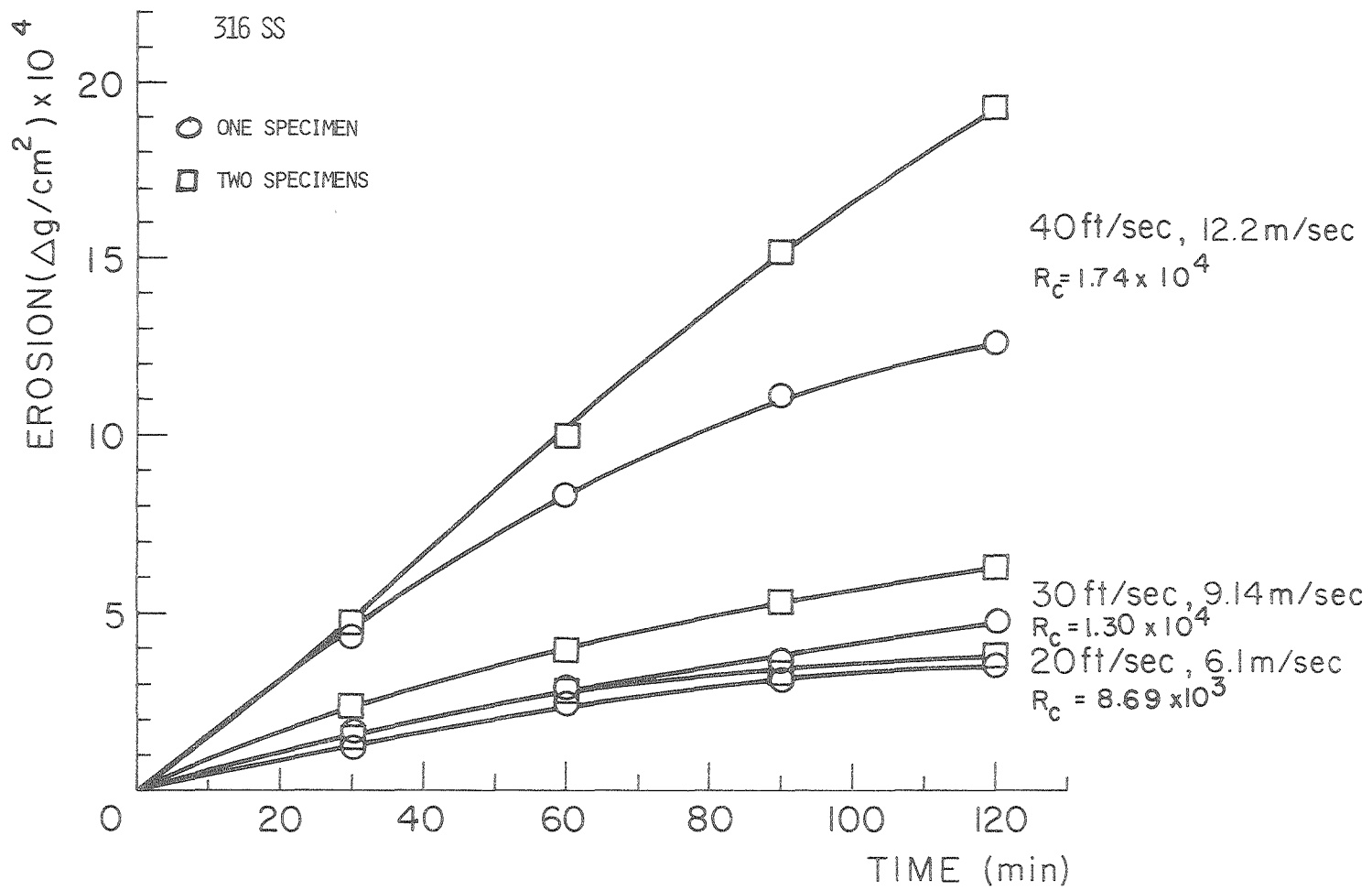


Fig. 8

XBL 803-8461



XBL801-48