Designation: G 75 – 95

Standard Test Method for Determination of Slurry Abrasivity (Miller Number) and Slurry Abrasion Response of Materials (SAR Number)[1]

This standard is issued under the fixed designation G 75; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers a single laboratory procedure that can be used to develop data from which either the relative abrasivity of any slurry (Miller Number) or the response of different materials to the abrasivity of different slurries (SAR Number), can be determined.

1.2 The test data obtained by this procedure are used to calculate either a number related to the rate of mass loss of duplicate standard-shaped 27 % chromium iron wear blocks when run for a period of time in the slurry of interest (Miller Number), or to calculate a number related to the rate of mass loss (converted to volume loss) of duplicate standard-shaped specimens of any material of interest when run for a period of time in any slurry of interest (SAR Number).

1.3 The requirement for a finished flat wearing surface on the test specimen for a SAR Number test may preclude application of the procedure where thin (0.002 to 0.005-in. or 0.051 to 0.127-mm), hard, wear-resistant coatings will not allow for surface finishing. The 6-h total duration of the SAR Number Test may not allow establishment of a consistent rate-of-mass-loss of the unfinished surface.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

G 40 Terminology Relating to Wear and Erosion[2]

2.2 *Military Standard:*

MIL-R-6855C Rubber, Synthetic, Sheets, Strips, Molded or Extruded Shapes[3]

3. Terminology

3.1 *Definitions*—Definitions used in this test method are in accordance with Terminology G 40 as follows:

3.1.1 *abrasive wear*—wear due to hard particles or hard protuberances forced against and moving along a solid surface.

3.1.2 *corrosive wear*—wear in which chemical or electrochemical reaction with the environment is significant.

3.1.3 *cumulative erosion-time curve*—a plot of cumulative erosion versus cumulative exposure duration, usually determined by periodic interruption of the test and weighing of the specimen. This is the primary record of an erosion test. Most other characteristics, such as the incubation period, maximum erosion rate, terminal erosion rate, and erosion rate-time curve, are derived from it.

3.1.4 *erosion*—progressive loss of original material from a solid surface due to mechanical interaction between that surface and a fluid, a multi-component fluid, or impinging liquid or solid particles.

3.1.5 *erosion-corrosion*—a conjoint action involving corrosion and erosion in the presence of a corrosive substance.

3.1.6 *instantaneous erosion rate*—the slope of a tangent to the cumulative erosion-time curve at a specified point on that curve.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *abrasion-corrosion*—a conjoint action involving abrasion and corrosion.

3.2.2 *mass concentration*—the mass of solid particles per unit mass of mixture, expressed in percent.

3.2.3 *Miller Number*—a measure of slurry abrasivity as related to the instantaneous rate of mass loss of a standard metal wear block at a specific time on the cumulative abrasion-corrosion time curve.

3.2.4 *SAR Number*—a measure of the relative abrasion response of any material in any slurry, as related to the instantaneous rate of mass-loss of a specimen at a specific time on the cumulative abrasion-corrosion time curve, converted to volume or thickness loss rate.

3.2.5 *slurry*—a mixture of solid particles in liquid, of such a consistency as to be capable of being pumped like a liquid.

3.2.6 *slurry abrasivity*—the relative tendency of a particular moving slurry to produce abrasive and corrosive wear compared with other slurries.

4. Summary of Test Method

4.1 The relative effect of slurry abrasivity in both the Miller Number and the SAR Number is determined by using the

[1] This test method is under the jurisdiction of ASTM Committee G-2 on Wear and Erosion and is the direct responsibility of Subcommittee G02.30 on Abrasive Wear.

Current edition approved Jan. 30, 1995. Published March 1995. Originally published as G 75 – 82. Last previous edition G 75 – 94.

[2] *Annual Book of ASTM Standards*, Vol 03.02.

[3] Available from Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.

FIG. 1 Miller Number Machine

measured mass loss of a standard-shaped metal block, driven in a reciprocating motion by a rotating crank, riding in the bottom of a tray containing the slurry. A direct load is applied to the block. For each test, the bottom of the tray is equipped with a new piece of a sheet of neoprene[4] to act as a lap. The interior of the tray has a flat-bottomed or truncated "V" shape formed by the filler, that confines the slurry particles to the path taken by the wear block. At one end of each stroke, the block is lifted off the lap by a cam action for sufficient time to allow fresh slurry material to flow under the block. The block holder is made of plastic, as are the trays, so that electrolysis inherent in certain slurries is minimized.

4.2 This test method was originally developed as a 16-h test to be run in 4-h increments. However, experience has shown that the extended test length is unnecessary and it has been established that a 6-h test, run in 2-h increments, gives essentially equivalent results. The current revision is based on the shorter test procedure.

5. Significance and Use

5.1 The Miller Number[5] is an index of the relative abrasivity of slurries. Its primary purpose is to rank the abrasivity of slurries in terms of the wear of a standard reference material. The wear damage on the standard wear block is worse as the Miller Number gets higher.

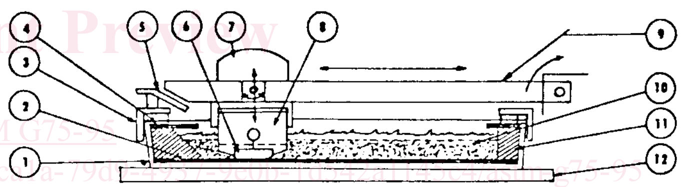
5.2 The SAR Number is an index of the relative abrasion response of materials as tested in any particular slurry of interest. The SAR Number is a generalized form of the Miller Number applicable to materials other than the reference material used for the Miller Number determination. A major purpose is to rank construction materials for use in a system for pumping a particular slurry. It can also be used to rank the abrasivity of various slurries against any selected construction material other than the reference material specified for a Miller Number determination. The slurry damage on the specimen of material being tested is worse as the SAR Number gets higher.

5.3 Experience has shown that slurries with a Miller Number or a SAR Number of approximately 50 or lower can be pumped with minor abrasive damage to the system. Above a number of 50, precautions must be observed and greater damage from abrasion is to be expected. Accordingly, the Miller Number and the SAR Number provide information about the slurry or the material that may be useful in the selection of pumps and other equipment and to predict the life expectancy of liquid-end parts of the pumps involved.

5.4 The SAR Number can be used to determine the most suitable materials for certain slurry systems.

6. Apparatus and Materials

6.1 Figs. 1 and 2 show the arrangement of a typical test machine.[6]



(1) Molded Plastic Tray
(2) Neoprene Lap
(3) Tray Clamp
(4) Splash Guard
(5) Block Lifting Cam
(6) Standard Wear Block 27 % CR-Iron
(7) Dead Weight
(8) Adjustable Plastic Wear Black Holder
(9) Pivoted Reciprocating Arm
(10) Sand Slurry
(11) Molded Plastic Filler "V" Channel Block
(12) Tray Plate

FIG. 2 Miller Machine Layout

6.2 *Description of Machine*:

6.2.1 The drive mechanism provides a horizontal reciprocating harmonic motion to the block arm of 200-mm (8-in.) travel. The arm is freely pivoted to a crosshead at a point that results in the arm being parallel (level) to the crosshead ways in the operating position. The crosshead is connected to a crank, rotating at 48 r/min, by an appropriate connecting rod.

6.2.2 The apparatus includes two operating arms for an averaging effect and as a check on the accuracy of measurements. It is possible to combine four arms on one machine so that two simultaneous tests can be run.

[4] Neoprene is a registered trademark of E. I. du Pont de Nemours and Co., Wilmington, DE 19898.

[5] "The Miller Number—A New Slurry Rating Index," *AIME Paper 73-B-300*, SME Meeting, Pittsburgh, PA, 1973.

[6] Machine and parts, including laps and wear blocks, are available from Falex Friction and Wear Test Machines, 2055 Comprehensive Dr., Aurora, IL 60505.

6.2.3 Each arm is loaded with a mass so that the total downward force on the face of the wear block is 22.24 N (5 lb).

6.2.4 A cam is provided on the tray clamp to momentarily lift each arm at the end of a stroke a distance of 0.8 mm (1⁄32 in.) off the rubber lap.

6.2.5 Plastic trays about 50 mm (2 in.) wide by 381 mm (15 in.) long by 50 mm (2 in.) high are used. A separate tray is required for each arm.

6.2.6 A special reinforced molded elastomeric filler is used to hold the lap in place in the bottom of the tray and to provide a V-shaped flat-bottom trough for the length of the wear block travel. There is a slope of 45° at the cam end of one stroke to generate a surge or back flow of fresh slurry under the lifted block. This filler is shown in Fig. 3.

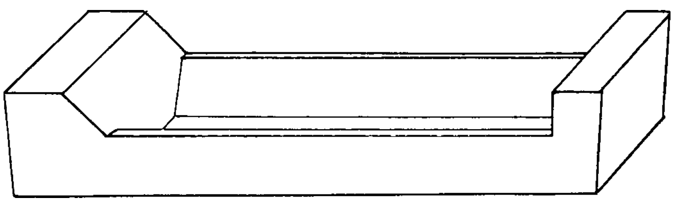


FIG. 3 Tray Filler

6.2.7 A block or specimen holder is machined from plastic to about 50 mm (2 in.) by 50 mm (2 in.) by 12.7 mm (½ in.) with a height-adjusting system and a slot to hold the block and a clamp-bolt to hold the block in alignment. See Fig. 4.

6.2.8 The holder is mounted on the arm in such a manner as to allow adjustment of the block vertically and to establish parallelism with the flat rubber lap.

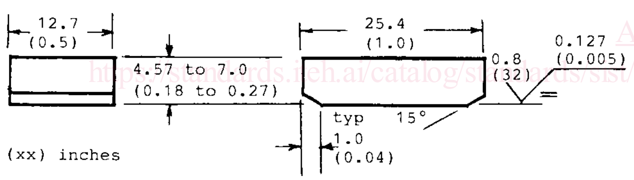


FIG. 4 Wear Block or Specimen Dimensions

6.2.9 Except for the block or specimen and stroke length, dimensional tolerances of the machined parts are not critical and the tolerances can be in the order of 0.5 % total.

6.3 The reference material[7] for the Miller Number is a proprietary alloy[8] of the type commonly used in pipeline applications. The nominal composition of this chromium-iron wear block reference material is: Carbon-2.5 %, Manganese-1.0 %, Silicone-0.6 %, Nickel-0.25 %, Chromium-28 %, Molybdenum-0.3 %, Vanadium-0.8 %, Iron-balance.

6.3.1 The material is obtainable in the form of a centrifugally cast cylinder, approximately 183-mm outside diameter by 152-mm inside diameter by 305 mm long (7.19-in. outside diameter by 6.00-in. inside diameter by 12 in. long).

6.3.2 In this case the following heat-treat procedure and specimen preparation procedure should be followed:

6.3.2.1 Anneal 24 h, turn and bore, approximately 179-mm outside diameter by 164-mm inside diameter (7.06-in. outside diameter by 6.44-in. inside diameter).

6.3.2.2 Heat to 1010°C (1850°F), 60 min.

6.3.2.3 Air cool, hardness 59 to 60 HRC.

6.3.2.4 Grind to approximately 178-mm outside diameter by 165-mm inside diameter (7.00-in. outside diameter by 6.50-in. inside diameter).

6.4 Using an abrasive wheel or wire EDM, cut 25.4-mm (1.0-in.) lengths or "rings" from the cylinder. Cut the rings into 15-mm (0.6-in.) wide segments. Grind the segments to the shape shown in Fig. 4.

6.5 As a final finish on the wearing surface, wet grind on 320-grit silicon carbide paper to remove machining damage.

6.6 The lap is a 3.18-mm (⅛-in.) thick sheet, 2¼-in. wide by xxx in. long. of molded neoprene rubber specified as a MIL-R-6855C, Class 2, Grade 80.

6.7 The SAR Number test specimen of any selected candidate material is machined and ground to the shape shown in Fig. 4.

7. Preparation of Apparatus

7.1 The following detailed description of the setup of the apparatus for the start of the test is appropriate for the commercially available unit. For other apparatus the procedure should be followed as closely as possible, particularly to ensure the alignment required.

7.2 *Wear or Specimen Block Preparation*:

7.2.1 Prepare duplicate wear or specimen blocks for each test. The blocks, polished or ground flat on the wearing surface, should be permanently marked with an identification mark or number on one side.

7.2.2 The block holders are designed to be adjustable so as to accept a block of any thickness up to about 10 mm (⅜ in.); therefore, it is possible to rework the wear blocks and realize many more runs, (except, of course, for coated or plated specimens).

7.2.3 The blocks are demagnetized initially so as to minimize the magnetic effects in precision weighing and possible effects in a magnetic slurry. Place the demagnetizer pole tip against the block. Move the tip over the entire block for a few seconds. Then move the demagnetizer slowly away and disconnect it from the power. Slow removal of the demagnetizer is particularly important.

7.2.4 Scrub the blocks with detergent and water, rinse and dry with a clean cloth, then place under a heat lamp or blow dry for about 5 min. Immediately after cooling, weigh each block to 0.1 mg and record the data.

7.3 *Preparation of Duplicate Trays for Each Test*:

7.3.1 Temporarily set the trays on the machine with those two on the front having the interlocking edge facing frontward and those on the rear with the interlocking edges facing rearward. This provides a stable support for the straight-edge check to follow.

7.3.2 Place new neoprene laps in the trays, after removing any protective coating prior to installation. Install a tray filler, (Fig. 3), with tapered or sloping end toward the left hand (Fig.

[7] Specimen available from White Rock Engineering, Inc., P.O. Box 740095, Dallas, TX 75374.

[8] Proprietary of Woolley Tool and Manufacturing Co., P.O. Box 3505, Odessa, TX 79760.

1) of the machine. Then install the splash guards. Temporarily install the right and left tray clamps and move the trays so that the projections fit into tray-ends. Then tighten the nuts against the clamps.

7.4 *Installation of Wear or Specimen Blocks*—Duplicate blocks are installed in two selected holders. Place the arms on the rack as shown in Fig. 5. Place the block in the jaws of the holder (see Fig. 6) with wear surface up and with identification mark facing the operator. Lightly tighten the clamp bolt until the block is snug. Tap the block lightly with a plastic hammer or wooden block to seat it firmly. Block alignment can be obtained by the use of the mounting jig furnished with the machine (Fig. 7). Raise the block or specimen with the set-screw so that the block-face is snug against the jig face. Tighten the clamp bolt.

7.5 *Final Block Alignment Check*—Slightly wet the surface of the block with an inked stamp pad and lower it onto a strip of white paper placed in the bottom of the tray (a simple check for block alignment). A full "imprint" of wetness should show on the paper.

7.6 *Drying Solids*—Dry, unwashed solids should be used to make the slurry. The moisture of the solids must be brought to equilibrium with the atmosphere by exposing a thin layer of the sample to air at room temperature for 24 h. Do not allow the temperature of the sample to exceed 20°F over room temperature. Sometimes a ready-mixed slurry may be furnished that will be run as-received and so noted.

7.7 *Filling Slurry Trays*:

7.7.1 *Miller Number*—Fill trays with the slurry to be tested. Each tray holds approximately 300 mL (10.6 fluid oz) of slurry and care should be taken to see that the proper concentration of slurry is maintained in transferring a mixed slurry from the container to the trays. It is usually more desirable to weigh out the dry material and the liquid and mix them directly in the trays to the 50 % by mass of dry solids required for the Miller Number. The usual mixture is 150 g of (5.3 oz) solids and 150 g of distilled water (or liquid specified, corrected for specific gravity). With some low-density solids, the proportion may be reduced to 100 g (3.5 oz) of solids and 100 g of liquid to prevent splashing.

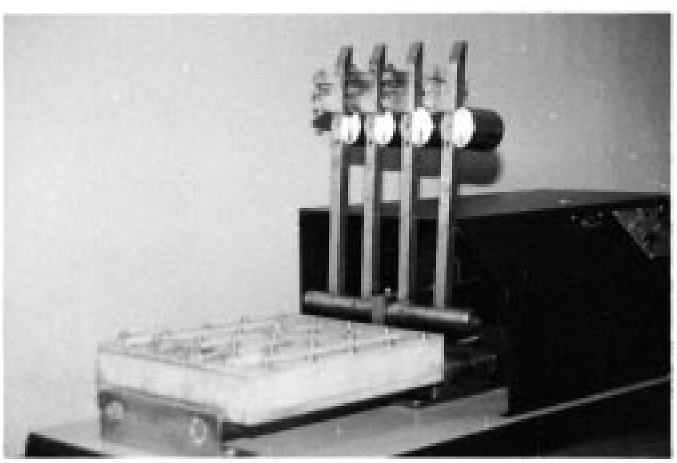


FIG. 5 Arms in Racked Position

7.7.2 For the SAR Number, the solids concentration and liquid are usually specified by the user or the already mixed slurry may be furnished. If a dry material sample is supplied, and no mixing instructions are furnished, distilled water should be used to mix a 50 % concentration and so noted in the report.

8. Procedure

8.1 Start the test with the mounted blocks placed in the trays. Make the first run for 2 h of uninterrupted testing, at which time the machine is stopped. Lift the arms from the trays and tilt back onto the rack. Remove the wear or specimen blocks, scrub in detergent and water, rinse and dry under a heat lamp or in an oven about 175°C for 15 min, weigh, and record.

8.2 Replace the blocks in the same holder, but with the identification number now facing away from the operator. (Alternating the orientation of the wear blocks in this manner for each of the three 2-h runs provides an averaging of the wear pattern.) Carry out the alignment procedure in accordance with 7.4.

8.3 Using a suitable paddle, remix any settled slurry in each tray before each 2-h run.

8.4 Three 2-h runs duplicated as in 8.1-8.3 constitute a complete test. Record the wear block or specimen mass loss for each run. The calculated rate of mass loss is an adequate measure of the effect of life of pump parts and pipeline. Accordingly, the Miller Number and the SAR Number are based on this rate of mass loss.

8.5 Record the final appearance of the worn lap wear in five degrees, namely:

8.5.1 *Trace*—Perceptible, track dulled,

8.5.2 *Light*—Mostly scratches or striations,

8.5.3 *Moderate*—Wear path less than 0.4 mm (1/64 in.) deep,

8.5.4 *Heavy*—Wear path less than 0.8 mm (1/32 in.) deep, and

8.5.5 *Severe*—Wear path 0.8 mm (1/32 in.) deep or greater.

8.5.6 In most cases, there is only a trace of lap wear, but a few slurries may cause more than usual wear.

9. Calculation of Results

9.1 *Miller Number (Also proceed through* 9.3 *for SAR Number)*:

9.1.1 The wear or specimen block mass loss, (the average of two runs in a typical slurry), is recorded. For example, see Table 1.

TABLE 1 Test Data

Wear Specimen	142		143	
	Mass, g	Cumulative Loss, mg	Mass, g	Cumulative Loss, mg
Initial	16.2810	0.0	16.2670	0.0
After 2 h	16.2723	8.7	16.2580	9.0
After 4 h	16.2668	14.2	16.2500	17.0
After 6 h	16.2594	21.7	16.2406	26.4

FIG. 6 Wear Block or Specimen Holder

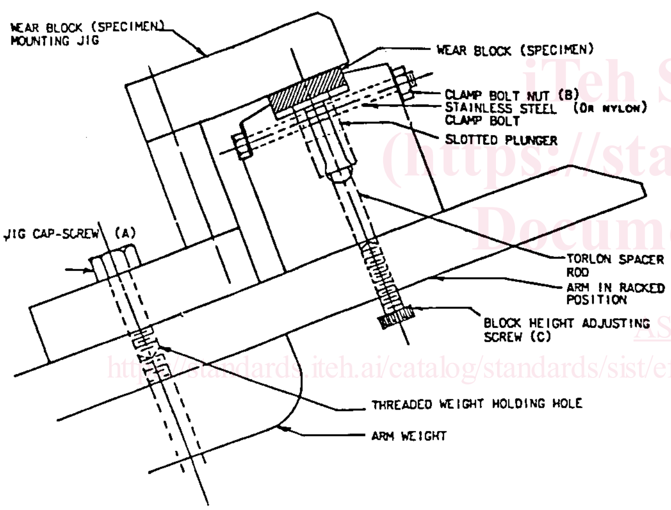


FIG. 7 Wear Block or Specimen Mounting Jig

The basic mathematical equation for a curve-fit of the data is:

$$\text{cumulative}-\text{mass}-\text{loss, mg} = At^{B} \quad (1)$$

where:
t = time, h

9.1.2 Using the least squares method, the values of A and B are calculated for the curve closely matching the test data curve. In this example, the following values are determined: $A = 4.38$ and $B = 0.943$.

9.1.3 The Miller Number and the SAR Number are described as indexes related to the rate at which the wear block or specimen loses mass at 2 h into the test, which can be calculated by using the first derivative of (Eq 1) at 2 h. This becomes the slope of the line tangent to the curve at 2 h as seen in (Eq 2):

$$\text{mass}-\text{loss}-\text{rate, mg/h} = A \times B \times t^{(B-1)} \quad (2)$$

For the example: mass loss rate $= 12.72 \times 0.72 \times 2_{(0.72-1)} = 7.5$ mg/h.

9.1.4 It is desirable to have a meaningful whole number for the expression of the abrasion-corrosion effects is used to force the Miller Number results to be 1 for sulfur and 1000 for 220-mesh Corundum.

9.2 An optional computer program for calculating results is given in Appendix X1.

9.3 *SAR Number*—The SAR Number is obtained simply by multiplying the Miller Number value by the ratio of the standard wear block material's specific gravity (7.58) to the specific gravity of the specimen material. For example, if the same mass losses were observed in a test run with specimens of 304L stainless steel which has a specific gravity of 7.95, the SAR Number would be:

$$\text{SAR Number} = \text{Miller Number} \times (7.58/\text{SG specimen}) \quad (3)$$

For the example: SAR Number = 136 × (7.58/7.95) = 130 (rounded to nearest integer).

10. Report

10.1 A sample laboratory test data recording form is shown in Fig. 8.

10.2 An acceptable report in the form of a computer printout is illustrated in X1.2 and X1.3.

11. Precision and Bias

11.1 The range of Miller Numbers encountered in practice is quite wide. Table 2 shows some examples of Miller Numbers for some slurries.

11.2 *Precision*:

11.2.1 The precision of this test method for measuring the Miller Number or SAR Number has been demonstrated in an interlaboratory test as shown in Table 3. Results obtained show that a coefficient of variation (C.O.F.) of 5.8 % was obtained for the Miller Number tests and 11.8 % for the SAR Number tests.

Project	—Test Number	:	________
	—Date	:	________
	—Description	:	________
Slurry	—Description	:	________
	—Concentration (S)	:	________
	—Temperature	:	________ °C
Wear Specimen	—Description (S)	:	________
	—Specific Gravity	:	________
	—Hardness	:	________ Rc
Lap Material	—Description (S)	:	________
	—Wear	:	Trace Light Moderate Heavy Severe

Tray	—	(________)	(Wear Specimen : ________)		(Corrected Specimen : ________)	
		(pH)	(Mass	Mass Loss)	(Mass	Mass Loss)
Initial	—	________	________		________	
First 2 Hours	—	________	________	________	________	________
Second 2 Hours	—	________	________	________	________	________
Third 2 Hours	—	________	________	________	________	________
Total	—			________		________
Notes	—	________				
Notes	—	________				

Tray	—	(________)	(Wear Specimen : ________)		(Corrected Specimen : ________)	
		(pH)	(Mass	Mass Loss)	(Mass	Mass Loss)
Initial	—	________	________		________	
First 2 Hours	—	________	________	________	________	________
Second 2 Hours	—	________	________	________	________	________
Third 2 Hours	—	________	________	________	________	________
Total	—			________		________
Notes	—	________				
Notes	—	________				

FIG. 8 Test Data Recording Form

TABLE 2 Examples of Miller Numbers for Some Slurries

NOTE 1—Generic minerals from different sources differ greatly in abrasivity.

Material	Miller Numbers
Alundum 400 mesh	241
Alundum 200 mesh	1058
Ash (fly)	83, 14
Bauxite	9, 22, 33, 45, 50, 76, 134
Clay	34, 36
Coal	6, 7, 9, 10, 12, 21, 28, 47, 57
Copper concentration	19, 37, 58, 68, 111, 128
Gypsum	41
Iron Ore	28, 37, 64, 79, 122, 157, 234
Kaolin	7, 7, 30
Lignite	14
Limestone	22, 27, 29, 30, 33, 39, 43, 46
Limonite	113
Magnetite	64, 67, 71, 134
Mud, drilling	10
Phosphate	68, 74, 84, 134
Potash	0, 10, 11
Pyrite	194
Sand/sand fill	51, 59, 75, 85, 93, 116, 138, 149, 246
Shale	53, 59
Sewage (raw)	25
Sulfur	1
Tailings (all types)	24, 61, 76, 91, 159, 217, 480, 644

11.2.2 Note that the data also shows the extent of deviation between the duplicate first 4-h runs, Tray 1, and Tray 2. The greatest deviation is shown with a coefficient of variation of 9.7 % for Test Number RM-2 (see Table 3 and X1.9).

11.2.3 The interlaboratory data are described in detail in X1.4-X1.9.

11.3 *Bias*—The procedure for the test method of measuring Miller Number or SAR Number has no bias because the value of the abrasivity can be defined only in terms of a test method.

12. Keywords

12.1 Miller Number; SAR Number; slurry abrasivity; slurry material wear

TABLE 3 Interlaboratory Tests

DECEMBER 1985							
Miller Number-27 % Chrome Iron in AFS 50–70 Sand Slurry							
Test Number	Company	Losses, mg Tray 1	Tray 2	Mean	Deviation	Coefficient of Variation, (C.O.F.), %	Miller Number
RM-1	A	34.4	33.0	33.7	1.0	2.9	139
RM-2	B	38.5	33.5	36.0	3.5	9.7	154
RM-3	C	39.2	35.7	37.5	8.5	6.7	154
						Standard deviation	8.7
						mean	149
						C.O.F. (%)	5.8
SAR Number—D2 Tool Steel in AFS 50–70 Sand Slurry							
Test Number	Company	Losses, mg Tray 1	Tray 2	Mean	Deviation	Coefficient of Variation, (C.O.F.), %	SAR Number
RS-1	A	32.4	32.2	32.3	0.1	0.4	135
RS-2	B	36.5	36.3	36.4	0.1	0.4	153
RS-3	C	43.6	41.9	42.8	1.2	1.2	171
						Standard deviation	18.0
						mean	153
						C.O.F. (%)	11.8

ANNEXES

(Mandatory Information)

A1. DISCUSSION OF FACTORS AFFECTING SLURRY ABRASIVITY

A1.1 *Abrasive*—The abrasivity of a slurry is a function of the concentration of the solids in the liquid vehicle and of the following characteristics of the solid particles:

A1.1.1 Hardness,

A1.1.2 Size,

A1.1.3 Shape,

A1.1.4 Size Distribution, and

A1.1.5 Friability.

A1.1.5.1 The variation in Miller Number in certain generic minerals such as coal can be considerable. Coal, for instance, can have from 5 to 25 % ash (the most abrasive constituent) and even the type of ash can vary from soft calcareous to hard and sharp siliceous and pyritic. The same holds true for many minerals, such as bauxite.

A1.2 *Slurry Concentration:*

A1.2.1 The intent of the Miller Number is to compare the relative abrasivity-corrosivity of slurries caused by the solids that make up those slurries. Certain standards had to be adopted for this reason. A solids concentration of 50 % by mass for the Miller Number test sample was chosen partly because most slurry projects deal with similar concentrations and partly because the higher concentration reduces the error of measurement. Early in the development of the test, the question of concentration was considered and preliminary tests were run with variations. Fig. A1.1 shows that above a certain value, the concentration of the solids has less effect on the Miller Number. This can be readily understood when it is realized that one is looking at the effect of particle size, shape, hardness, and distribution. These are factors that affect the relative abrasivity of the slurry, and it is generally accepted that above a certain low minimum concentration of solids, reciprocating pump part's life is not so much related to concentration as to the other physical characteristics mentioned. For instance, the sand content of drilling mud must be reduced to less than 2 % before an appreciable savings in pump part's life can be realized.

A1.2.2 Fig. A1.1 shows that the change in Miller Number in a sand test from the standard 50 % to a 12 % test concentration is only about 15 %. However, the abrasivity then rapidly drops from that relatively high value at 12 % concentration to zero at zero concentration. Accordingly, it is not meaningful to run Miller Number tests with extremely low concentrations. Even in the case of typical low-concentration slurries like mine water or mill water, it is desirable to run these at the standard 50 % concentration of the dry solids.

A1.3 *Particle Size and Shape:*

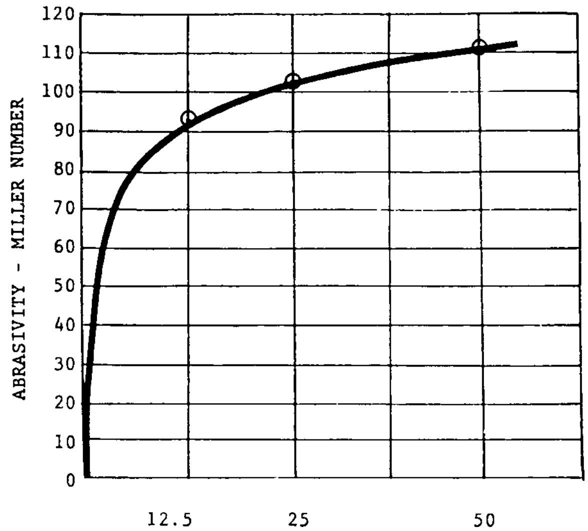
A1.3.1 The size and shape of the solid particles have a profound effect on slurry abrasivity. For example, Fig. A1.2 shows the particle shape and relative size of several sources of silica sand. Note the variation in Miller Number with respect to the general appearance.

A1.3.2 Considerable work is being undertaken in the matter of the effects of particle size and shape but in the meantime, The Miller or SAR Number will reveal the effects of the combination of the two factors.

A1.4 *Corrosion*—The effects of abrasion and corrosion must be considered in the selection of materials for pumps and equipment for slurry pumping. There is no doubt that the combination of abrasion and corrosion is much more severe in regard to metal-loss than either alone. The insidious aspect in the pumping process is that the products of corrosion, that may otherwise provide protection, are rapidly removed by abrasion. This presents a fresh surface to the effect of corrosion, thereby exacerbating the situation. The chromium iron used for the Miller Number wear blocks is in itself somewhat corrosion-resistant, but in certain ores, particularly those containing copper, a great deal of metal loss can be attributed to pitting corrosion, no doubt due to the fact that by nature the slurry carries considerable oxygen (air) from agitation both in the tests and in actual pumps. From one standpoint, the Miller test could be run without regard to corrosion, but for practical reasons it is best to try to separate the effects if possible. For example, the effects of acid corrosion can be greatly inhibited by a strong dose of NaOH, to a pH of over 13. If corrosion is suspected, it is best to run two different tests, one sample unaltered and the other inhibited. The results will give a clue as to the true abrasivity and the significance of corrosion. For example, the Miller Numbers for different samples are shown as follows for a particular copper ore. It will be seen that the high abrasivity in the uninhibited sample is due to the typical combination of abrasion and corrosion.

Sample	pH	Miller Number
No. 3	5.9	117
No. 3 NaOH Inhibited	13 +	33

A1.5 *Oil-Mixed Slurries*—Oil-mixed slurries run on the Miller Number System exhibit a lower mass loss than the same solids in a water-mixed slurry. For example, a 70-mesh sand run for one hour with chromium-iron wear blocks showed the following results: with water-mixed slurry, 13.4 mg loss; with oil-mixed (No. 6 Fuel) slurry, 0.8 mg loss. In another case, a spent industrial waste containing diatomaceous earth mixed with oil showed no wear block loss at the end of four hours, but the same material washed in solvent and remixed to the same concentration in water showed 4.2 mg loss. Consequently, the fluid nature of the slurry should also be considered in application of the Miller Number. In addition, since the neoprene laps furnished for the Miller Number are coated with protective paraffin, it is important that such laps be thoroughly cleaned so that a residue of wax does not interfere with the accurate abrasivity measurement, particularly with low-abrasivity materials.



Solids Concentration—Percent by mass
Example—70 mesh urn sand
Data Points—12.5 %-94; 25 %-104; 50 %-112
Showing the abrupt change in the relationship of solids concentration to abrasivity in the region below about 10 to 12 % solids

FIG. A1.1 Solids Concentration Versus Abrasivity

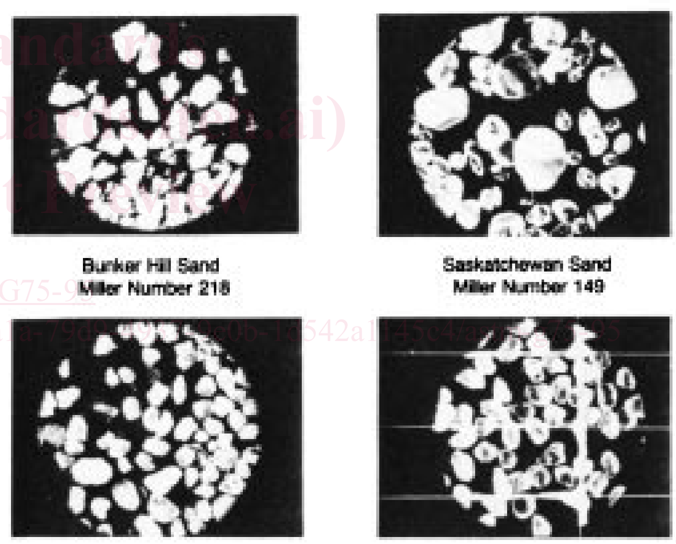


FIG. A1.2 Abrasive Particles

A2. DEPARTURE (See Fig. A2.1.)

A2.1 The cumulative wear block mass losses recorded for any particular test very seldom follow a linear relation to time. Sometimes the rate of weight loss decreases indicating that the slurry abrasivity decreases with time or, in a sense, the slurry particles wear out with time. However, some slurries show an actual increase in abrasivity. For example, the rate of mass loss increases with time. Such a phenomenon is described as *departure* from the Miller Number and the SAR Number. The departure is the percentage rate of change of the mass loss as calculated by the following formula, being minus (−) if decreasing and plus (+) if increasing:

$$\text{Departure} = \frac{A \times B \times (B-1) \times t^{(B-2)} \times 100}{A \times B \times t^{(B-1)}} \qquad \text{(A2.1)}$$

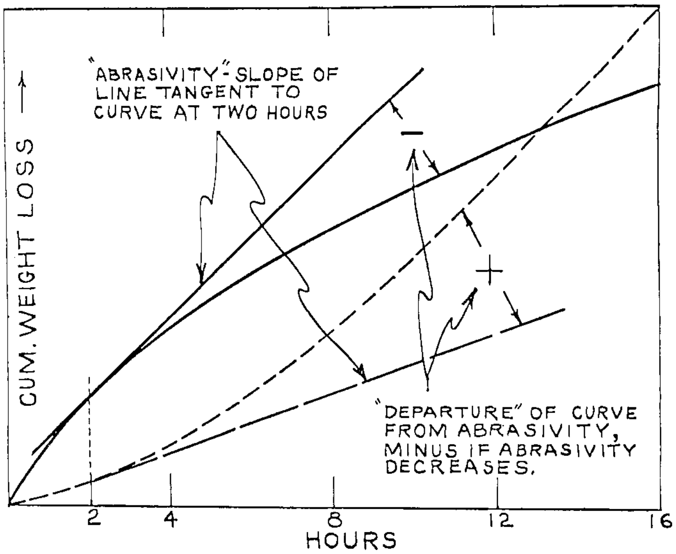


FIG. A2.1 Departure

where:
t = time, h

A2.2 In the example, used in Section 9:

$$\text{Departure} = \frac{12.72 \times 0.72 \times (0.72-1) \times 2^{(0.72-2)} \times 100}{12.72 \times 0.72 \times 2^{(0.72-1)}} = -14\ \%$$

This calculation for departure is included in the Computer Program, Appendix X1. Slurries that sometimes exhibit a plus (+) progression in change of abrasivity are usually the softer solids such as coal, limestone, and bauxite with inclusions of harder material, notably highly abrasive silica and pyrite. These harder particles are released as the host particles break down and begin to abrade the wear block at a higher rate.

APPENDIX

(Nonmandatory Information)

X1. COMPUTERIZED REPORTING

X1.1 This program uses mass loss data as obtained from the Miller Number apparatus to compute the Miller Number (Miller Number results) and SAR Number (SAR Number results). The program also calculates an additional value for departure which is described in Annex A2.

X1.2 *Program List*—Microsoft Quick (Fig. X1.1).

```
DECLARE FUNCTION WEIGHT# (AW#, IW#)
  V9$ = "ABRASIVITY ANALYSIS V03-02"' DATE OF UPDATE: 9-SEP-92
  'WRITTEN BY: JIM MILLER
  'DATE WRITTEN: 02-FEB-74
  PRINT
  PRINT 'THIS PROGRAM CALCULATES THE "MILLER NUMBER" OR '
  PRINT 'SLURRY ABRASION RESPONSE INDEX "SAR NUMBER" AND'
  PRINT 'PRINTS A ONE PAGE REPORT'
  DIM P$(21, 41), Q$(21), I$(20)
  M$(1) = "INITIAL"
  M$(2) = "AFTER 2 HOURS"
  M$(3) = "AFTER 4 HOURS"
  M$(4) = "AFTER 6 HOURS"
  F1$ = "\        \\        \##.#### ###.#     \   \##.#### ###.# ##### #####"
  T1$ = "          TOTAL          #####          #####"
  I$(2) = SPACE$(27)       I$(8) = SPACE$(27)
  I$(10) = SPACE$(27)
  I$(12) = SPACE$(27)
  I$(4) = "MASS LOSS, MG"
  I$(6) = "          "
  I$(18) = "3-BOTH WEAR SPACI."
  I$(20) = "*-LOSS, BEST FIT"
  TI$ = SPACE$(18)
  PRINT
  OPEN "MILLER.DOC" FOR OUTPUT AS #1
Begin:
  PRINT
  PRINT
  INPUT "TEST NUMBER OR <CR> TO EXIT          :"; TEST.NUMBER$
  IF TEST.NUMBER$ = "" THEN CLOSE 1: END
  S1 % = S2 % = S3 % = S4 % = 0
  PRINT
  PRINT "1) MILLER NUMBER"
  PRINT "2) SAR NUMBER"
  PRINT "3) MODIFIED MILLER NUMBER"
  PRINT
Type.of.Test:
  INPUT "TYPE OF TEST          :"; S1 %
  IF S1 % = 1 THEN
    LSET TI$ = "MILLER NUMBER"
  ELSEIF S1 % = 2 THEN
    LSET TI$ = "SAR NUMBER"
  ELSIF S1 % = 3 THEN
    LSET TI$ = "MOD.MILLER NUMBER"
  ELSE GOTO Type.of.Test
  END IF
  PRINT "TEST DATE          :";
  LINE INPUT TEST.DATE$
  PRINT "PROJECT DESCRIPTION          :";
  LINE INPUT PROJECT.DESC$
  PRINT "SLURRY DESCRIPTION          :";
  LINE INPUT SLURRY.DESC$
  PRINT "SLURRY CONCENTRATION - 'S' FOR 50 % BY MASS:";
  LINE INPUT SLURRY. CONC$
  IF UCASE$ (SLURRY.CONC$) = "S" THEN S2 % = -1: SLURRY.CONC$ = "50 % BY MASS"
  PRINT "WEAR SPECIMEN MATERIAL - S FOR 27 % CHROME:";
  LINE INPUT WEAR.SPECIMEN$
  IF UCASE$ (WEAR.SPECIMEN$) = "S" THEN S3 % = -1: WEAR.SPECIMEN$ = "27 % CHROME IRON"
  PRINT "SPECIMEN SG          :";
  INPUT SPECIMEN.SG
  IF SPECIMEN.SG = 0 THEN SPECIMEN.SG = 7.58
  PRINT "SPECIMEN - HARDNESS          :";
  INPUT SPECIMEN.RC$
```

FIG. X1.1 Microsoft Quick Basic