NATIONAL BUREAU OF STANDARDS REPORT

9459

PROGRESS REPORT

July 1 through September 30, 1966

Development of Methods of Test
For Quality Control of Porcelain Enamels

by

M. D. Burdick and M. A. Rushmer

Porcelain Enamel Institute Research Associateship

National Bureau of Standards

Washington, D. C.

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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SUMMARY

Research has been completed on a tentative method for the numerical evaluation of the cleanability of porcelain enamel surfaces. The method, based on the use of an oily soiling agent containing a fluorescent tracer, measures the time required to restore a soiled surface to its original appearance of cleanliness. The method is equally applicable to surfaces of many materials regardless of gloss, color or texture, and has been shown to be in essential agreement with less precise, non-numerical estimates of the cleanability characteristic.

A method for calibrating the high-voltage continuity of coating test equipment has been developed and a round robin test has been arranged to determine whether this calibration procedure is applicable to all types of high-voltage test equipment currently in use.

The one-year inspection of the enamels included in the 1965 Weathering Test of Porcelain Enamels on Aluminum was completed with the examination of the enamels exposed at Kure Beach and Los Angeles.

The last enamel to be included in the 1966 Weathering Test of Nature-Tone enamels on Steel was received and the test specimens were installed at one of the three exposure sites.

I. CLEANABILITY

INTRODUCTION

The ease with which porcelain enamels can be cleaned is one of their important performance characteristics. There is currently no satisfactory test procedure by which to evaluate differences in cleanability among various porcelain enamel types. It is felt that there is a need for a test method which will permit a numerical determination of cleanability. Such a test should assist in comparing various surface finishes for products intended for the same service. A cleanability test would also be helpful in quality control as well as in the development of porcelain enamels with increased cleanability.

This is a report of progress during a quarterly period. A background of previous work may be obtained from previous reports in this series.

RESULTS AND DISCUSSION

A. The development of a Stable Soiling Agent.

The instrumental method for evaluating the cleanability of surfaces requires a stable soil, the composition of which will not change with time, as well as reproducible methods for soiling and cleaning and for the extraction and determination of small residual amounts of soil.

Previous work had suggested that the solubility of the fluorescent compound of the soil in the oil base was of the order of 0.3 percent. A new soil was compounded in which the fluorescent material was reduced from 3.3 to 0.3 percent. The fluorometer was calibrated with solutions of known concentration of the new soil in toluene. Extended trails of this soil gave results that were consistent within a group of similar specimens and were repeatable from day to day. Typical results of individual determinations on polished plate glass, porcelain enamels, and a fiberglass-reinforced polyester are given in Table 1. The scatter of results among six specimens of the same material, as indicated by the standard deviations (0.03 to 0.07 $\mu g/cm^2$), was quite small when compared to the magnitude of the average values of the retained soil.

The present procedure is now considered satisfactory for the accurate determination of small amounts of retained soil remaining on cleaned specimens.

B. The Effect of Surface Abrasion on the Cleanability of Porcelain Enamels.

Many domestic appliances which have been in service show a random pattern of surface scratches. In many cases the appearance is not seriously affected other than to reduce the glossiness of the surface. The ease with which these scratched or abraded surfaces may be cleaned would be expected to change in such a way that cleaning would become more difficult. A limited experiment was performed, using a matte and a high gloss porcelain enamel, to verify that abrasion would result in an increase in the amount of soil retained after six minutes of cleaning time. The results given in Table 2 shown a decrease in gloss retained and an increase in the amount of retained soil as the abrasion treatment was prolonged.

C. A Comparison of the Instrumental Procedure with Other Estimates of Cleanability.

Round-robin testing is often employed to determine whether different operators in different laboratories, using the same method, can obtain the same result. The purpose of this experiment, on the other hand, was to determine whether individual operators using various methods of hand cleaning could select the easier cleaning of two surfaces in a way that would agree with an instrumental selection.

Nine candidate materials were selected from the group on which instrumental determinations had previously been made. These were arranged in three groups of three as indicated in Table 3. The code letter of the surfaces, described in Table 6, is given together with the amount of soil in $\mu g/cm^2$ retained after six minutes of cleaning time. It can be seen that if three specimens, Nos 1, 2 and 3, are rated easy, medium or difficult to clean, with respect to each other, the rating process provides information for comparing the ease of cleaning of No 1 with No 2; No 2 with No 3, and No 1 with No 3. The specimens for use in this test were selected in such a way that some specimen-pairs had widely different amounts of soil retained after six minutes of mechanical cleaning, and other pairs differed by intermediate and by small amounts of retained soil under the same conditions.

The first three specimens (Part A) were soiled with the standard amount of the soil used in the instrumental determination, and were presented to the first operator. By the use of dry, cleaning tissues he was asked to select the surface which was easiest to clean, which was hardest to clean, and if possible which was intermediate. This procedure was repeated for the other specimen groups. The results given in the lower part of Table 3 reflect the judgements of eight operators each working with the same nine specimens.

When the difference in retained soil between the two specimens of a pair, was over two $\mu g/cm^2$, all of the operators were able to select, as easier to clean, the specimen which retained the smaller amount of soil after 6 minutes of cleaning time. From those pairs with differences in retained soil between one and two $\mu g/cm^2$ the operators selected the same specimen that was instrumentally determined to be the more easily cleanable, 62 percent of the time. When the difference in retained soil was 0.5 $\mu g/cm^2$ or less there was only 55 percent agreement between the operators' ranking and that determined instrumentally.

With eight operators ranking nine pairs of specimens there were 72 individual comparisons of operator judgement with instrumental ranking. In 68 percent of these comparisons there was agreement between the operators and the instrumental method. In 22 percent of the cases the operator was undecided and made no selection. In only two specimen pairs was the operators' average ranking at variance with the instrumental ranking. In both of these cases the difference in retained soil was small and there was a marked color difference between specimens which may have reduced the objectivity of the operators.

D. The Cleaning of Soiled Surfaces.

1. The Procedure Used in the Present Test.

In the preceding section of this report specimens which had been uniformly soiled were subjected to a mechanical cleaning process. A brass disc, covered with a wiping tissue was moved back and forth across the specimen which was attached to a horizontally rotating, wheel. The tissues were changed at specified intervals according to the following schedule: the first two tissues were used for one-half minute each, the third was used for one minute and additional tissues were used for two minutes each. The soil retained on the specimen after six minutes was used as a preliminary index of cleanability.

2. The Mechanisms Involved in the Procedure.

There appear to be two separate parts of the cleaning process. The first is the removal of the gross excess soil by a combination of rubbing and absorption on the tissue. It is believed that the removal of the excess in normally completed during the first minute in the mechanical procedure described above. Additional cleaning action appears to result in a continuous thinning of the film of soil which is more or less firmly adherent to the surface by chemical and/or physical forces.

3. Rate of Soil Removal.

The rates of soil removal were determined by two types of cleaning experiments. Fluorometric analyses of small discs cut from the soiled tissues allowed an estimation of the amount of soil removed as a function of time. Another approach was to extract the soil remaining on a series of specimens which had been cleaned for times between zero and ten minutes. The results of these experiments indicated a rapid and difficult to measure, rate of soil removal during the first one or two minutes of cleaning. After two minutes, however, the soil removal continued at a decreasing rate which could be accurately measured. The logarithm of the soil retained was proportional to the logarithm of the cleaning time for various surfaces for cleaning times up to 60 minutes, as illustrated in Figure 1.

The slopes of the curves in Figure 1 are measures of the rate at which soil is removed from various surfaces when subjected to a particular cleaning action.

4. The Selection of an End-Point for the Test.

The cleaning rate curves described above can be used to estimate the time required to reduce the soil to any desired level. It was desired to select a suitable level of cleanliness for use as an end-point for the test. Specimens of a glossy white porcelain enamel were soiled with the black soil and then cleaned by the regular procedure for periods of time between one and 30 minutes. Before the soil remaining was extracted, a spot at the specimen center was covered with 1-1/4 inch diameter mask. The entire surface of the specimen, except under the mask, was cleaned by rubbing with tissues moistened with toluene. This treatment removed all parts of the soil including the graphite coloring agent. The visibility of the soil remaining within the masked spot on a white specimen after a given cleaning treatment depended entirely on the amount of coloring agent (colloidal graphite) present. The extraction process dissolved and removed only the oil and fluorescent tracer but left the graphite intact. The visual appearance of the spot remained unchanged after the extraction of the oil and tracer. Following the extraction of the fluorescent components of the soil, the group of specimens was examined by eight individuals who were in unanimous agreement regarding which spots could not be seen.

The results of this experiment are given in Table 4 and the values up to six minutes of cleaning time are plotted as curve C in Figure 1. These results led to the selection of 0.5 $\mu g/cm^2$ as a practical, end-point for the test, which had for its basis, the threshold value, below which black soil was not visible on a white specimen surface.

E. The "Soilability" of Surfaces.

This property has been defined[1/] as "the relative ease with which extraneous matter attaches to or builds up on the surface of a material". For the purpose of this discussion it will be considered that the y-intercept at one minute cleaning time on the log-log plot of retained soil vs cleaning time, is a parameter which is related to or is a measure of the "soilability" of a surface. During the collection of the data which form the basis for Figure 1 it was observed that matte enamels such as M and H (Table 5) appeared very dirty after one minute of cleaning when compared with glossy enamels such as D and E after the same cleaning time. It may be rationalized that the y-intercept at one minute cleaing time represents the soil level at or near the time at which the removal of the gross excess of soil has been completed. Reference to Table 5 suggests that this measure of "soilability" depends, to some extent, on the gloss level and/or the profilometer roughness height.

F. The Selection of an Index of Cleanability of Surfaces

Some of the factors that are involved in the determination of a cleanability index are shown in hypothetical relationships in Figure 2. Various levels of "soilability" are indicated along the ordinates as high (H), medium (M) and low (L). The diagonal lines represent cleaning-rate curves. The dashed lines in the lower portions of the plots represent the end-point value (0.5 $\mu g/cm^2$).

1/ ASTM Defintions relating to Porcelain Enamel, C-286.

Figure 2A suggests that surfaces with different levels of "soilability" but with the same rates of soil removal would require different cleaning times to reach the end-point value of cleanliness. Figure 2B illustrates a condition where a surface, K, with a high degree of soilability and a rapid cleaning rate is compared with surface J, having a lower soilability value but a less rapid rate of soil removal. Although the cleaning rates of the surfaces J and K are quite different, the cleaning time required to reach the end-point level of cleanliness would be the same because of their different soilabilities. The relationship shown in Figure 2C would result if curve K were translated to the same soilability level as that of J. The use of times t_1 and t_2 as indices of cleanability would emphasize the importance of the rapid cleaning rate of K and avoid the influence of their differences in "soilability".

It is rationalized however, that the primary concern of the user of surfaces such as these, is the ability to clean an appliance in the minimum of time (or effort). If the translation of curves such as in Figure 2C was employed to avoid the effect of differing soilabilities, surface K would receive a more desirable cleanability index than surface J. In reality, the housewife might be equally satisfied with either surface J or K because the cleaning time (or effort) is the same. Following this reasoning, the translation of curves does not seem advisable and has not been suggested in the proposed procedure outlined in paragraph G.

A preliminary index of cleanability has been used previously in this report series: the soil retained after six minutes of cleaning time. Table 6 shows both of these indices for a series of surfaces. It can be seen that either criterion places this group of surfaces in the same relative order. The criterion expressed in units of time has several advantages:

1. Units of time required to clean a surface are more easily interpreted than are units of weight retained per unit area.

2. This index is based on the time that would be required to get all surfaces to the same degree of cleanliness, as compared to the preliminary index in which the specimens are compared although some are clean and others are not.

3. The use of a log-log plot of the cleaning rate permits the use of the y-intercept as an estimation of the soilability of the surface.

G. A Proposed Procedure for Evaluating Cleanability.

Details for the various operations will subsequently be prepared. In essence the evaluation of the cleanability of a candidate surface involves the use of 12 specimens as follows:

a) Determine the average amount of soil retained on six specimens after six minutes of the cleaning treatment;

b) If the average soil retained is less than two micrograms per square centimeter, repeat the operations on the remaining six specimens using a cleaning time of two minutes for each specimen; or

c) If the average amount of soil retained on the initial group of six specimens is 2 $\mu g/cm^2$ or more, determine the average retained soil on the second group of six specimens using a cleaning time of 12 minutes;

d) The average values of soil retained after the two cleaning periods (2 and 6 minutes or 6 and 12 minutes) are plotted on log-log paper with the soil retained and time as the ordinate and abscissa respectively.

e) A straight line through these two points is extrapolated, if necessary, to intersect the end-point soil level of 0.5 $\mu g/cm^2$;

f) The time, in minutes, corresponding to the above intersection is taken as the index of cleanability.

PLANS FOR THE NEXT REPORT PERIOD

One of the inadequacies of this procedure for determining cleanability is that it can be applied only to those surfaces which resist the solvent action of toluene. It is planned to substitute another fluorescent compound in the soil composition so that a less agressive solvent can be employed in the extraction.

The present procedure will be written for consideration as a tentative, or interim Porcelain Enamel Institute method of test.

II. CONTINUITY OF COATING

INTRODUCTION

Porcelain enamel is often applied to a metal not only to add a pleasing appearance, but also to protect the base metal from corrosion. A visual inspection of the older two and three coat glossy porcelain enameled products was sufficient to determine whether the product had adequate enamel coverage to protect the base metal from corrosion. However, visual inspection of the new matte nature-tone enamels and the thinner direct-on enamels often pass enamels that have extremely small areas of poor coverage. These areas tend to permit early corrosion of the base metal and the resultant iron oxide diffuses over the enamel surface forming an unsightly irridescent or rust colored film. This suggests the need for a test for continuity of porcelain enameled coatings. The development of such a test method has been one of the goals of the PEI Research Associateship.

RESULTS AND DISCUSSION

The major effort toward the development of a test for continuity of coating during this report period was focused on developing a method for calibrating the test equipment. This was particularly necessary if both ac and dc test equipment were to be used since the effects of maximum voltage and charging currents in ac instruments could not be predicted by simply checking the voltmeter on the test equipment with an independent voltmeter.

The method of calibration selected was a modified spark-gap measurement - that is, measuring the voltage necessary to just arc across a gap of a given thickness. However, instead of measuring the spark gap with a set of fixed electrodes surrounded by air, it was decided to re-probe porcelain enameled specimens ranging in thickness from 2-20 mils that had been previously punctured with the high-voltage test equipment. While this method does not give a uniform test geometry, it is indicative of the types of geometries, or defects, that would be encountered when testing virgin specimens for continuity of coating. The results of this calibration for both ac and dc test equipment are illustrated in figures 3 and 4. The points in these figures are the average thickness plotted against the average air-gap voltage for each enamel tested. The curves are the least squares lines through these points. Although there is some scatter in the data, it is believed to be caused mainly by the different configurations of defects that the spark had to pass through on its way to the base metal. The effect of test geometry is illustrated in Table 7 where handbook values for the dielectric strength of air tested with different geometries are given.

The effects of the type of probe and relative humidity were investigated. Figure 5 illustrates the shift in the curve caused by probing the specimens with a wire brush probe instead of a 100 mesh wire gauze probe. Although there is only a slight change in the calibration curve, the correlation coefficient is slightly better when the gauze probe is used. For this reason a gauze probe will be recommended in the test procedure.

A 48 percent change in relative humidity of the test atmosphere caused a shift in the calibration curve of approximately 50 volts as illustrated in figure 6. This is less than ten percent of the voltage required to puncture the thinnest enamel with reputedly "bad" continuity. This indicates that minor fluctuations (10-20%) in humidity that would occur in a laboratory are not of major importance in this test procedure.

After developing calibration curves for both ac and dc instruments and determining the effect of type of probe and relative humidity, it was desired to determine whether replicate specimens of the same enamel tested with ac and dc equipment would fail at similar voltages. To do this the replicate specimens were probed with increasing voltage, both ac and dc, until failure occurred. The thickness of the enamel was measured and the voltage necessary to arc across the air gap was determined from the appropriate calibration curve (figure 7). The difference between the air-gap voltage and the puncture voltage was calculated and is called the "overvoltage" required to puncture the enamel.

The overvoltage required to puncture replicate specimens of the same enamel with both ac and dc test equipment is represented graphically in figure 8. It can be seen that a good linear correlation exists between the overvoltage necessary to puncture an enamel with either ac or dc test equipment. If the overvoltages were equal for both types of test equipment, the slope of the least squares line in figure 8 would be 1.0. However, inherent differences between the ac and dc test equipment have reduced the slope of this line to 0.42.

The overvoltage, both ac and dc for the individual enamels probed is given in table 8. The enamels in this table have been listed as having "good" or "bad" continuity based on either 1) the manufacturer's estimate of continuity or 2) whether they rusted after 7-yrs of exposure at Kure Beach, North Carolina- 80 feet from the ocean. The average overvoltage required to puncture "good" enamels was 2.09 and 1.96 times that needed to puncture the "bad" enamels for the ac and dc test equipment respectively. This indicates that either type of test equipment would be on the average, equally sensitive for separating the "good" and "bad" enamels. A further analysis of these data are given in Table 9. Here pairs of "good" and "bad" enamels have been arranged according to enamel type and thickness. The overvoltages required to puncture the individual pairs of enamels using both ac and dc test equipment are also given. If the overvoltage necessary to puncture the "good" enamels was higher than that required to puncture the "bad" enamels, then the voltage required to puncture the "good" enamels could be lowered slightly to pass them but still puncture the "bad" ones, thus separating the good from the bad. The data in table 9 indicate that 6 of the 8 pairs of enamels could be separated with either type of test equipment, again indicating that similar results can be obtained by using either type of test equipment.

PLANS FOR NEXT REPORT PERIOD

A tentative procedure for calibrating high-voltage continuity of coating test equipment has been prepared. This procedure, together with the specimens we used to calibrate our test equipment, will be sent to three companies that have agreed to participate in a round-robin test. This test involves calibrating the high-voltage test equipment and then testing some enamels to determine the overvoltage required to puncture them. Replicate specimens of the tested enamels will then be sent to the other companies participating in the round robin. This test should 1) determine whether all test instruments give similar calibration curves and more important 2) whether the same enamel will be punctured at the same overvoltage regardless of test equipment used.

III. WEATHERING TESTS OF PORCELAIN ENAMELS

INTRODUCTION

Weathering tests are one of the long-term projects of the research associates. During this quarter the enamels exposed at Los Angeles and Kure Beach in the 1965 Weathering Test of Porcelain Enamels on Aluminum were returned for their one-year inspection. Specimens of the last enamel to be included in the 1966 Weathering Test of Nature-Tone Enamels on Steel were received; also, those enamels included in a preliminary exposure test of Nature-Tone enamels on steel were returned for their final inspection after one-year's exposure at Kure Beach-80.

INSPECTION PROCEDURE

1. Cleaning of Specimens

Before meaningful gloss and color measurements can be made on specimens that have been exposed it is necessary to remove accumulated dirt, fingerprints etc. from the enamel surface. The procedure selected for cleaning the enamels in the above tests was to 1) scour 30 strokes with a sponge that has been moistened with a solution containing one weight percent trisodium phosphate and sprinkled with calcium carbonate, 2) rinse with tap water, 3) rinse with distilled water and 4) rinse with alcohol.

2. Gloss and Color

The 45° specular gloss of the specimens was measured at four orientations near the center of the specimen. The gloss is reported as the percentage of initial gloss retained after exposure.

The change in color was measured with a color difference meter. One of the three storage specimens of each enamel was used as the standard in measuring the color difference. This was done to obtain maximum efficiency with this type of instrument. The storage specimens were, in turn, measured against NBS color standards to determine whether the enamels have changed color during cleaning and storage. Since there were no extra specimens available in the preliminary nature-tone test, these enamels were compared directly with the NBS color standards. The color change after exposure is reported as color retention which is 100 minus the color change in NBS units.

RESULTS AND DISCUSSION

A. The 1965 Weathering Test of Porcelain Enamels on Aluminum

1. Cleaning of Specimens

The enamels exposed at Los Angeles and Kure Beach were returned to the laboratory at the National Bureau of Standards for their one-year inspection. The specimens exposed at Kure Beach appeared fairly clean while those exposed at Los Angeles were covered with a loosely adhering dirt film. The enamels exposed at both sites were easily cleaned by the above cleaning treatment.

2. Gloss and Color

The gloss and color were measured as previously described. These data have been reduced to percentage gloss retained and color retention and are reported in Table 10.

The extreme color change of the black enamels exposed at Kure Beach was unexpected. However, this large color change does correlate with the acid solubility of the enamels.

3. Nature-Tone Enamels on Aluminum

Eight nature-tone enamels on aluminum were to be added to this test after the one-year inspection. However, extreme delays in the production of one enamel have cancelled its inclusion in this test program. The remaining seven enamels will be added to the exposure racks when the original enamels are re-exposed.

B. 1966 Weathering Test of Nature-Tone Enamels on Steel

The last enamel to be included in this test was received during this report period. It was measured for gloss, color, acid resistance, thickness and continuity of coating as described in previous reports.

The specimens have been installed in the exposure racks near Biscayne Bay, Miami, Florida.

C. 1965 Weathering Test of Nature-Tone Enamels on Steel

1. Final Inspection

The 1965 Preliminary Weathering Test terminated with the one-year inspection report. This preliminary test program will be superceded by the expanded 1966 Weathering Test of Nature-Tone Enamels on Steel. The following are the results of one-year's exposure at Kure Beach for the Enamels included in the preliminary test.

2. Gloss and Color

The color retention and percentage gloss retained for the Nature-Tone enamels exposed for one-year in a preliminary test are given in table 11. The blue enamels, as a group, appear to be less stable than the other colors although there is one red-brown enamel, MC-9, which exhibited quite a large color change.

It was also noted that the enamels with an initial gloss lower than 18 showed increased gloss retention between six months and one-year's exposure.

3. Continuity of Coating

The main defect that was revelaed by this short-term exposure test was the lack of continuity of coating. After six months' exposure 25% of the enamels showed rust on their surfaces. This rusting tendency has continued, and following one-year's exposure 50% of these enamels have rust visible on their surfaces.

PLANS FOR NEXT REPORT PERIOD

A. 1965 Weathering Test of Porcelain Enamels on Aluminum

The specimens in this test are to be returned to the exposure racks during the next report period. The next inspection is tentatively planned after 2 years' exposure.

B. 1966 Weathering Test of Nature-Tone Enamels on Steel

The enamels in this test are to be put on the exposure racks at Gaithersburg, Maryland and Kure Beach. The first inspection of these enamels will be made after six months' exposure.

Table 1. Individual Determinations on Polished Plate Glass Specimnes Showing the Amount of Soil Retained after Six Minutes of Cleaning.

Spec. No.	Retained Soil	Spec. No.*	Retained Soil	Spec. No.	Retained Soil	Spec. No.*	Retained Soil
	μg/cm²		μg/cm²		μg/cm²		μg/cm²
1	0.71	1	0.74	10	0.74	10	0.77
2	0.73	2	0.74	11	0.68	11	0.65
6	0.75	6	0.85	12	0.71	12	0.72
8	0.65	8	0.65	13	0.66	13	0.72
5	0.65	5	0.72	14	0.65	14	0.66
7	0.61	7	0.64	16	0.66	16	0.62
				17	0.66	17	0.61
Ave.	0.68		0.72		0.68		0.68
S. D.	.056		.076		.034		.059

*Repeat determinations made on previously used specimens.

Individual Determinations on Four Porcelain Enamels and a Gel Coat Showing the Amount of Soil Retained after Six Minutes of Cleaning Time

Specimen	Enamel "C"	Enamel "G"	Enamel "F"	Enamel "A"	Gel Coat "P"
	μg/cm²	μg/cm²	μg/cm²	μg/cm²	μg/cm²
1	0.33	0.46	0.39	0.15	2.1
2	.26	.42	.41	.08	2.5
3	.42	.44	.32	.11	2.4
4	.28	.34	.47	.24	2.5
5	.29	.29	.46	.07	2.7
6	.33	.49	.38	.14	2.3
Ave	0.32	0.41	0.40	0.13	2.4
Std. Dev	.057	.076	.055	.062	.041

Table 2 Effect of Abrasion on Cleanability of Porcelain Enamels

Porcelain Enamel	Initial Gloss	Abrasion Time 1/	Retained Gloss	Retained Soil After 6 Minutes Cleaning 2/
		min.	percent	μg/cm²
C	63	0	100	0.32
		2	82	1.9
		6	55	7.8
		10	34	13.6
N	9	0	100	4.7
		2	81	174.

1/ Using the PEI Abrader

2/ This value used as an index of Cleanability; small amounts of retained soil are associated with good cleanability.

Table 3. A Round-Robin Test Comparing Two Methods for Determining the Cleanability of Surfaces.

Specimens Used

Part A	D-BUFF 0.32	J-GLASS 0.69	N-LAVENDER 4.7
Part B	I-PINK 0.55	K-WHITE 0.84	P-WHITE FRPE a/ 2.4
Park C	A-BLUE 0.13	F-WHITE 0.40	O-LAVENDER 0.59

Analysis of Results

Specimen Pairs		Difference in the Instrumental Determination of the Total Soil Retained After 6 Minutes Cleaning Time	Agreement Between Individual Operators and the Instrumental Determination b/
		μg/cm²	percent
D-N	BUFF-LAVENDER	4.4	100
J-N	GLASS-LAVENDER	4.0	100
I-P	PINK-FRPE*	1.8	62
K-P	WHITE-FRPE*	1.5	62
A-O	BLUE-LAVENDER	0.5	100
D-J	BUFF-GLASS	0.4	0
I-K	PINK-WHITE	0.3	62
A-F	BLUE-WHITE	0.3	12
F-O	WHITE-LAVENDER	0.2	100

a/ Fiberglass Reinforced Polyester

b/ 100 percent agreement was considered to be attained when each of the operators selected as the more cleanable of a pair, the same surface that retained the lesser soil after six minutes of mechanical cleaning time.

Table 4

The Determination of a Practical Level of Visual Cleanliness

Specimen No.	Cleaning Time	Retained Soil	Visual Inspection Results 1/
	min.	$\mu g/cm^2$	
54	1	1.8	visible
96	2	0.97	"
53	3	.62	"
78	4	.49	not visible
101	6	.23	" "
99	8	.19	" "
102	17	.10	" "
118	30	.08	" "

1/ Eight individuals examined this series of soiled specimens in a random arrangement and unamimously reported the results shown. All specimens were a glossy white porcelain enamel (C) soiled with the black, oily, soiling agent developed in this research.

Table 5. The Relationship of 45° Specular Gloss, Soilability and the Roughness Height of Several Surfaces.

Surface	45° Specular Gloss	Soilability $\mu g/cm^2$ a/	Roughness Height micro-inches b/
		Matte Surfaces	
M	8	11	52
H	6	10.5	36
		High Gloss Surfaces	
F	67	5.5	--
K	58	4.0	12
L	56	3.4	--
B	60	3.0	11
G	64	2.7	--
E	60	2.5	--
I	61	2.3	9
D	55	2.2	8
C	63	1.8	12
J	55	1.4	--
A	56	0.8	--

a/ Relative numbers which are related to the soilability of these surfaces. They were experimentally determined as the y-intercept at one minute cleaning time, from the log-log plot of retained soil as a function of cleaning time.

b/ Arithmetic average height as indicated by a Talysurf Profilometer.

Table 6. Experimental Values for Cleanability and Soilability of a Series of Surfaces

Surface Code	Soil Retained After 6 Minutes Cleaning Time	Time Required To Reduce Soil To 0.5 $\mu g/cm^2$	Soilability a/
	$\mu g/cm^2$	minutes	$\mu g/cm^2$
A	0.13	2	0.8
B	.26	4	3.0
C	.32	4	1.8
D	.32	4	2.2
E	.35	4	2.5
F	.40	5	5.5
G	.41	5	2.7
H	.47	6	10.5
I	.55	9	2.3
J	.69	11	1.4
K	.84	11	4.0
L	2.0	800	3.4
M	5.6	3000	11.0

Characterization of Surfaces

Surface Code	Material	Color	Specular Gloss	Acid Resistance	Roughness Height micro-inches
A	P/E	Blue	56	C	--
B	P/E	Brown	60	AA	11
C	P/E	White	63	A	12
D	P/E	Buff	55	A	8
E	P/E	Blue	60	B	--
F	P/E	White	67	AA	--
G	P/E	White	64	--	--
H	P/E	Lavender	6	C	36
I	P/E	Pink	61	B	9
J	Plate Glass	Clear	55	--	--
K	P/E	White	58	AA	12
L	FRPE b/	White	56	--	--
M	P/E	Lavender	8	A	52

b/ Fiberglass Reinforced Polyster

a/ Relative numbers which are related to the soilability. They were experimentally determined as the y-intercept at one minute cleaning time, from the log-log plot of retained soil as a function of cleaning time.

Table 7. Dielectric Strength of Air, volts/mil

From Handbook of Chemistry and Physics

Test Voltage kV	Test Geometry 2.5 cm Spheres	5 cm Spheres	10 cm Spheres	25 cm Spheres	Points
25	84.6	82.6	81.5	78.5	29.0
20	87.6	84.6	82.0	79.5	29.0
15	90.7	86.6	82.8	79.5	29.2
10	94.0	87.6	84.6	79.5	30.2
5	97.8	84.6	84.6	79.5	30.2

Table 8. Comparison of "Good" and "Bad" Porcelain Enamels

"Good" Enamels				"Bad" Enamels			
Enamel	Overvoltage AC	Overvoltage DC	Thickness (mils)	Enamel	Overvoltage AC	Overvoltage DC	Thickness (mils)
G-W	0.04	0.33	4.7	B-W	0.00	0.04	3.6
G-4	0.23	0.72	4.8	B-4	0.03	0.91	4.9
G-8	0.26	0.74	8.8	B-8	0.07	0.17	8.5
M-3	0.30	0.76	5.5	N-4	0.23	0.81	4.9
H-1	0.89	2.32	8.0	N-3	0.21	0.87	5.4
D-2	1.69	4.08	10.5	B-3	0.56	1.54	11.0
PA-3	0.29	1.22	8.0	P-2	0.69	1.00	8.2
RA-3	0.02	0.64	12.1	SA-1	0.03	0.14	12.1
Average	0.48	1.35			0.23	0.69	

Table 9. Comparison of "Good" and "Bad" Porcelain Enamels of the Same Type and Thickness

Type of Enamel	"Good" Enamels: Enamel	Overvoltage AC	Overvoltage DC	Thickness (mils)	"Bad" Enamels: Enamel	Overvoltage AC	Overvoltage DC	Thickness (mils)	Separation* AC	Separation* DC
Direct-On, Laundry Basket	G-W	0.04	0.33	4.7	L-W	0.00	0.04	3.6	Yes	Yes
Direct-On, Cover Coat	G-4	0.23	0.72	4.8	B-4	0.03	0.91	4.9	Yes	No
Ground Coat, Architectural	M-3	0.30	0.76	5.5	N-3	0.21	0.87	5.4	Yes	No
Two-Coat, Architectural	H-1	0.89	2.32	8.0	P-2	0.69	1.00	8.2	Yes	Yes
Two-Coat, Architectural	PA-3	0.29	1.22	8.0	P-2	0.69	1.00	8.2	No	Yes
Direct-On, Cover Coat	G-8	0.26	0.74	8.8	B-8	0.07	0.17	8.5	Yes	Yes
Two-Coat, Architectural	D-2	1.69	4.08	10.5	B-3	0.56	1.54	11.0	Yes	Yes
Two-Coat, Architectural	RA-3	0.02	0.64	12.1	SA-1	0.03	0.14	12.1	No	Yes

*If the overvoltage required to puncture a "good" enamel was higher than that required to puncture a "bad" enamel then the breakdown voltage of the good enamels could be lowered to pass them but to puncture, or fail the bad enamel - thus separating the good from the bad.

Table 10. Summary of Data for Porcelain Enamels on Aluminum Exposed for One Year at Kure Beach and Los Angeles

Enamel	Kure Beach				Los Angeles				Visual Color	Acid Solubility mg/in^2
	Gloss		Color		Gloss		Color			
	6 mo.	1 yr.	6 mo.	1 yr.	8 mo.	1 yr.	8 mo.	1 yr.		
AA-A	85.5	95.2	99.4	98.1	95.6	97.8	99.5	99.3	White	5.5
AA-B	94.0	87.5	99.3	98.7	103.0	100.9	99.3	99.0	White	5.9
AA-C	90.7	107.4	98.3	97.6	96.0	96.8	99.0	98.5	White	5.0
AA-D	76.0	33.0	98.3	97.0	101.0	100.4	98.2	98.8	White	12.7
AB-A	81.2	88.4	98.8	97.8	84.9	88.3	98.7	98.6	White	7.2
AB-C	79.6	86.4	99.6	99.1	83.6	87.9	99.4	99.3	White	4.9
AB-D	75.3	80.2	98.5	97.6	79.6	98.1	98.4	99.1	White	7.9
AC-A	90.2	90.7	99.4	98.7	102.6	101.0	99.1	98.7	White	6.4
AC-B	85.8	37.3	98.7	98.1	102.1	101.3	98.6	99.2	White	11.3
AC-C	90.6	65.3	98.3	96.9	98.2	98.1	98.9	98.8	White	9.9
AD-A	87.6	96.9	98.9	97.6	90.3	95.7	99.4	99.3	White	6.2
AD-B	89.0	93.8	99.4	98.3	92.4	94.9	99.4	99.3	White	6.7
AD-C	82.8	91.3	98.1	96.9	87.5	95.4	98.5	98.4	White	7.1
AD-D	87.5	58.0	98.1	97.3	88.6	103.1	98.4	98.9	White	12.4
AE-A	76.4	68.4	99.1	94.3	80.5	80.5	99.8	97.2	Black	6.5
AE-B	65.1	55.8	98.6	89.1	87.9	86.6	99.7	99.1	Black	10.1
AE-C	72.6	68.2	98.9	92.9	91.1	89.9	99.4	99.2	Black	12.1
AE-D	71.1	37.8	98.6	76.6	85.5	83.2	99.4	97.2	Black	15.5
AF-A	65.6	67.9	98.4	88.8	85.7	84.3	99.6	97.9	Black	14.2
AF-B	69.7	58.5	99.1	88.7	96.1	96.5	99.6	99.4	Black	9.0
AF-C	72.2	76.8	98.4	93.1	87.5	86.6	99.6	98.3	Black	10.1
AG-B	82.0	83.7	97.6	88.2	79.5	103.1	99.3	98.1	Black	12.5
AG-C	46.9	112.8	98.2	97.1	33.2	103.8	99.4	99.0	Black	7.5
AH-A	90.8	79.3	97.5	93.5	103.7	113.2	97.4	96.9	Red	8.1
AH-B	64.3	44.8	93.0	83.1	76.8	77.6	95.5	94.4	Red	8.8
AH-C	73.9	59.2	90.1	86.3	77.6	77.4	91.9	91.4	Red	6.5
AH-D	59.7	37.8	83.6	70.2	83.2	81.8	91.0	88.4	Red	10.5
AO-A	76.6	60.9	95.4	91.7	83.3	83.3	99.9	99.2	Dk. Green	19.9
AO-B	72.5	67.0	99.5	97.3	84.6	86.0	99.8	99.4	Dk. Green	10.1
AO-D	74.1	50.8	97.8	92.0	87.0	84.2	98.9	98.6	Dk. Green	17.0
AP-A	82.2	80.4	98.7	95.2	90.2	97.4	99.3	99.3	Lt. Green	12.3
AP-B	75.5	87.1	99.4	98.7	77.0	89.6	99.6	99.6	Lt. Green	6.4
AP-C	73.9	84.1	99.5	98.9	72.5	91.3	99.2	99.6	Lt. Green	6.2
AP-D	87.5	88.9	99.1	97.1	88.0	95.2	99.2	99.3	Lt. Green	10.0
AR-A	47.0	128.2	99.6	99.6	25.5	122.2	99.6	99.6	Lt. Green	4.4
AR-B	0.0	96.1	99.4	98.8	0.0	81.7	99.6	99.6	Lt. Green	5.5
AR-C	0;0	105.9	99.4	98.3	0.0	81.6	99.5	99.4	Lt. Green	8.1
AS-A	78.2	59.9	98.7	96.2	92.1	93.0	99.5	99.6	Gray	13.4
AS-B	83.7	86.4	98.9	97.3	82.5	84.6	99.3	99.3	Gray	7.4
AS-C	92.5	97.7	99.8	99.6	93.3	95.5	99.8	99.6	Gray	5.4
AT-A	75.2	93.8	99.0	97.4	71.4	91.0	99.1	99.3	Blue	6.2
AT-B	79.8	93.4	98.6	94.9	90.9	95.5	97.9	97.8	Blue	7.0
AT-C	81.5	82.0	98.7	96.2	82.0	84.0	99.0	98.9	Blue	6.1
AU-A	89.1	89.8	99.3	99.4	87.7	92.5	99.7	99.7	Brown	5.3
AU-B	75.7	93.4	99.2	99.4	80.3	94.9	99.8	99.7	Brown	7.5
AU-C	87.4	94.7	99.8	99.6	91.4	97.9	99.8	99.8	Brown	7.6
AW-A	81.4	80.1	99.2	98.7	85.3	85.8	99.6	99.5	Yellow	7.8
AW-B	78.8	79.2	99.3	97.3	93.7	95.2	99.3	99.3	Yellow	8.7
AW-C	72.1	47.6	98;9	95.9	91.7	90.3	99.4	99.5	Yellow	18.6
AZ-A	100.9	50.1	97.7	98.9	104.1	102.1	98.9	99.1	White	9.5
AZ-B	94.2	110.7	99.1	97.8	99.1	98.0	98.8	98.8	White	5.2
Average	75.8	77.9	98.2	95.1	82.9	92.9	98.9	98.7		

Table 11. Summary of One-Year Exposure Data for Nature-Tone Enamels Exposed at Kure Beach-80

Enamel	Visual Color	Color Change		Initial Specular Gloss	Specular Gloss Retained (percent)		Acid Solubility (mg/in^2)	Thick-ness (mils)	Number of Specimens Rusted	
		6-mo.	1-yr.		6-mo.	1-yr.			6-mo.	1-yr.
MA-4	Light Gray	99.2	99.1	1.8	0.0	126.3	0.9	9.1	0	1
MC-5	Light Gray	99.8	99.2	25.7	93.0	79.9	1.1	8.7	0	0
MA-5	Medium Gray	98.4	99.2	10.4	71.8	86.5	1.8	9.3	0	0
ME-3	Medium Gray	99.7	99.3	18.7	95.2	89.2	0.8	9.9	0	0
MB-5	Gray	99.3	99.4	5.3	45.5	1178.9	7.0	14.3	0	0
MC-6	Dark Gray	99.0	98.5	30.2	94.5	74.3	1.6	8.7	1	1
MA-12	Dark Gray	98.5	99.0	20.4	74.0	70.1	1.2	9.8	0	0
MC-10	Black	99.7	99.0	22.4	89.5	80.8	1.1	8.1	0	1
MD-5	Black	99.6	98.6	29.6	108.9	89.1	1.1	7.6	0	0
ME-8	Black	99.2	98.4	25.6	82.4	129.2	1.9	8.6	1	2
ME-12	Black	99.4	99.2	17.1	79.4	84.1	1.3	8.9	0	1
MA-3	Yellow-Green	99.4	99.3	6.5	55.5	99.1	2.1	9.1	0	0
MB-4	Yellow-Green	99.4	99.6	8.5	82.5	112.3	9.0	11.6	0	0
ME-2	Chartruse	99.6	98.8	17.6	79.9	83.4	1.7	10.8	0	2
MD-6	Medium Green	99.3	98.3	48.4	99.7	78.7	0.6	9.5	0	0
ME-6	Green	99.7	99.3	7.2	62.3	114.4	0.9	9.3	2	2
ME-7	Dark Gray-Green	99.0	99.2	12.7	74.0	90.0	1.2	6.6	2	2
MC-2	Light Blue	98.7	97.8	22.0	87.2	81.3	1.2	9.3	0	1
MC-12	Light Blue	98.4	96.8	5.5	62.6	116.4	3.2	8.1	1	1
MC-4	Blue	98.0	97.3	22.0	89.5	80.9	1.3	8.7	0	1
MD-1	Peacock Blue	99.4	96.0	20.5	94.9	87.4	1.2	7.2	1	1
ME-4	Slate Blue	99.2	98.8	36.0	81.7	71.8	1.0	9.5	1	2
ME-9	Steel Blue	99.7	99.1	20.2	90.6	83.7	0.7	7.4	1	1
MA-6	Red-Brown	99.3	99.2	8.8	57.3	88.9	1.7	9.1	2	2
MC-9	Red-Brown	99.0	94.4	30.1	92.6	74.8	1.0	7.8	1	1
MD-4	Red-Brown	99.2	99.1	26.6	88.6	76.9	0.9	7.5	0	1
ME-5	Red-Brown	98.8	99.4	21.7	82.7	79.5	0.7	11.0	1	2
ME-11	Brown	99.8	98.5	1.2	0.0	296.9	0.9	8.7	0	1
MD-3	Chocolate Brown	99.3	99.1	25.4	94.4	82.8	0.9	8.1	0	1
ME-10	Chocolate Brown	99.1	98.1	19.1	81.7	78.2	2.6	7.9	1	2
	Average	99.2	98.6		76.4	132.2		Total	15	29

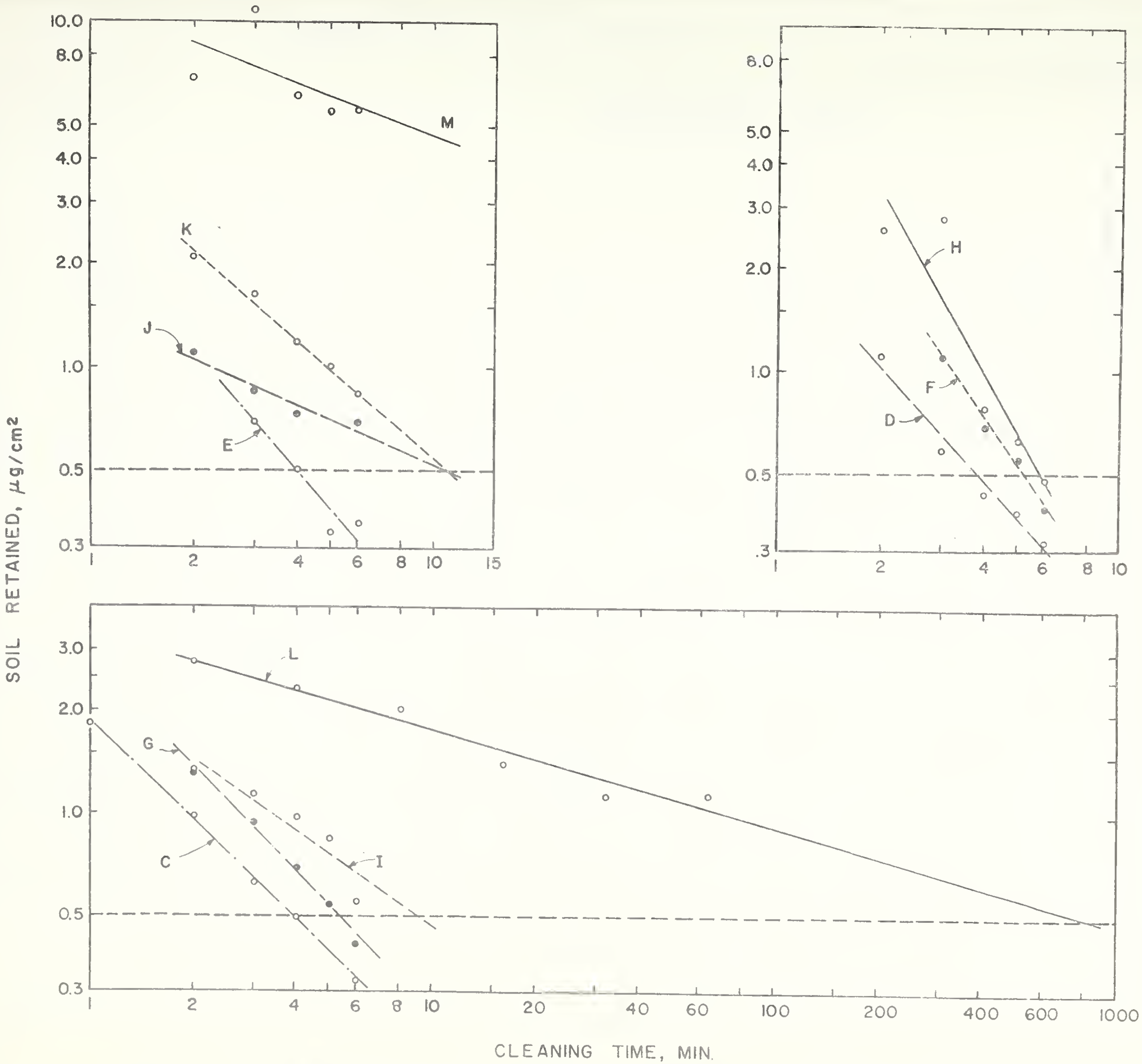

Figure 1. Cleaning Rates of Several Surfaces as Shown by Log-Log Plots of Soil Retained after Certain Cleaning Times.

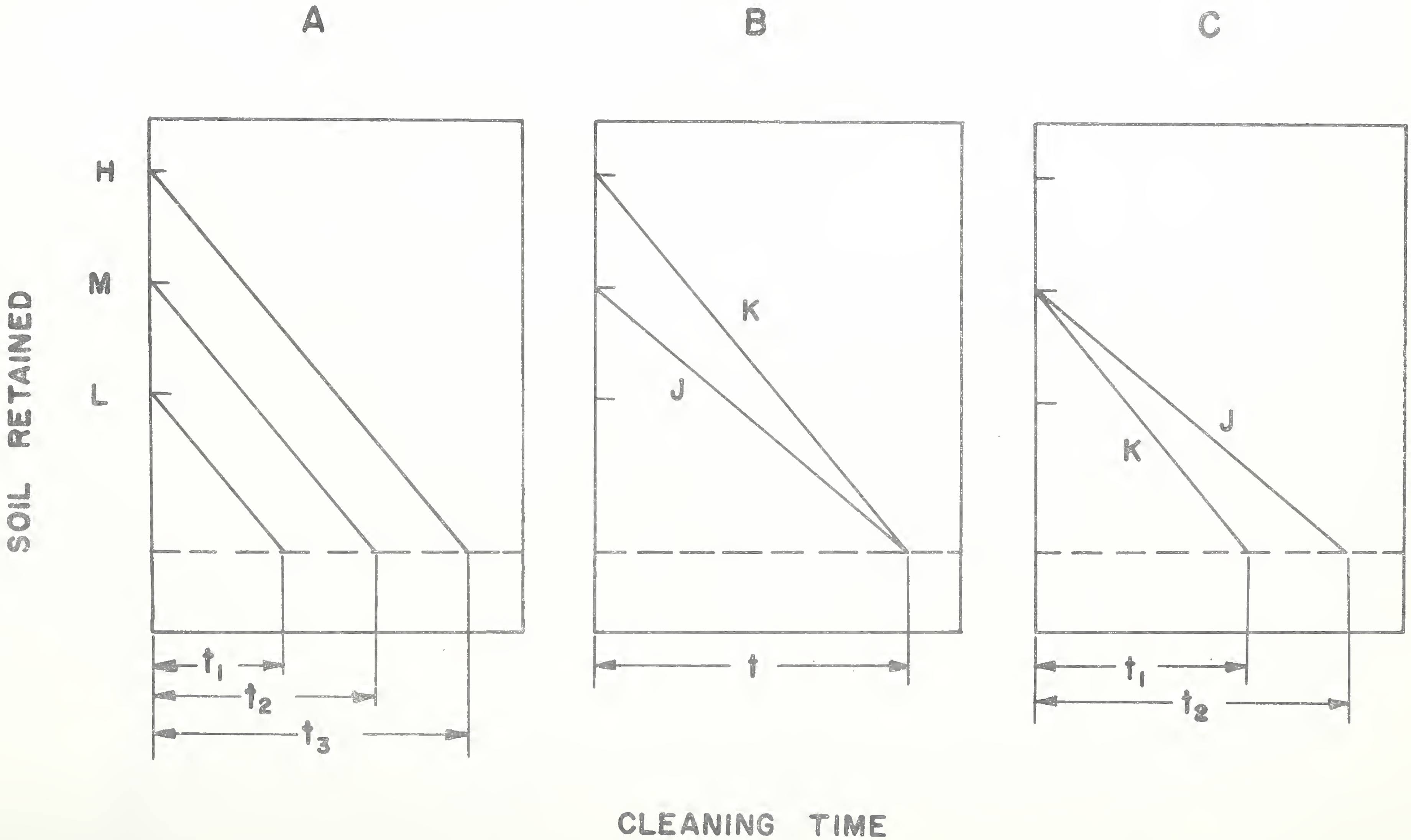

Figure 2. Hypothetical Interrelations between Soilability, Cleaning Rate, and Cleaning Time. (log-log plot).

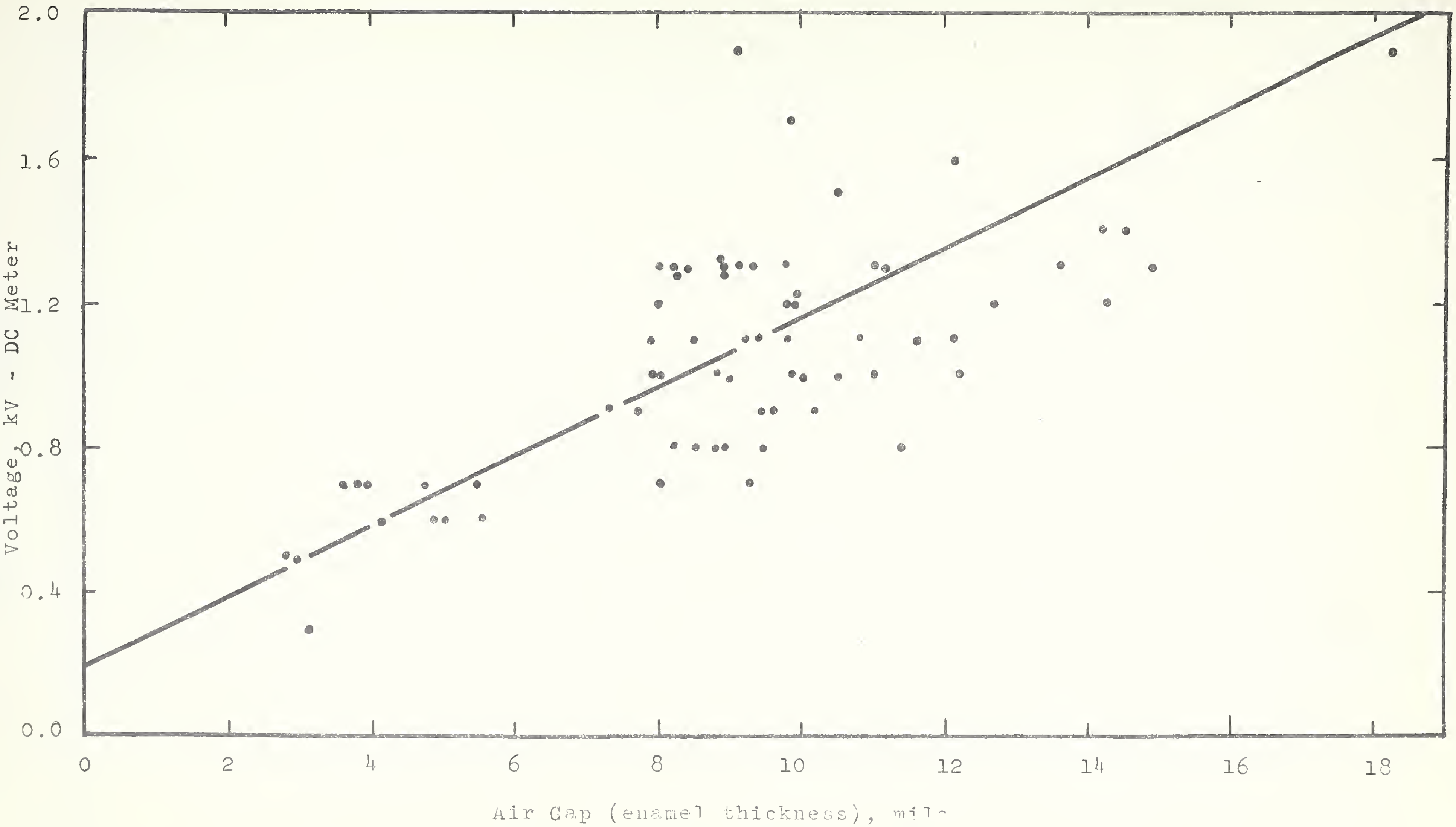

Figure 3. Calibration Curve for Hypot, DC Test Equipment

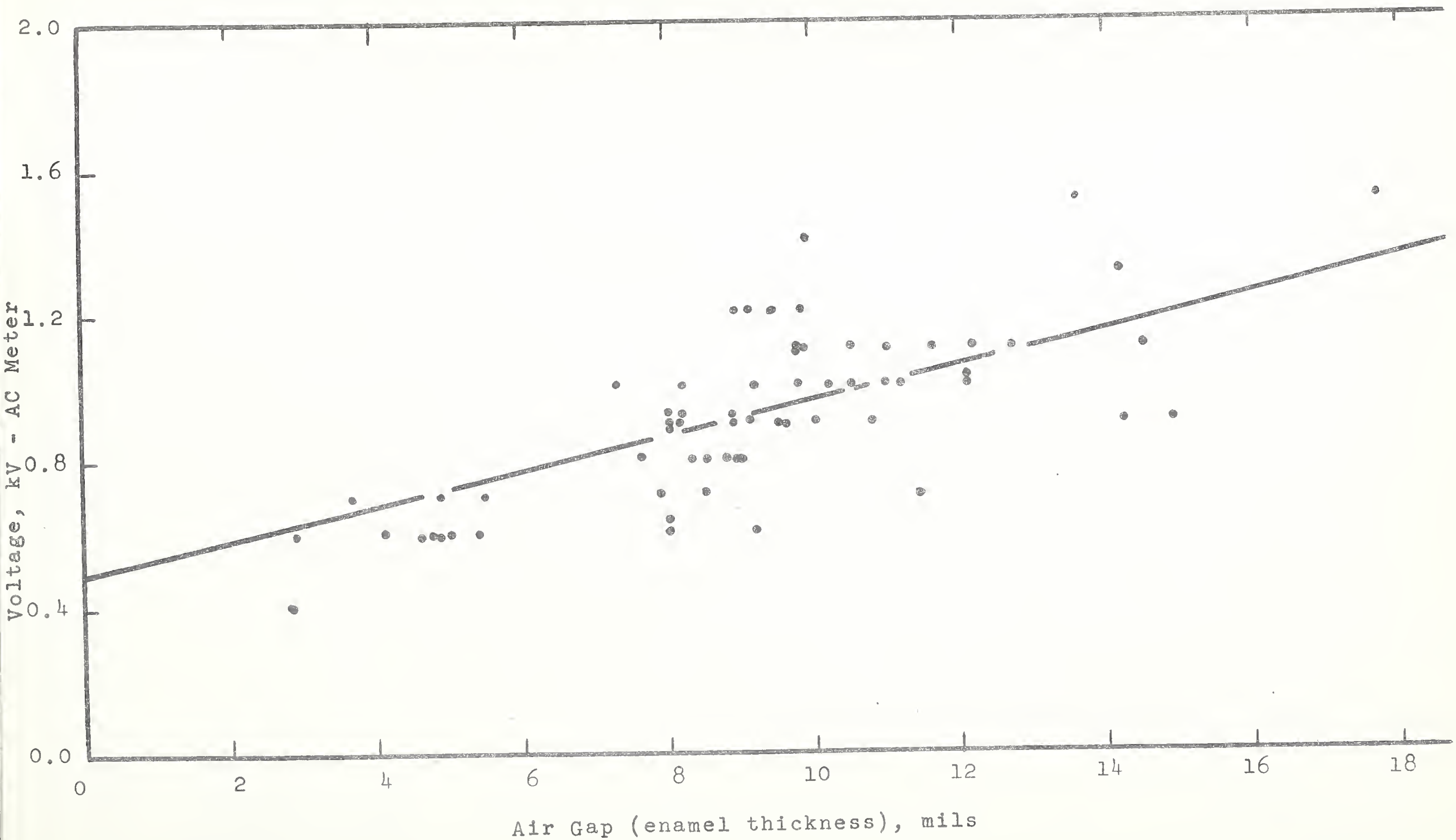

Figure 4. Calibration Curve for Hypot, AC Test Equipment

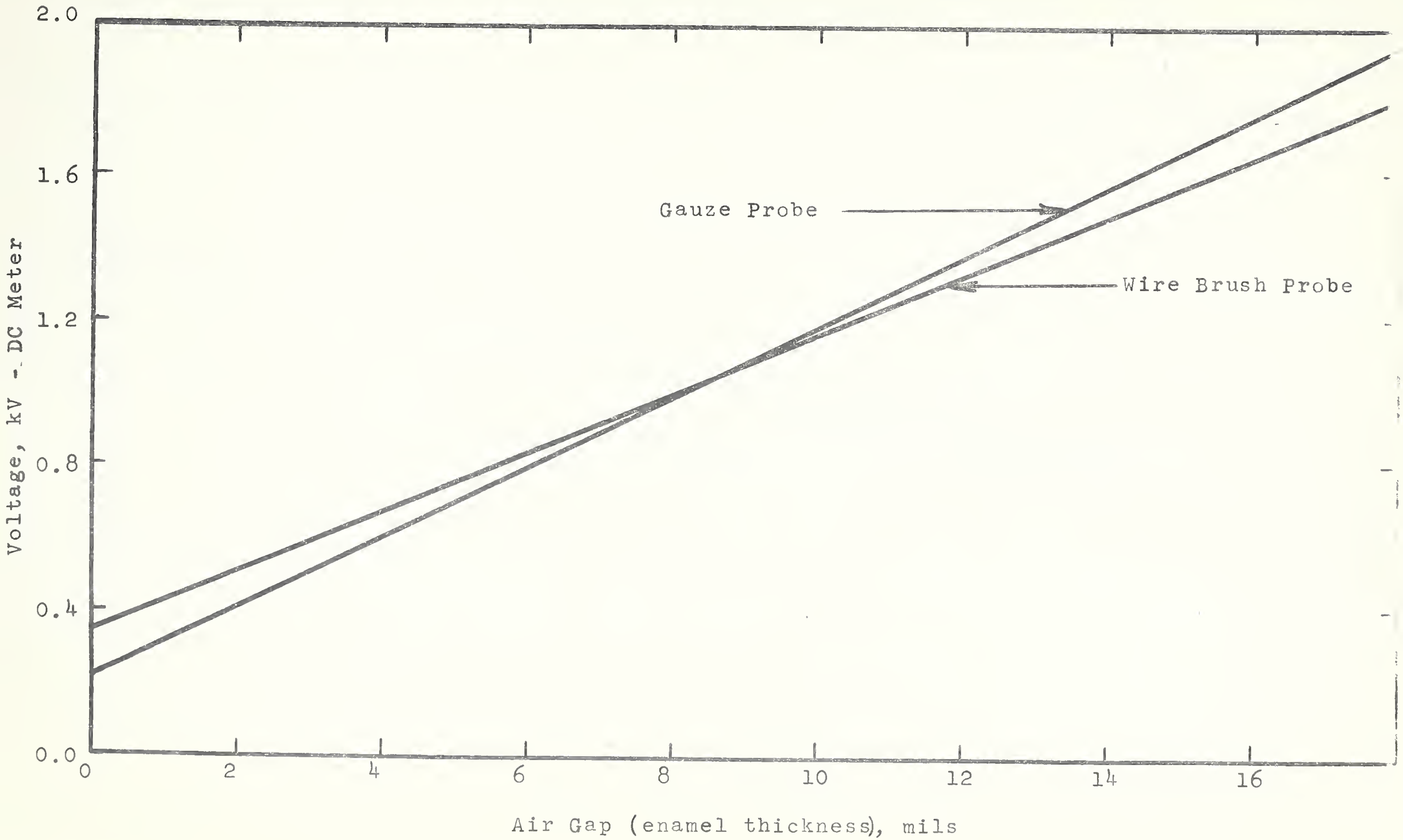

Figure 5. Comparison of Calibration Curves Developed by Probing with Different Probes.

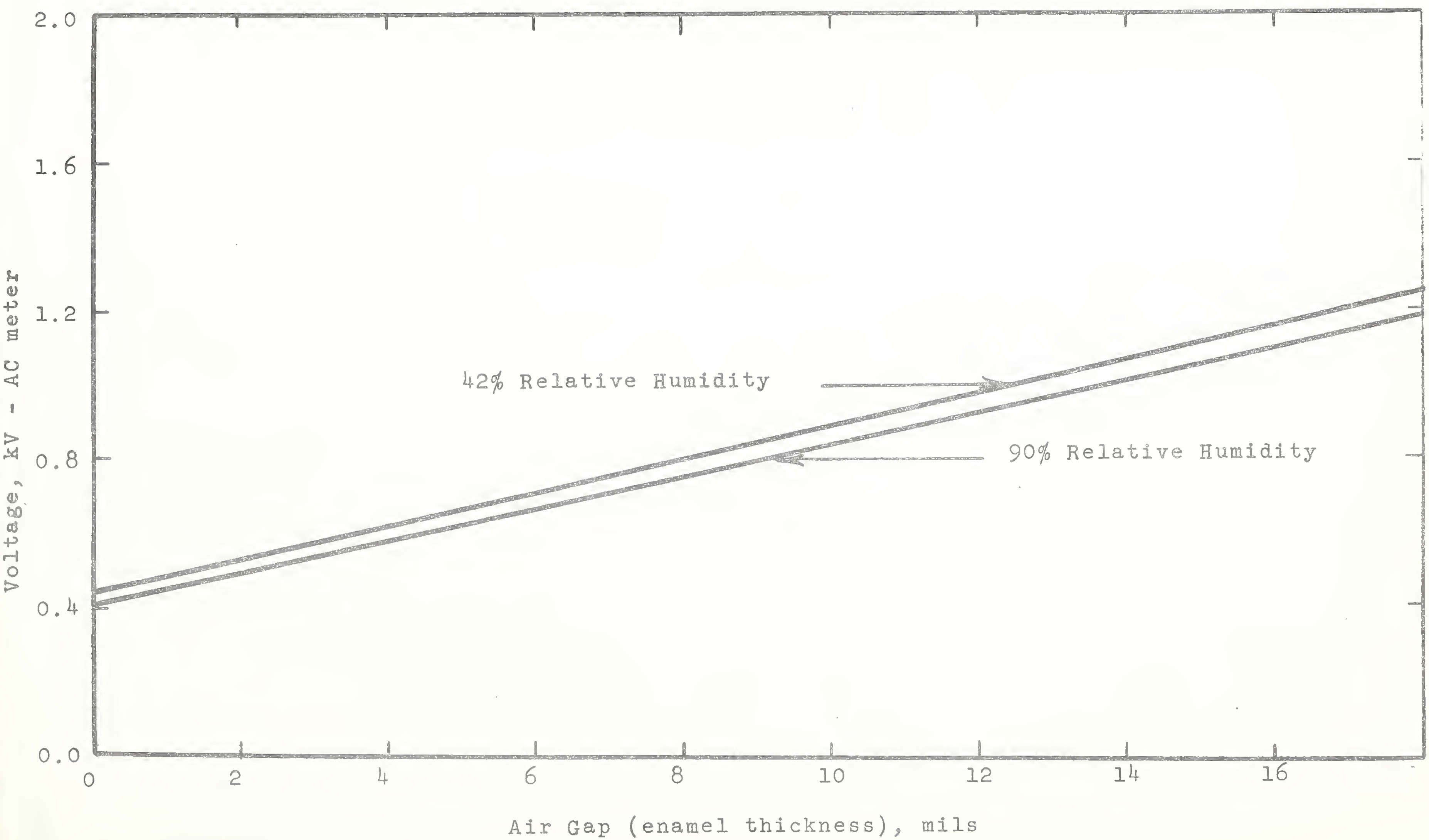

Figure 6. Effect of Humidity on the Air Gap Voltage - AC equipment used

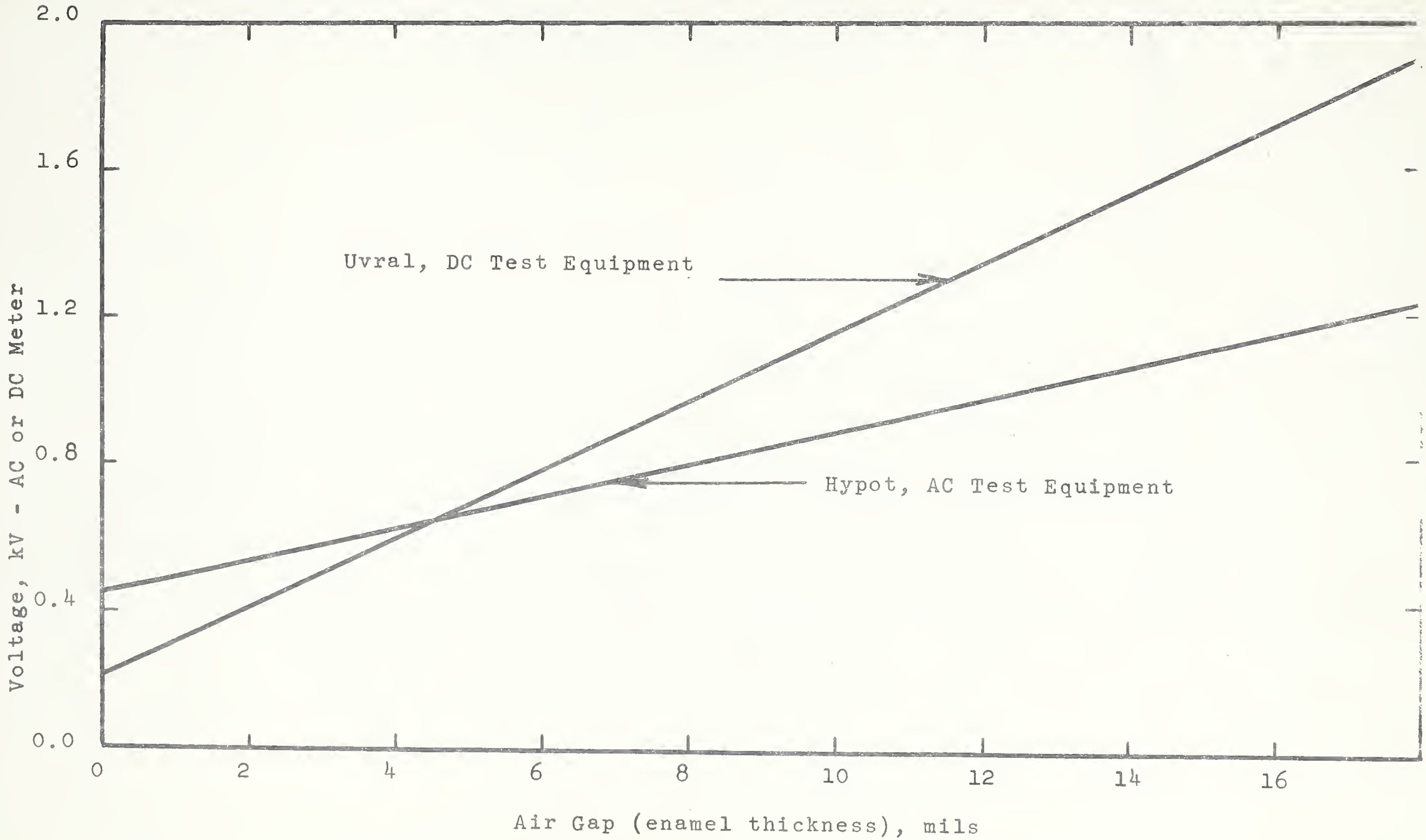

Figure 7. Comparison of Air Gap-Voltage Calibration Curves for AC and DC Test Equipment

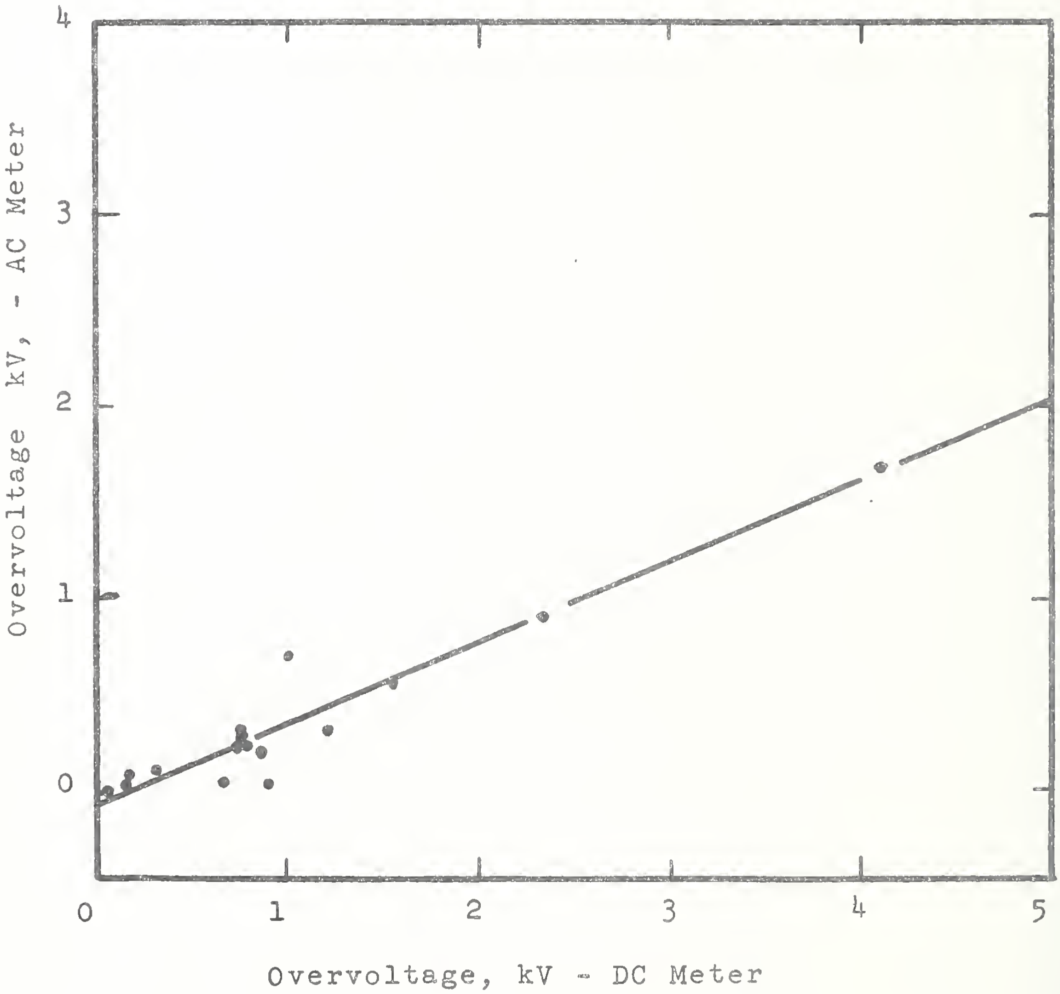

Figure 8. Comparison of Overvoltages Necessary to Puncture Virgin Enameled Specimens.