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A Comparison of Sheffield Instruments for Smoothness and Porosity With Others Now Used

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A Comparison of Sheffield Instruments For Smoothness and Porosity With Others Now Used

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Abstract

This report shows that there is a correlation between Bekk and Sheffield smoothness and between Gurley and Sheffield porosity. The correlation is not as good in the upper Bekk smoothness range or in the upper Gurley range.

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I. General Discussion of Porosity

Paper is a highly porous material. It has a low specific gravity compared to cellulose. Commercial papers contain as much as 70% air, due to: (1)

1. True pores, the openings which extend entirely through the sheet.
2. Recesses, those openings connected to one surface only.
3. Voids, the air spaces connected to neither surface.

In a rather typical paper the true pore volume was 1.6% of the total air present. (1) The remaining 98.4% of the air present was the recess and void volume.

Casey (1) gives a comprehensive discussion of porosity from which the material in the following paragraphs is taken.

Total air volume, which does not distinguish between pore, recess, and void volumes, can be determined by the formula: 1 – specific gravity of paper/ specific gravity of cellulose. Apparent density (calculated from the basis weight and thickness using the metric system) is used in the place of specific gravity, since it is impossible to determine the specific gravity of paper by the displacement of water. The pore volume of paper is equivalent pore radius. Equivalent pore radius is defined as the radius of a single pore of length equal to the sheet thickness which would give the same flow as the average value for all the pores in a unit area of the paper. It has been stated that the average effective pore size varies from 0.2 microns for coated book paper to 1.2 microns for bond paper. Blotting paper varies from 0.4 to 4.0 microns.

Porosity is measured by the resistance of a paper sample of given dimensions to the passage of air under standard conditions of pressure, temperature, and relative humidity. The results are expressed in time taken for the passage of a given volume of air or the amount of air passed in a given period of time. The flow of air through paper:

1. Is directly proportional to the pressure difference. (for a small pressure difference.)
2. Is directly proportional to the time of flow.
3. Is directly proportional to the effective area.
4. Is inversely proportional to the thickness of the sample.

Air resistance varies inversely as the fourth power of the radius of the pores. Two papers may have the same equivalent pore radius but different air resistance if the papers differ in thickness, since equivalent pore radius is independent of sheet thickness, whereas air resistance is dependent upon sheet thickness. Air resistance increases greatly with increasing solid fraction. There is no absolute relationship between sold fraction and air resistance, however, because papers made from different pulps have different air resistance, even at the same solid raction. The average pore diameter is greater in the machine direction than in the cross direction.

II. Importance of Testing Porosity (1)

Air-resistance measurements are commonly used as control tests for paper manufacture because of the indirect correlation between porosity and strength of the paper. Porosity is of direct importance in writing and printing papers, since it is a factor in the adsorption of inks. It is an important property of coating rawstock for pigment-coated papers, where it affects the adsorption of adhesive. It is definitely related to oil resistance although not to the rate of oil penetration, and is therefore an important property of greaseproof and oil-resistant papers. Porosity is an important property of unimpregnated electrical insulating papers because of its influence upon the dielectric constant.

Porosity is an extremely important property of saturating papers. It is very important in bag papers to be filled by valve connection where the bags must have a certain porosity to prevent bursting during filling. In cigarette papers, the porosity must be controlled through the use of filler (calcium carbonate) to regulate the burning rate. Anti-tarnish wrapping papers should be made with as low a porosity as possible. Porosity is very important in filter papers. Porosity or more specifically, void volume, is of particular importance in insulating papers. The voids in the paper should be small so that circulation of air within the voids is held to a minimum.

III. Detailed Discussion of Porosity Instruments to be Studied

A. Gurley Densometer (2)

The instrument consists of an outer cylinder which is partly filled with oil, and an inner cylinder, having an open top, sliding freely in the outer cylinder. Air pressure for the test is supplied by the weight of the inner cylinder. The sample is held between clamping plates having a circular orifice of 1.00 sq. in. in area. The clamping plates form the top of the inner cylinder. There is an elastic gasket between the clamping plates. The purpose of the gasket is to prevent leakage of air between the surface of the paper and the clamping plate.

Limitations of the Instrument (3)

1. Leakage at the edges.
2. Small testing area.
3. Lack of sensitivity.
4. Length of time required to test papers of low permeability.

B. Gurley S-P-S. Tester (2)

This instrument will be covered more fully in the smoothness section of this report.

C. Sheffield Porosimeter (4)

The Porosimeter consists of a precision fixture through which air is directed, and a Precisionaire metering device to measure the flow of air through the paper. The upper gage head is held against the paper by spring pressure. Air from the air gage, under a constant pressure of 10 lb. per sq. in., is brought thru passages in the base of the fixture, up thru the large orifice in the center of the lower gage head.

There is a rubber ring which acts as a seal against edge leakage and theoretically assures that all of the air passes through the paper. The 10 lb. per sq. in. pressure also serves to hold the paper sample firmly against the brass plate in the upper head. All of the air must flow through the paper and through the accurately drilled holes in the brass plate, finally exhausting to the atmosphere through holes in the upper block. The air gage is arranged so that the more porous the paper the higher the reading.

IV. General Discussion of Smoothness

Smoothness is concerned with the surface contour or mechanical perfection of the paper surface. Smoothness can be measured in two ways, under pressure and not under pressure. When smoothness is measured under pressure it is known as printing smoothness. The methods of measuring the smoothness of a free surface, not under pressure, are: (5)

1. Topographic mapping of a surface by means of a mickroscope.
2. Electrical pick-up method- The needle of an electrical phonograph pick-up moves over the paper surface and smoothness is evaluated in terms of the amplified response of the pick-up.
3. Frictional methods in which the coefficiant of friction between paper surfaces or between paper and a standard surface are measured.
4. An optical method which depends upon the difference in apparent reflectance of a surface when the incident light strikes at a large angle.
5. An electrical capacitance method in which the paper sample forms the dielectric.

Smoothness measurements under pressure are usually made by air flow instruments which measure the rate of flow of air across the surface of the paper. Air-flow smoothness testers are based upon the principle that the volume of air voids between a paper and a plane surface is proportional to the roughness of the paper, and that the rate of flow between these two surfaces is proportional to the volume of the air voids. (1) In carrying out the test, the paper is clamped under definite pressure, and the time is taken for a given volume of air to flow either between the paper and a standard surface, or between two or more sheets of the paper.

V. Importance of Testing Smoothness (1)

Increased beating of the stock increases the smoothness of the final paper. The shake on Fourdrinier machines is another important factor in improving smoothness. The type of wire and type and weave of felts used on the machine also affect the smoothness. Increased wet pressing and increased calendering improve the smoothness, but in general, it is better to make the sheet smooth rather than try to calender it smooth. Calendering a rough paper so that it is smooth creates hard spots in the paper which tend to swell when the paper is wet. Most printing papers are, however, calendered to increase their smoothness. Filling improves the smoothness, particularly after calendering. Surface sizing improves smoothness, and pigment coating has a very definite effect on smoothness, particularly if the coated paper is supercalendered. The type of pulp has an important effect on smoothness.

Groundwood pulps, as a rule, produce rough papers, because of the fiber bundles. Southern kraft pulps and some of the West Coast pulps produce rough papers because of the large size of the fibers. On the other hand, well-beaten spruce sulfite and rag pulps tend to produce smoothness papers because of the plastic nature of the paper at the time of wet pressing.

Smoothness is related to the appearance of the paper because, as a rule, a rough paper is unattractive. Paper with excessive wire and felt marks, or paper which is lumpy, fuzzy, or badly crushed is considered unsatisfactory. On the other hand small, even irregularities often give a pleasing appearance of pattern or texture. The most important factor is the average size of the surface irregularities, although the size, distribution, and arrangement of the irregularities are also important. Smoothness is of importance for writing papers where it affects the ease of travel of the pen over the surface of the paper. It is very important in printing papers because of its correlation with printing qualities.

One of the most important single properties of paper for relief printing is the smoothness or finish of the paper, because this determines the ease with which the printing plate can be brought into contact with thepaper. The printing plate carries an ink film about 3 to 10 microns in thickness, only about one-half of which is transferred to the paper. No contact will be made between the plate and the low spots in the paper if the depressions are deeper than the thickness of the ink film at the time of impression. Since the pressure received during printing may be as high as several hundred pounds per square inch, printing smoothness is determined by the softness and resiliency of the paper at high pressure, as well as the initial smoothness. Softness and resiliency, in combination with smoothness are better indications of printability than smoothness alone. A paper for letterpress needs to be smooth to enable fine half-tone screens to be reproduced. In offset lithography the interposition of the rubber blanket between the plate and the paper means that smoothness is much less important. In photogravure, smoothness is of the greatest importance.

VI. Detailed Discussion of Smoothness Instruments to be Studied

A. Bekk Smoothness Tester (6)

Theprinciple behind the Bekk smoothness tester is that the closer a rigid flat surface comes in contact with a paper surface, the smoother that surface. The closeness of contact between the two surfaces can, therefore, be measured by determining the degrees of tightness. The time is taken for a given volume of air to flow under reduced pressure between the paper surface and a flat polished glass surface having an area of 10 square centimeters. The air passed between the two surfaces is contucted through a circular aperture in the glass surface into a vacuum chamer. The vacuum is created in the chamber by means of a mercury pump, a mercury manometer being used to show the difference between the pressure in the chamber and the atmospheric pressure. The paper is placed with the surface to be tested in contact with the polished glass and rubber pad placed on the paper. A metal pressure disk is then placed on top of the rubber and a pressure of one Kg. per square cm. is applied through this plate to the paper by means of a pressure bar. The air pressure in the chamber is the adjusted to 380 mm., and the time is taken for the pressure to drop to 360 mm. representing the passage of 10 cc of air between the paper and the glass surface.

Limitations of the Instrument (7)

1. It is assumed that the spaces formed between paper and glass open into each other so as to form continuous air channels. Altho this is true in most cases, it is possible to have a rough surface with a honeycomb or closed cellular structure which will have a very high Bekk smoothness figure, because the surface provides few open passages from the circumference to the center of the metal ring.
2. Because of the compressibility of paper the smoothness changes rapidly during the first few minutesof application of pressure.
3. The rate of flow through a tube, other things being equal, depends upon the fourth power of the radius of the tube. This means that the effect of the larger air channels is greatly weighted at the expense of the smaller, and a surface which provides a few large and many small channels may appear to be rougher than is actually the case. Thus, the instrument fails to differentiate between a surface on which the irregularities are large but comparatively few and one on which they are small but numerous.

B. Gurley S-P-S Tester (1)

The paper is clamped between two optically flat metal surfaces having an effective area of one square inch. Pressure is applied by unweighted lever arm to place the paper under a pressure of 3 psi., which is lower than the pressure of the Bekk tester and one of the reasons for the lack of agreement between the two testers. Ordinarily, eight sheets of paper are tested at one time, which gives an over-all, top-to-bottom average of 16 surfaces in one reading. In carrying out the tests, the eight sheets are arranged so that the wire sides are in contact. A hole is then punched through the pad of sheets. The test does not differentiate between top and bottom side smoothness, but instead gives an average of the two sides. The results are usually reported as the number of seconds required for 50 ml. of air to pass between the test surfaces of 8 thicknesses of sample. In the case of paperboards, smoothness may be tested in the S-P-S tester by placing two specimens (the top one having a hole in it) between two pieces of rubber (the top one having a hole in it). The paper-board surface to be tested should be tested should be in contact with the corresponding surface on the other specimen so that the air flows out between two similar surfaces.

Limitations of the Instrument: Same as the Bekk instrument plus the fact that you cannot measure the smoothness of felt and wire sides separately.

C. Sheffield Paper Smoothness Tester (8) & (9)

The principle used was developed by Bendtsen, in Denmark. Further work was done by Sankey and White in Canada.

The air leak takes place across a distance of only 0.015 inch. The instrument is therefore particularly sensitive to irregularities in the paper surface which affect the printing smoothness under the contact of the type face.

The quality determined is a measure of the rate of flow of air which the paper permits to pass under the lands of the Bendtsen head, a higher reading thus meaning that the paper is rougher.

The essential part of the tester is a head, which consists of a weight having two accurately machined annular lands on its underside. The head is placed on the sample of paper with the space between the lands connected to a constant pressure air supply. The pressure is about one and three-eighths pounds per square inch. The only pressure on the paper is the wt. of the head itself. The air enters through the orifice and fills the annular groove between the two lands. This air then escapes or leaks across the surface of the paper and under these annular lands.

Effect of Variables in the System:

1. Effect of Variation in Air Pressure-The system must reduce the compressed air supply to a standard value, and maintain this standard. This requirement must be by manometer as a pressure gage is not sufficiently accurate.
2. Effect of Variation in Head Weight- The effect of head weight is much less critical than that of air pressure and the suggested tolerance is plus or minus two grams.
3. Effect of Changes in the Supporting Surface- At low head weights, giving low effective pressure under the lands of the tester, the apparent roughness is much greater with a soft backing than with a firm one, At higher head weights the apparent roughness of the paper is slightly less with soft backing.

VII. Principle of Precisionaire Type Meters (10)

The meters consist of:

1. A tapered glass tube set vertically in the air piping system with its large end at the top.
2. A metering float which is free to move vertically in the tapered tube.

The air flows through the tube from bottom to top. When no fluid is flowing the float rests at the bottom of the tapered tube and its maximum diameter is usually slected so that it blocks the small end of the tube almost completely. When flow commences in the pipe lines and the air reaches the float, the buoyant effect of the air lightens the float. However, as the float has a greater density than the air, the buoyant effect is not sufficient to lift the float. Therefore, the flow passage remains blocked and fluid pressure starts increasing. When the upward air pressure plus the buoyant effect exceeds the downward pressure due to the weight of the float, then the float rises and truly "floats" within the fluid stream.

With upward movement of the float toward the larger endof the tapered tube, and annular passage is opened between the inner wall of the glass tube and the periphery of the float, and through this opening the fluid passes. The float continues to rise till the annular passage is large enough to handle all the fluid coming through the pipe. Concurrently, the fluid velocity pressure drops till it, plus fluid buoying effect, exactly equals the float weight. The float then comes to rest in dynamic equilibrium. Any further increase in flow rate causes the float to rise higher in the tube, and decrease caused it to sink to a lower level.

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Experimental Outline

General Summary of Experimental Work

My experimental work will be divided into three main parts:

1. The determination of a correlation or lack of correlation between the Sheffield Smoothness Tester and the Bekk Smoothness Tester.
2. The determination of a correlation or lack of correlation between the Sheffield Porosimeter and the Gurley Densometer.
3. An attempt to determine the relative sensitivity of the Sheffield Smoothness Tester and the Bekk Smoothness Tester.

Detailed Discussion of Experimental Work

1. The determination of a correlation or lack of correlation between the Sheffield Smoothness Tester and the Bekk Smoothness Tester.

The paper used will be tested, in as far as possible in the same spot with the testers. Five grades of paper will be used which should cover the smoothness and porosity range of most printing papers. These five grades are:

1. Newsprint
2. Tub Sized Bond
3. Super Calendered Book
4. Machine Finish Coated
5. Two Side Coated Enamel

The estimated time to do this work will be three six hour periods. This figure was determined as follows:

Bekk Smoothness

Two minutes per test-20 tests---	40 minutes
Sample Cutting and Miscellaneous--	20 minutes
	60 minutes

Sheffield Smoothness

15 seconds per test-20 tests---	5 minutes
Circling of test area and recording---	20 minutes
	2 hours 25 minutes

This leaves 3 hours and 45 minutes of a six hour period of which 45 minutes is set aside for a conference. This means that I should be able to finish two grades per day with about an hour left for computation on the adding machine.

2. The determination of a correlation or lack of correlation between the Sheffield Porosimeter and the Gurley Densometer.

The same five grades of paper will be used and the paper will be tested in the same spot by the two testers. The estimated time to do this work will be five six hour periods. This figure was determined as follows:

Gurley Densometer

15 minutes per test-20 tests----	5 hours (probably less)

Sheffield Porosimeter

Two minutes per test-20 tests--	5 minutes
Circling of test area and recording----	20 minutes
	5 hours 25 minutes

This leaves only 35 minutes for computing but I don't think that all grades will require five hours to run the Gurley Densometer.

3. An attempt to determine the relative sensitivity of the Sheffield Smoothness Tester and the Bekk Smoothness Tester.

I will attempt to determine the relative sensitivity of the testers by running the smoothness on a sample of uncoated stock and marking the test area. I will then give the sample one pass through the laboratory calender and retest in the same spot as before. This procedure will then be repeated. By determining the standard deviation from the mean for each case and comparing the extent of the standard deviation it should be possible to predict the relative sensitivity of the two testers. I would like to spend three or four weeks on this attempt.

The remaining three or four weeks of the semester will be used to complete the computations, make additional tests (if necessary), and make the many graphs and charts which will be required.

IX. Experimental Results

A total of 100 tests were run in the smoothness series. I had to run 119 tests in the porosity series in order to fill an important gap in the curve. Figure one represents the smoothness results in graphical form and Figure two represents the porosity. I made an effort to straighten the curves by the use of log-log paper and then to draw conclusions from them but was unsuccessful.

X. Discussion of Results

Smoothness (Figure one)

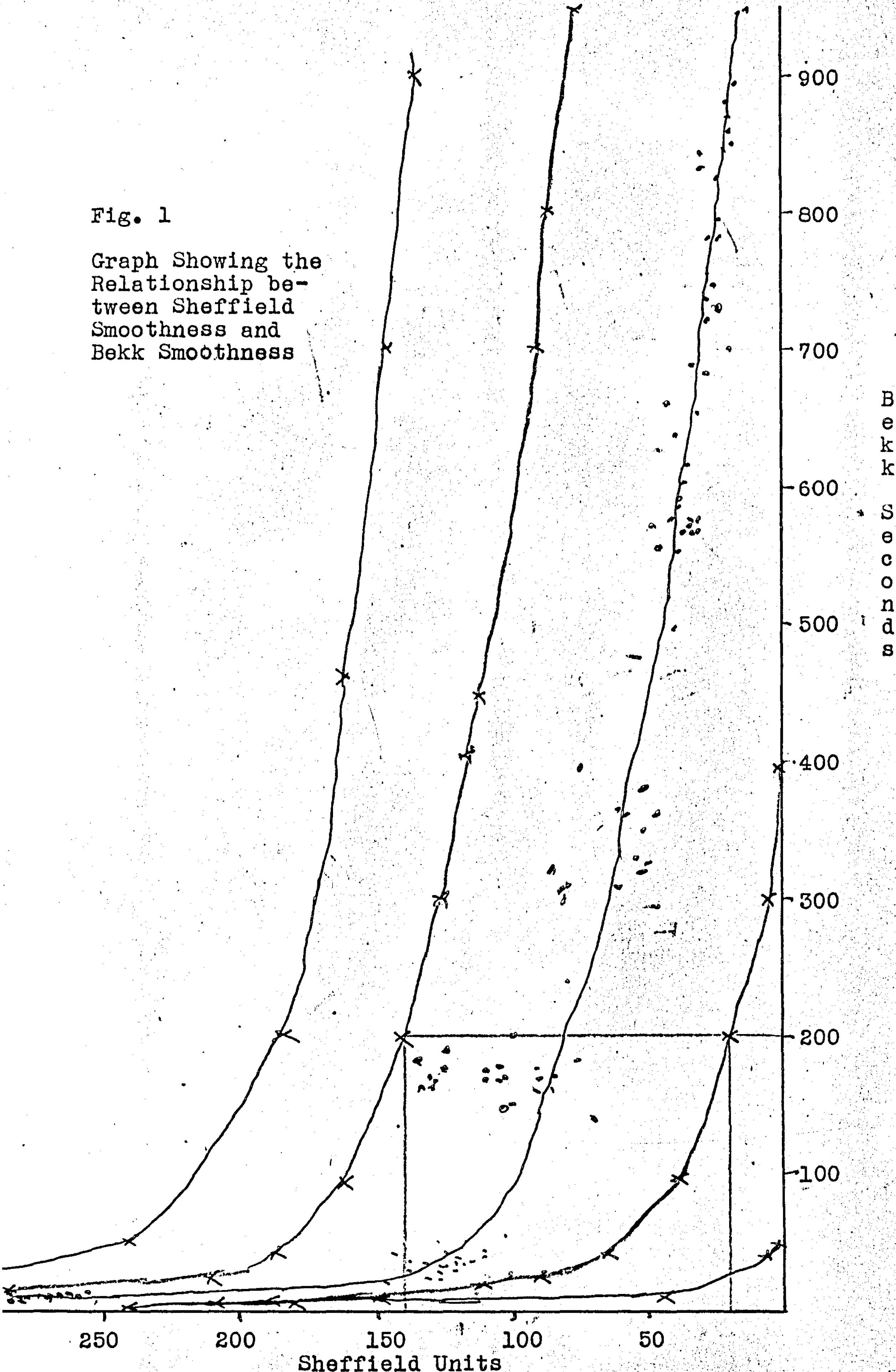
The curve passing through the points is, of course, the curve of the points themselves. The boundry curves in black are from the unsuccessful attempt using log-log paper. The boundry curves in red are one standard error of estimate away from the curve of the points.

In order to evaluate the information the graph I picked a value on the Bekk axis and found the spread of values on the Sheffield axis. An example of this is shown in blue in the graph. I then divided the Bekk reading by the spread of Sheffield readings. The results are tabulated below:

Bekk Reading	Spread of Sheffield Readings	Bekk/Sheffield
800	85	9.4
500	105	4.75
300	120	2.5
200	120	1.67
100	130	0.77
50	120	0.42

Fig. 1

Graph Showing the Relationship between Sheffield Smoothness and Bekk Smoothness



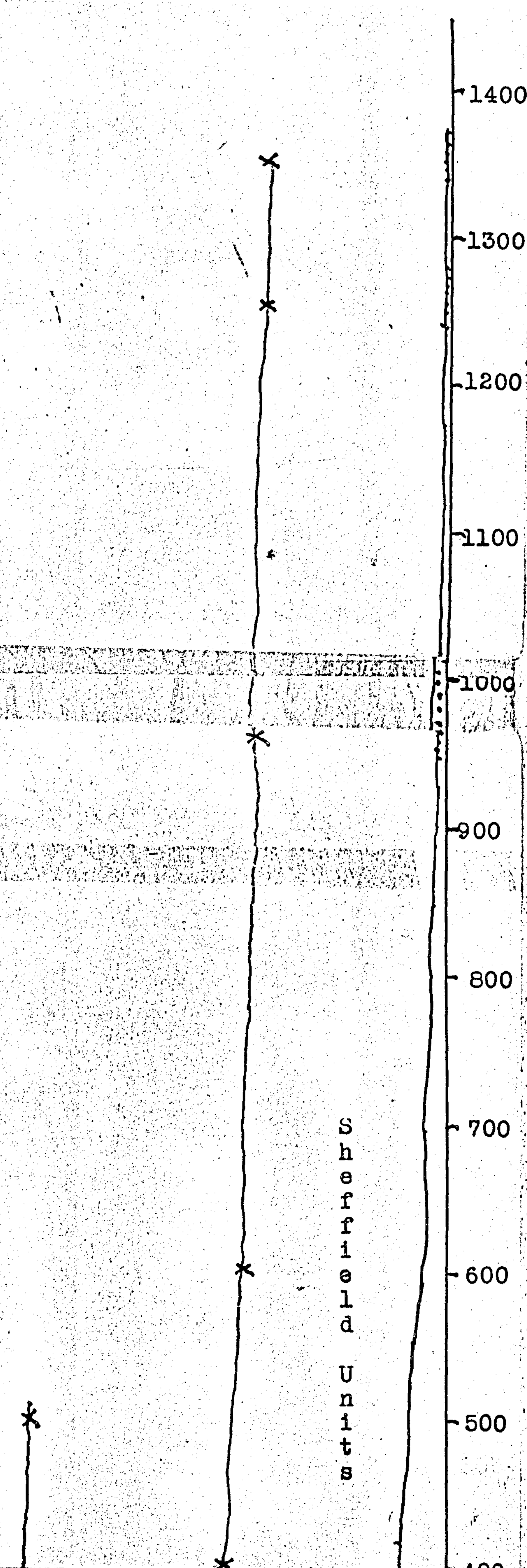


Fig. 2

Graph Showing the Relationship between Gurley Densometer and Sheffield Porosimeter

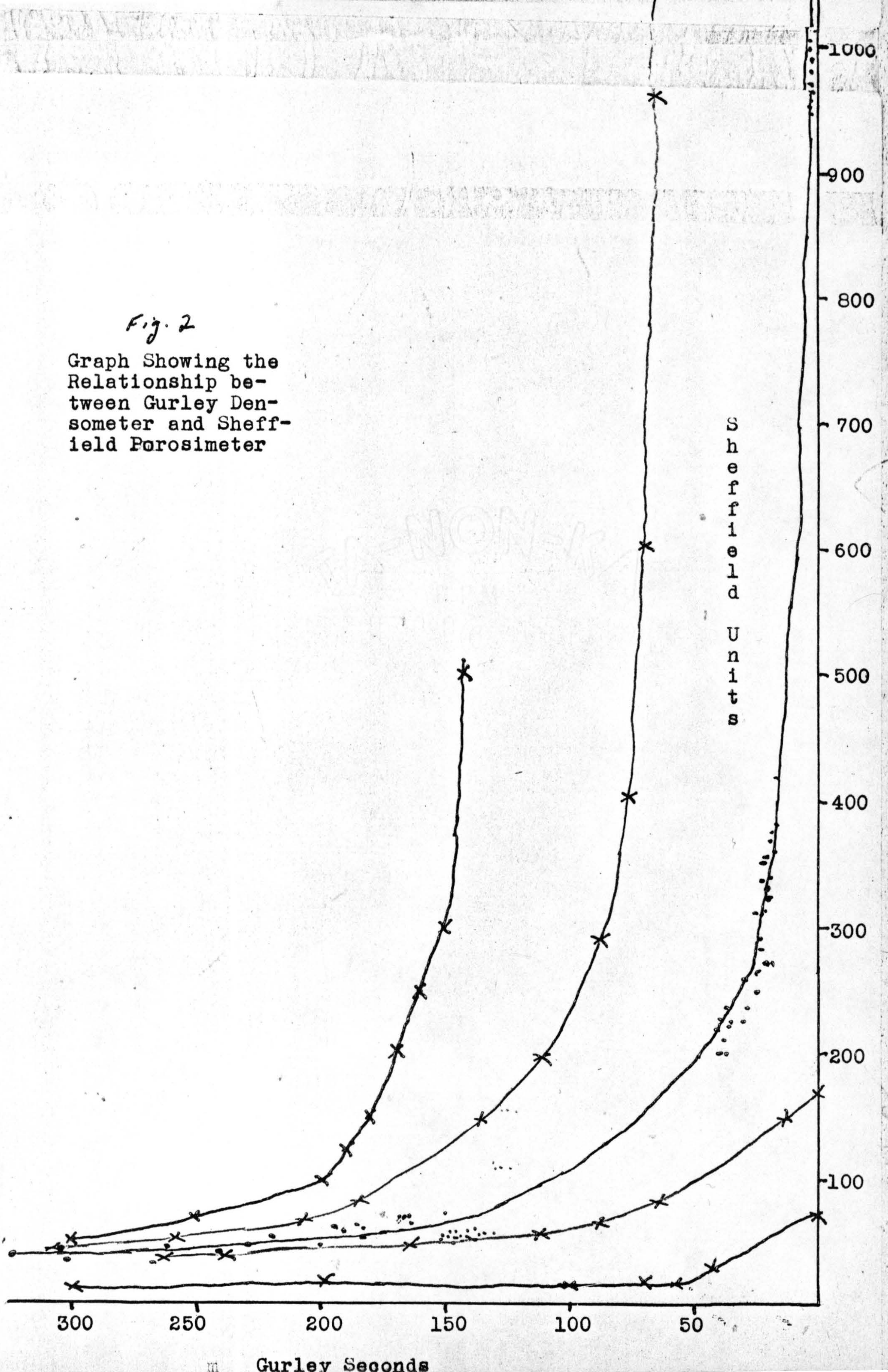


Fig. 2

Graph Showing the Relationship between Gurley Densometer and Sheffield Porosimeter

Porosity (Figure two)

This graph is set up the same way as the smoothness graph. The curves correspond to those on the smoothness graph.

The graph was evaluated in the same manner except that a value was picked on the Sheffield axis and the spread was found on the Gurley axis. It doesn't matter which axis was picked the same order of results would be obtained either way. The results are tabulated below:

Sheffield Reading	Spread of Gurley Readings	Sheffield/Gurley
550	74	7.4
300	125	2.4
115	100	1.2
75	115	0.65
50	140	0.36

XI. Conclusions

Smoothness

It is evident from the shape and uniformity of the curve that there is a correlation between Sheffield smoothness and Bekk Smoothness. The emperical figure obtained from dividing the Bekk reading by the spread in Sheffield values shows, however, that this correlation is not as good in the high range of Bekk readings as it is in the low range. This figure decreases as the paper gets rougher.

Porosity

The results show a parallel between the porosity findings and the smoothness findings. The emperical figure obtained from dividing the Sheffield reading by the spread of Gurley readings decreases as the paper gets more porous.

XII Recommendations

It would seem, except in the case of the smoothest and most dense papers, that the Sheffield instruments are good for the control testing of paper. The speed of testing is an important factor in making this recommendation.

June 1, 1956 John B. Yonker