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Note on Sintered Metal

with a view to its use as a Porous Surface in
Distributed Suction Experiments

By

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of the Aerodynamics Division, N.P.L.

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CURRENT PAPER NO. 9

ERRATA

Cover Page 1. Author's name should read J. H. PRESTON.

The graph labelled 9641 Fig. 1 should read Fig. 6.

The National Physical Laboratory,
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Note on Sintered Metal with a View to its use as
a Porous Surface in Distributed Suction Experiments

- By -

M. H. Preston, B.Sc., Ph.D. and A. G. Rawcliffe, B.A.,
of the Aerodynamics Division, N.P.L.

9th February, 1946

1. Summary.

(a) Reasons for Enquiry.- Considerable theoretical work has been done on boundary layer flow involving distributed suction through a permeable surface, on the other hand there have been few experiments to check the theory and these have used a series of slots to represent a porous surface. Their use in one case led to negative results because of their adverse effect on the pressure gradient. Hence the need for a truly porous surface.

(b) Range of Investigation.- Attention in this note is mainly confined to sintered bronze - a material which has wide range of porosity. A brief description of its properties is given and also the results of tests on a number of samples representative of the range available for commercial purposes. Measurements were also made of the porosity of beechwood and of Plaster of Paris.

(c) Conclusions.- The size of pores, their distribution and the resistance offered to the flow make porous a very suitable material for constructing models with porous surfaces. It has the definite advantages of some mechanical strength and it can be welded and soldered. There is one disadvantage - the surface cannot be machined as the pores might be closed up, hence accuracy of model manufacture depends on the precision to which it can be moulded and the distortion present after being furnaceed.

2. Introduction.

The mathematical theory of boundary layer flow with distributed suction has received considerable attention (see R. & M. 2244 by one of the present authors⁽¹⁾). As a means of boundary layer control, particularly in maintaining laminar flow and in preventing separation, distributed suction is very attractive. It has received little attention experimentally, presumably because of the difficulty of simulating the porous surface visualised in the theory. A few experiments^{(2), (3)} have been carried out using a number of relatively widely spaced slots, but these were not successful - failure in one case being traced to the strong adverse pressure gradients associated with the flow through the slots. Ackeret and Pfenniger⁽³⁾ however, were successful in their suction experiments, in which they used closely spaced slots. The building up of a surface of considerable extent by such means obviously presents difficulties.

Mathematical theory visualises a continuous homogenous flow through the surface, which, for simplicity, may be constant over the surface through which suction takes place. The ideal surface would be one of fine tubular structure in the form of a honeycomb, the tubes being sufficiently fine for a considerable resistance to the flow to be developed for a thin sheet. This is desirable because in experiments it may be necessary to achieve uniform suction for comparison with theory. Thus the suction head inside the aerofoil or other body must be low enough to 'swamp' the external pressure variations, at the same time the suction velocity through the surface will be fairly low. The nearest approach to this ideal appeared to be materials such as are used in fine filters. We then got into touch with C.R.L. and learned of the existence of sintered metal, which it seems will go far towards meeting our requirements.

3./

3. Description of Sintered Bronze.

Sintered bronze is manufactured by "Sintered Products Limited" Sutton-in-Ashfield Nottingham, under the trade name of "Porosint". It is apparently made from metallic granules, which are pressure moulded to the desired shape and then heated in a furnace. The following notes are based on information given in the manufacturers' brochure.

It is claimed that the pore size and porosity are carefully controlled. The pores are said to be uniformly distributed and interconnected. The porosity is controlled both in respect of volume from 10% to 60% and in size of pores from 2½ microns to 200 microns. The following grades are available.

Grade No	Maximum Particle to pass	Recommended thickness for filtration.
A	0.0001"	1/16"
B	0.0002"	1/16"
C	0.0005"	3/32"
D	0.001"	3/32"
E	No particulars given	

The tensile strength in general varies with the porosity. Grade A gives an ultimate tensile strength of from 2 to 3 tons p.s.i. with an elongation of 3%. The ductility varies with porosity and is between 3% and 15% in tension.

It must be noted that the surfaces cannot be machined as the pores would tend to close up. It is therefore necessary to rely on accuracy in moulding, if a surface of a specified shape is required. The material can be welded and soldered. The material in sheet form can also be bent if care is taken.

A certain number of standard shapes are available as listed below.

Cones	Max. Dia.	3"
	" Ht.	4"
	Wall thickness	3/32" to 3/16"
Sheets	Max. Length	12"
	" Width	6"
	Thickness	1/16"
Discs	Max. Dia.	6"
	Thickness	1/16" to 3/8"
Hollow Cylinders,	Outside Dia.	Max. Length
	5/8" to 1"	6"
	1" to 3"	2"
	Thickness	3/32" to 1/4"

Messrs. 'Sintered Products Ltd.' kindly supplied us with two samples, representing the extreme grades A and E. Grade A has an extremely fine porous structure, which is almost invisible to the unaided eye. Grade E is quite coarse, the pores being distinctly visible and the surface texture reminiscent of sandstone. Fig. 1 shows micro-photographs (magn 25) of the untouched surfaces and specially prepared sections, which show up the details of the porous structure. It will be noted that the pores do not lead through from one surface to the other in one plane, but are 3-dimensional. Experiments to measure the resistance to air-flow are given in section 5.

4. Application to Models.

From the point of view of aerodynamic experiments the only standard shapes of any interest are the circular cylinder and the hollow cone. The latter might/

might form the expansion of a rapid diffuser, in which separation is prevented by suction.

There is no reason why small aerofoils (5" chord x 8" span) suitable for the N.P.L. H.S.T. should not be made by moulding in two halves, which could be brazed together. Aerofoils of 8" chord (for the C.A.T.) might similarly be made in sections which could be joined together to form a wing of 4' span. Nose pieces for thin aerofoils, designed to achieve high lifts by use of nose suction, could also be built up for models of 30" chord, which might be tested in the 13' x 9' or the 9' x 7' tunnels. Surfaces of considerable extent say for large chord (6') aerofoils designed for testing the stability of laminar flow with suction would have to be built up from small sheets and might prove to be a difficult undertaking if precision in shape is required.

The great advantages of this material over ceramics from the point of model making are (a) some mechanical strength, and (b) possibility of attachment by brazing or soldering. There should be no difficulty in locating pressure tubes in the surface.

5. Resistance Measurements on Samples of Grade A and Grade E 'Porosint'

A graph was supplied by the manufacturers showing the pressure drop in lbs./sq.in. against mean velocity of flow through discs 1/8" thick for grades A and E. At small rates of flow 1ft. sec.⁻¹ the curves produced did not pass through the origin and as our experiments were likely to be concerned with flows of this order (1 ft. sec.⁻¹) it was decided to make measurements on the two samples.

Method of Tests

Specimen discs of roughly 2" dia. were washed in petrol to free the surface from grease or dirt which might have accumulated through handling. They were in turn placed in the apparatus shown in Fig. 2. Particular care was taken that no leakage could occur around the ends of the discs. Pressure air from one of the H.S.T. air bottles was led in through a filter. It then passed through the specimen disc and was metered on one of two 'Rotometers', covering a range of 0 - 8 cu.ft./min. These were loaned by the Engineering Division and had been carefully calibrated. The pressures on either side of the specimen were recorded against atmosphere, using a U-tube containing water or mercury. The pressure on the outlet side was closely atmospheric, but for the grade A specimen, the pressure on the inlet side was considerable and because of this, the inlet and outlet velocities of flow through the disc were different. The velocity on the inlet side was computed by assuming isothermal conditions.

Results

The results for grade A are shown on Fig. 3. The resistance is considerable. The pressure difference Δp when plotted against the outlet velocity gives a gentle curve through the origin which is convex upwards. When plotted against the inlet velocity the curve is concave upwards and when plotted against the mean velocity a straight line results - showing that the flow is of a truly viscous type. For the benefit of those who are used to thinking in terms of a pressure coefficient, defined by $C_p = \frac{\Delta p}{\frac{1}{2} \rho V^2}$, where V is the mean velocity, a graph of C_p against V is shown, which is hyperbolic. For instance, at $V = \frac{1}{2}$ ft./sec. $C_p = 15,000$. At 2 ft./sec. this has fallen to $C_p = 3,750$. Ordinary gauzes or perforated plates have resistance coefficients ranging from 0.5 to 20.0.

Figs. 4a and 4b show the results for the coarse grade E. It is evident that it is only at low speeds that the flow is viscous, as the curve is appreciably curved in a manner suggesting that 'hydraulic' resistance is predominating at the higher speeds, where the resistance coefficient is tending to a value of 10.

Fig. 5 shows the comparison with the manufacturers' results for grades A and E, and considerable discrepancies exist, particularly for grade E. It is not known whether these can be attributed to a less precise method of measurement being used by the firm, or to variations of porosity amongst specimens of the same grade. Nevertheless, it is evident from this figure that a very wide range of porosity and resistance/

resistance can be covered by sintered bronze.

6. Further Tests on Samples of Porous Bronze and on Other Materials.

With the completion of tests on the two extreme grades of porosint, other grades became available and were tested. In addition tests were carried out on a disc made from Plaster of Paris, and on a disc of beechwood cut normal to the direction of the grain (the pores of beechwood being more closely and more uniformly distributed than in any other wood). All the specimens were approximately 1/8" thick.

Results.- These are shown in Fig.6. The resistance of the two 'Porosint' grade 'A' samples differ greatly. The remaining samples have resistances which are intermediate between those of grades 'A' and 'D' and these differ appreciably from the values determined by the makers. Plaster of Paris has a much greater resistance than the finest porous bronze specimen (grade A) for a given rate of flow. It will be noted that Plaster of Paris and grade A 'Porosint' give a linear relation between pressure drop and mean velocity of flow through the disc. For beechwood and the 'Porosint' specimens grades B to E, the graph of pressure drop against velocity is curved in such a manner as to suggest that the flow is not truly viscous at the high rates of flow and that 'hydraulic' resistance is present.

7. Conclusions.

'Porosint' from the model point of view would appear to be the best porous material so far discovered, as it can be really attached to solid metal parts. Although the surface cannot at present be machined, there is a hope that thin sheet can be cold-pressed to the correct shape. The variations of resistance between samples of the same grade imposes limitations on model construction, as it would mitigate against a number of sheets being joined together. On the other hand, more careful control during manufacture might get rid of this trouble.

Subject to the requisite precision in model manufacture being attained by pressure moulding, porous bronze, particularly the finer grades, should meet the requirements for distributed suction tests. The pores appear to be fine and closely spaced, so that the destabilising effects arising from the use of widely spaced slots or holes, of dimensions comparable with the boundary layer thickness, should be absent. The resistance to flow of the finer grades will be of the viscous type i.e. the pressure drop varies directly as the velocity and inversely as the thickness.

Plaster of Paris has too great a resistance for thicknesses which would be used in model experiments and moreover it is too fragile.

Beechwood is a possibility for model work, but with the grain running normal to the surface it is very weak. Also it seems fairly likely that variations of porosity will occur across the sheet due to natural causes and the sawing and planing processes.

8. Acknowledgements.

To Mr. Roff of C.R.L., who called our attention to this material.

To Dr. Northcott of A.R.D. (Metallurgical Section) for general information and for the photographs of Fig.1.

To Mr. Prosser of Engineering Division for the loan of two 'Rotometer' flow meters.

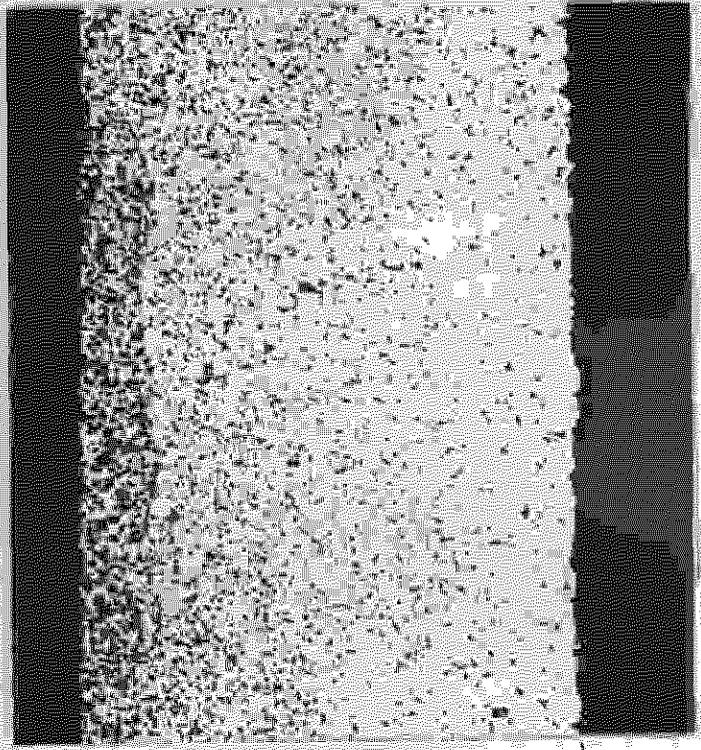
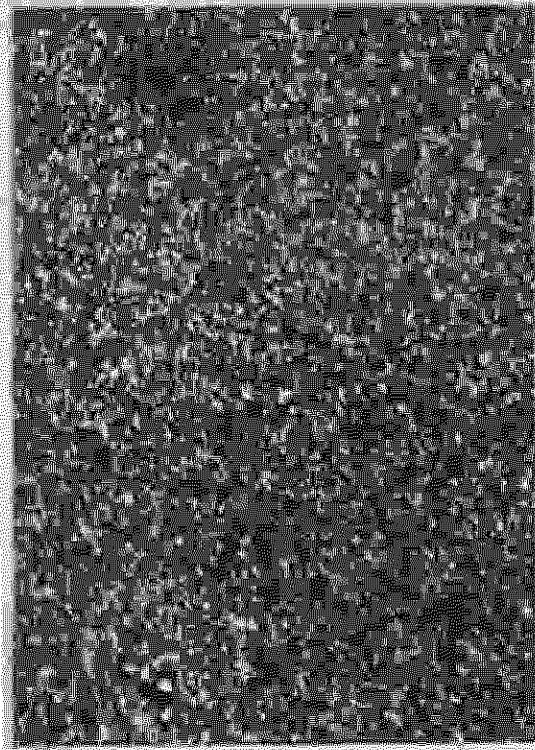
To 'Messrs. Sintorel Products Limited' for information and the two sample filter discs.

9. N.B. Since the publication of this note, M. R. Head⁽⁴⁾ has measured the resistance of other porous materials suitable for experiments on boundary layer control.

References

<u>No.</u>	<u>Author</u>	<u>Title</u>
1.	J. H. Preston.	The Boundary Layer Flow over a Permeable Surface through which Suction is Applied. R. & M. 2244.
2.	J. A. Zaloveak, J. W. Wetmore and A. E. von Doenhoff.	Flight Investigation of Boundary Layer Control by Suction Slots on an N.A.C.A. 35-215 Low-Drag Airfoil at High Reyn lds Numbers. N.A.C.A. Advance Confidential Report. A.R.C. 7955.
3.	J. Ackeret and W. Pfenninger.	Prevention of Turbulent Boundary Layers by Suction. R.T.P. Translation No. 1819. A.R.C. 7023.
4.	M. R. Head.	Tests of Porosity of Materials for Use in Experiments on Boundary Layer Control. A.R.C. 12,337.

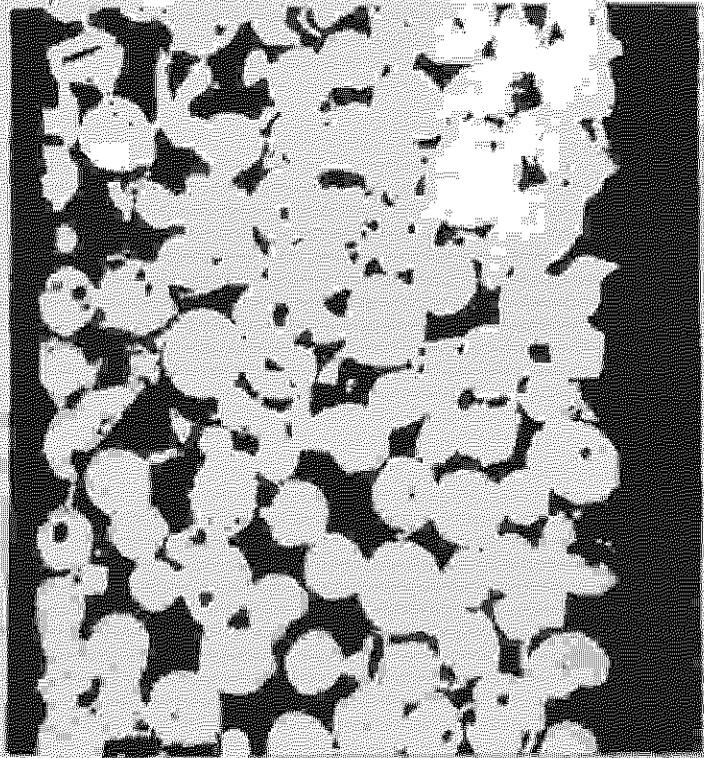
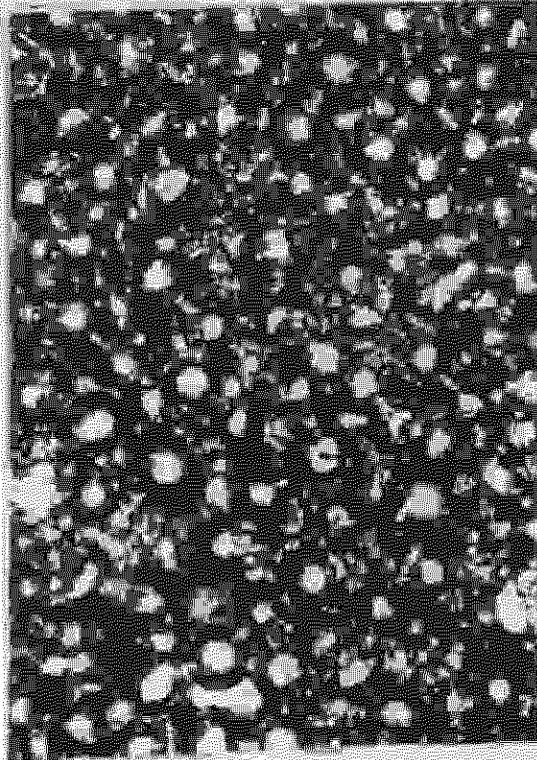
Grade "A"



View on Surface

Section thro' disc

1/8" approx.

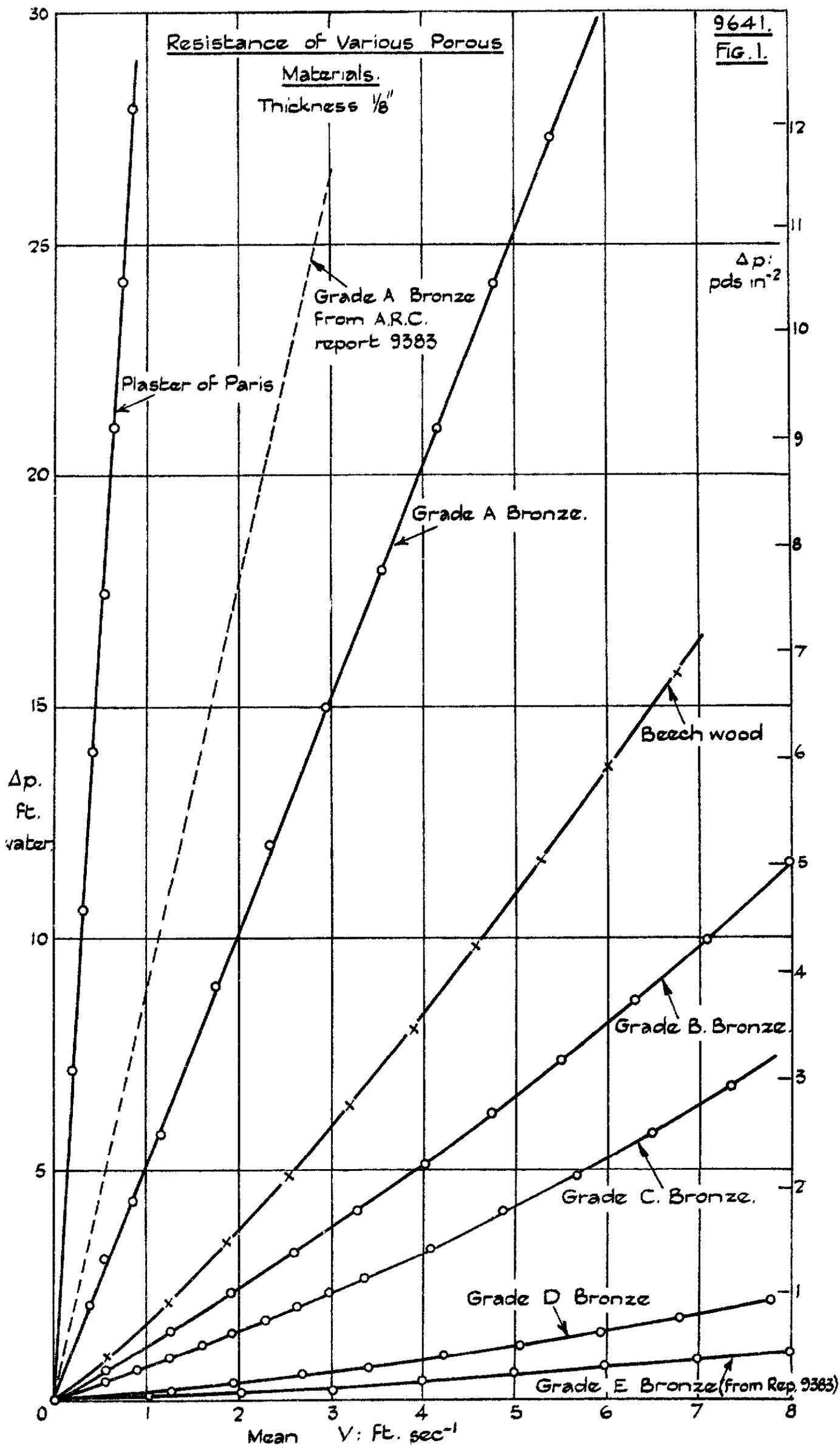


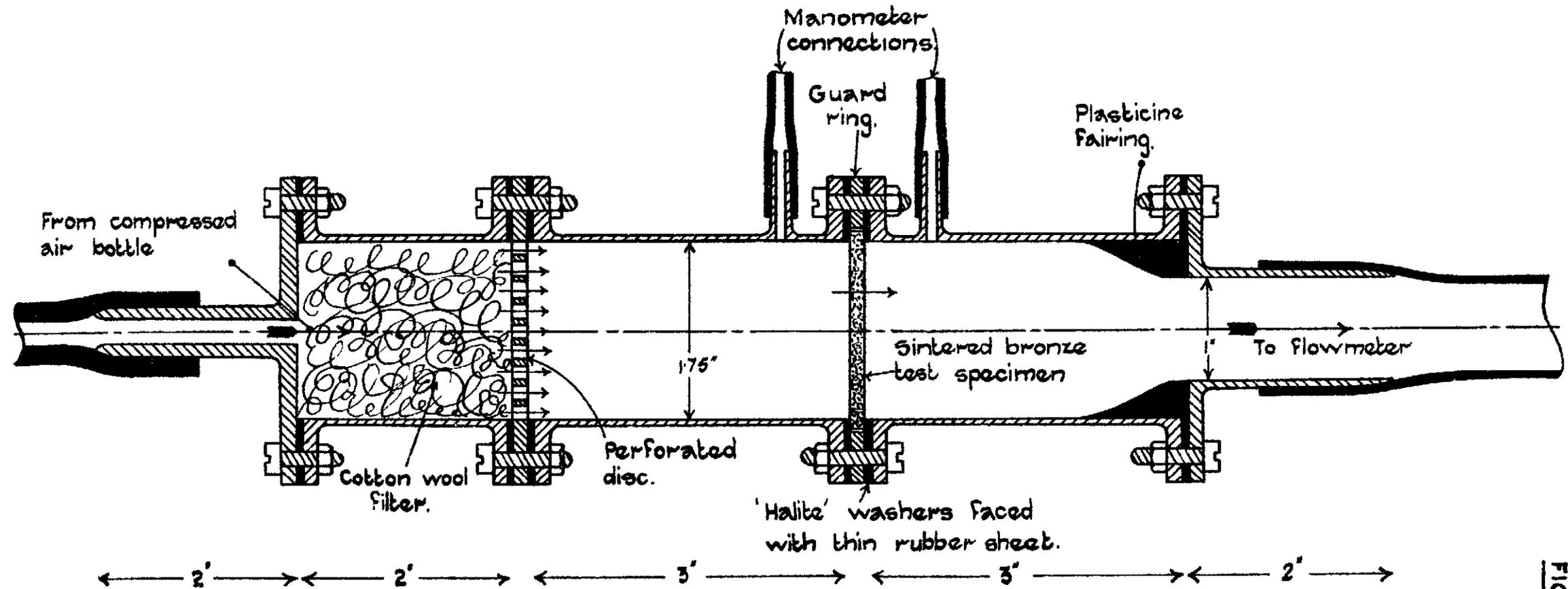
Grade "E"

Photographs of Porosint (Magnification 25).

Resistance of Various Porous
Materials.
Thickness $\frac{1}{8}$ "

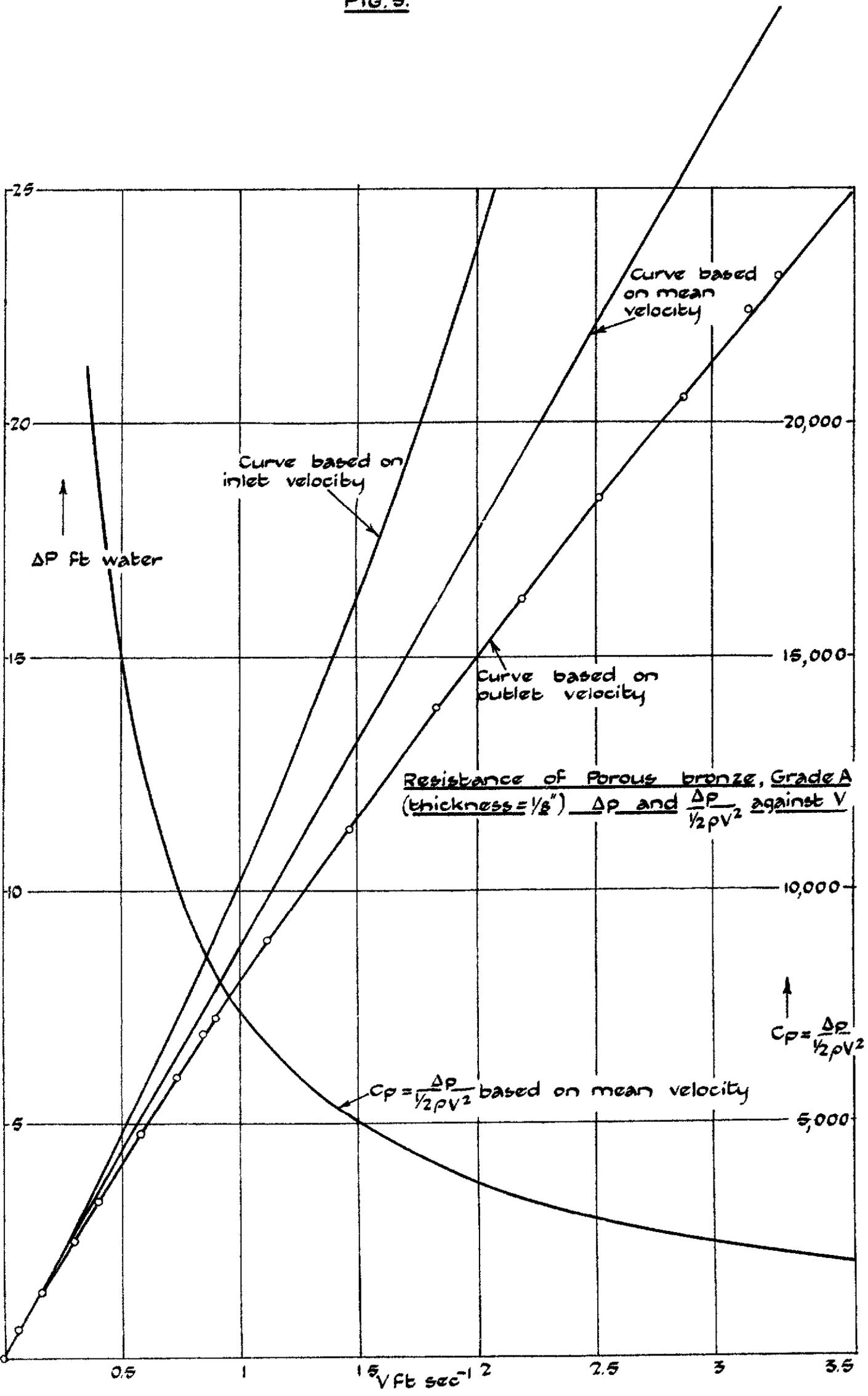
9641.
Fig. 1.





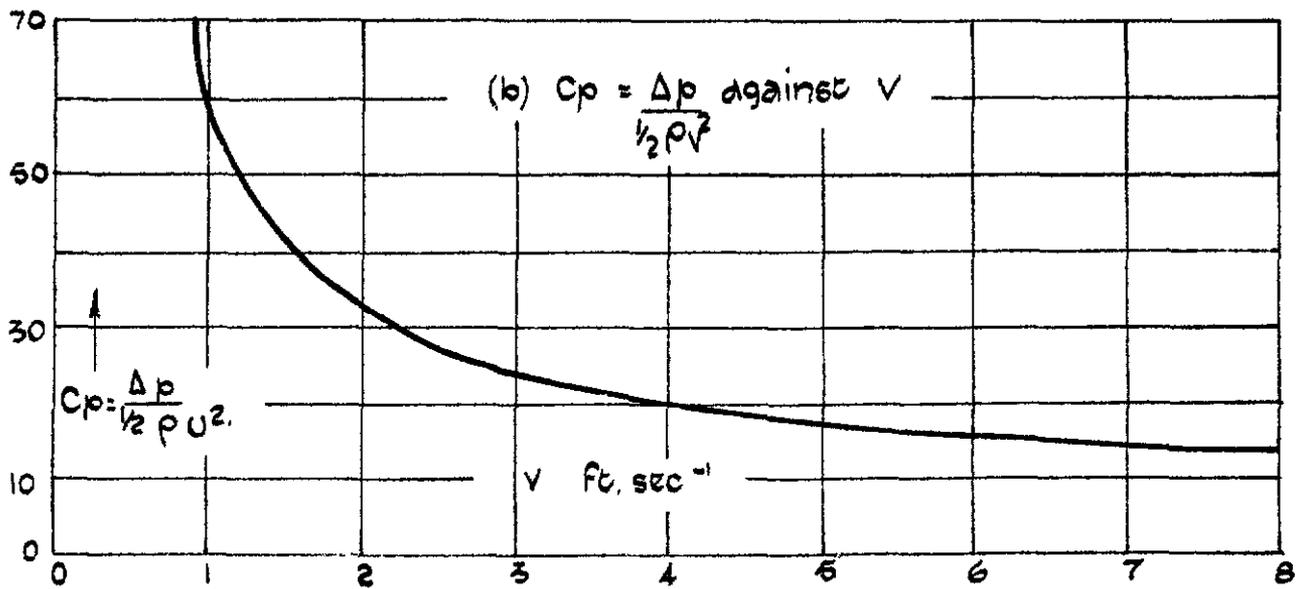
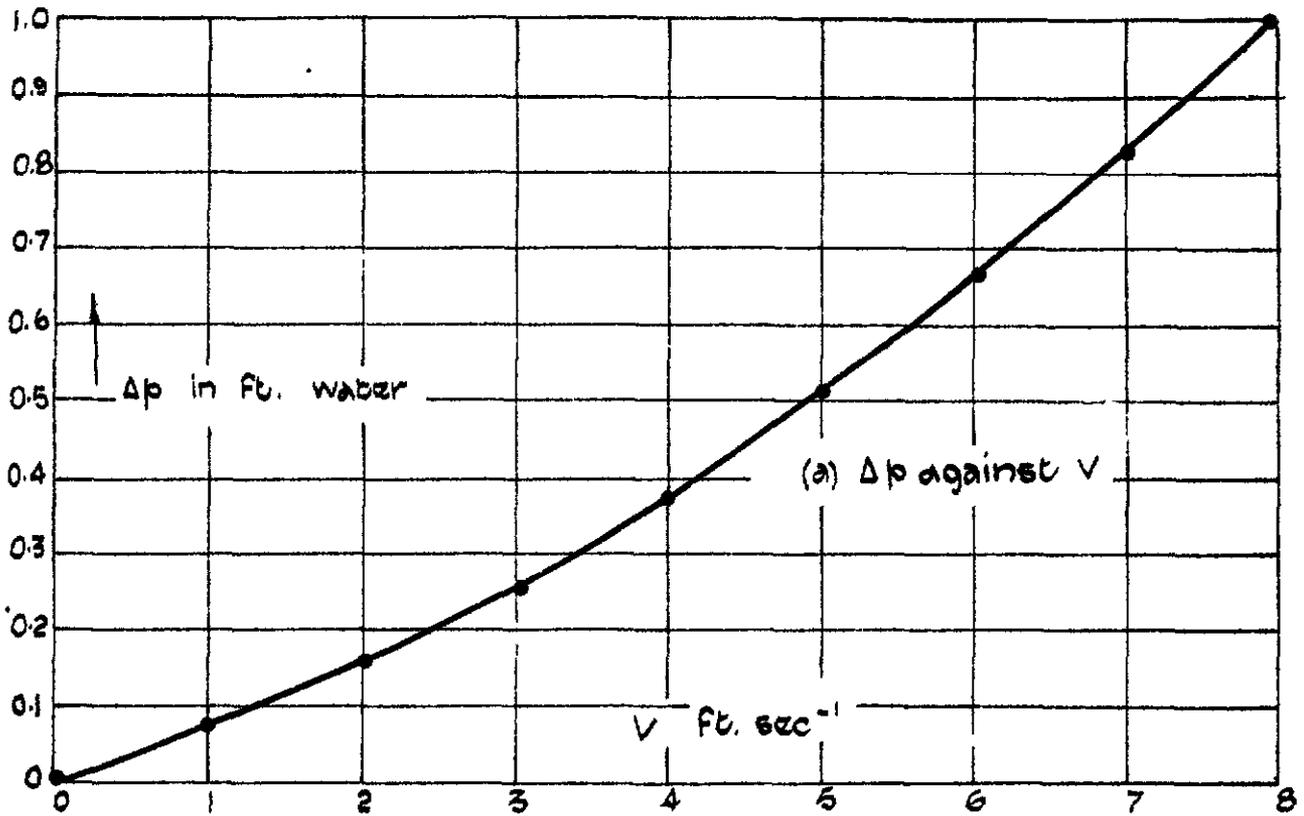
Test apparatus for specimens of porous material.

9363
Fig. 3.

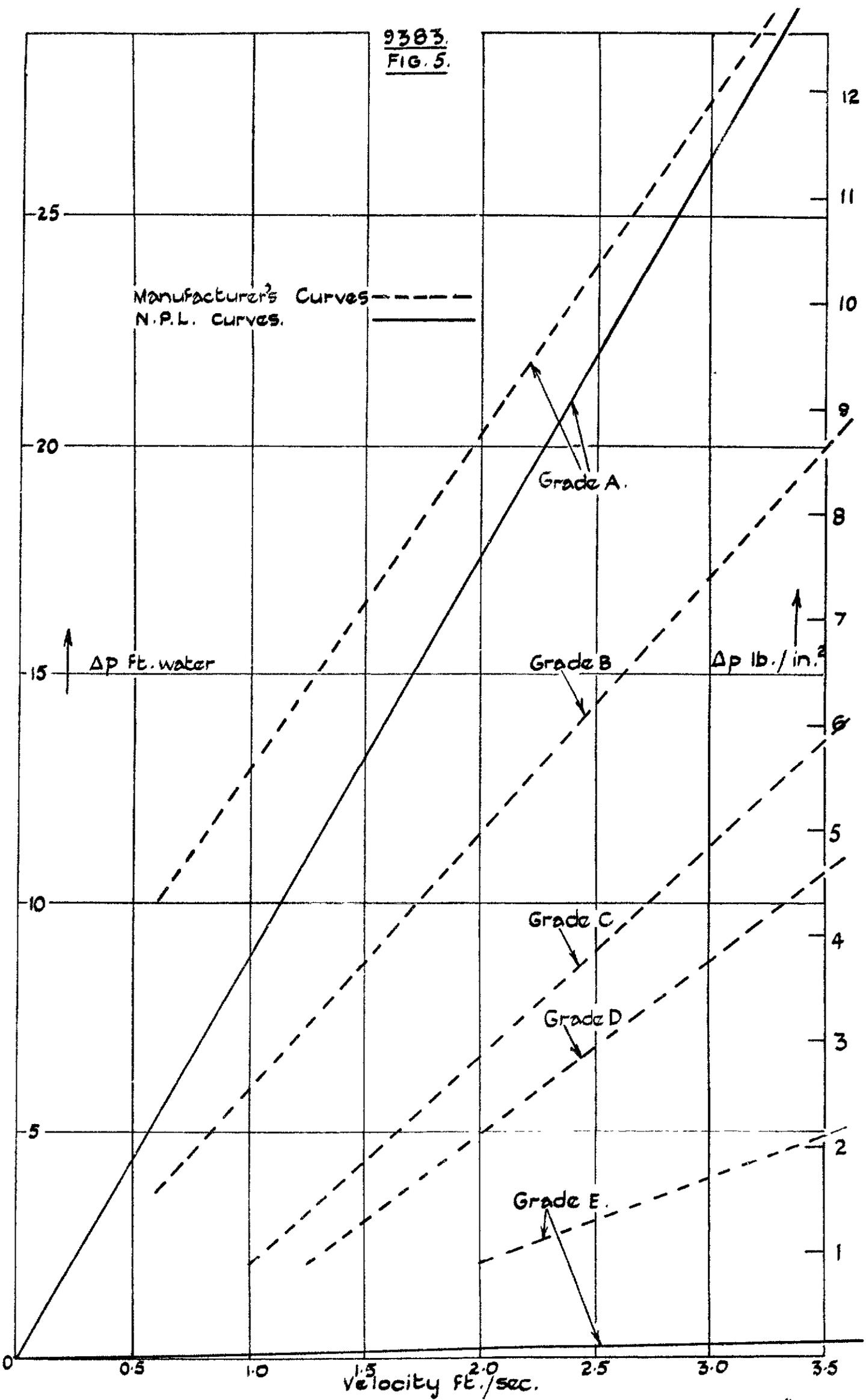


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FIG 4



Resistance of Porous Bronze Grade E
(Thickness = $\frac{1}{8}$ ").



Resistance of various grades of porous bronze (thickness = 1/8"). vs.

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