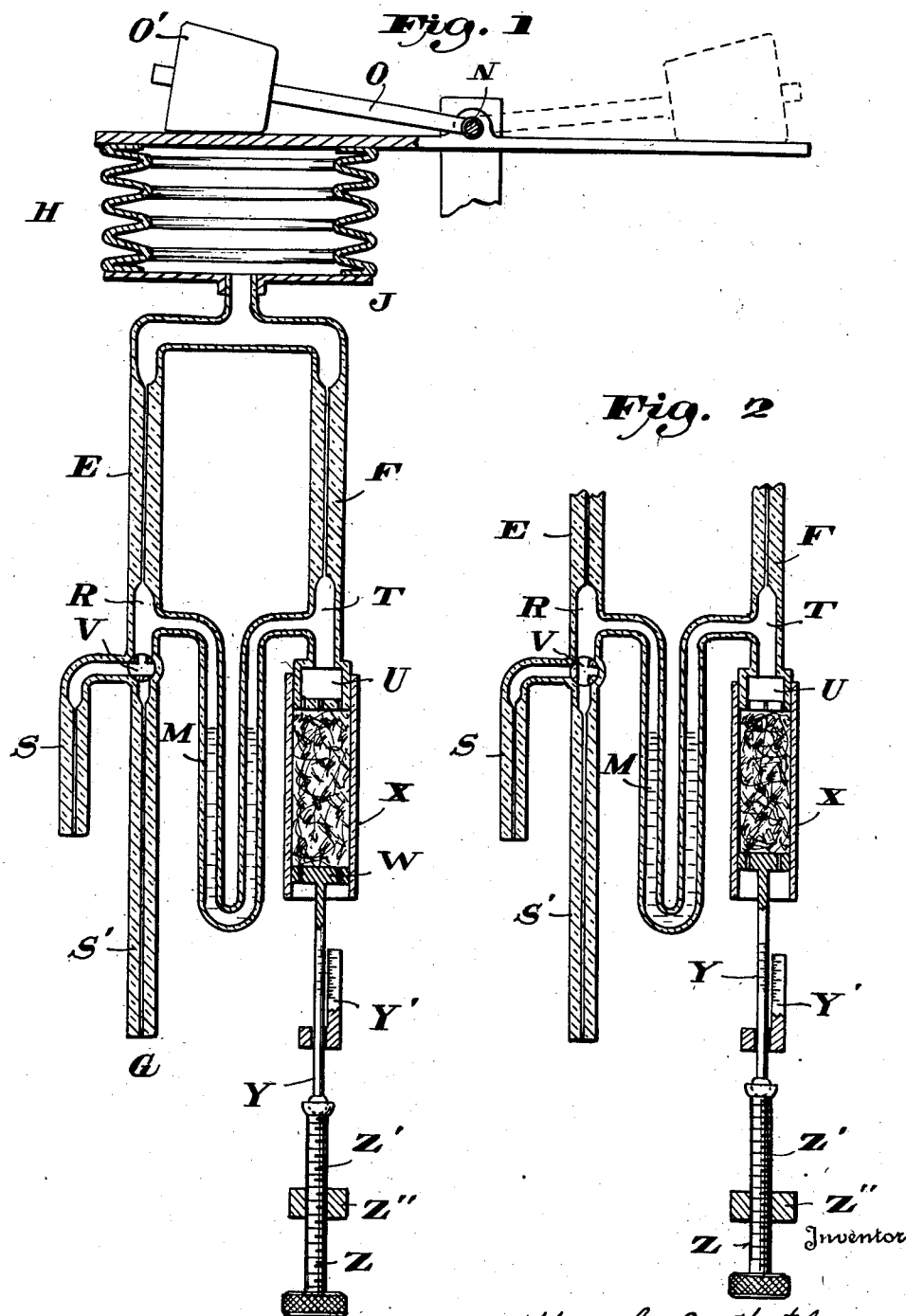


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K. L. HERTEL
METHOD OF AND APPARATUS FOR DETERMINING PHYSICAL PROPERTIES
OF POROUS COMPRESSIBLE MATERIAL
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Kenneth L. Hertel,
By Stone, Boyden & Mack,
Attorneys

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METHOD OF AND APPARATUS FOR DETERMINING PHYSICAL PROPERTIES OF POROUS COMPRESSIBLE MATERIALS

Kenneth L. Hertel, Knoxville, Tenn., assignor to University of Tennessee Research Corporation, Knoxville, Tenn., a corporation of Tennessee

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8 Claims. (Cl. 73-51)

This invention relates to a method of and apparatus for determining physical properties or factors related to the resistance to fluid flow offered by a confined mass of porous, compressible material.

The present application is a division of my prior, co-pending application, Serial No. 294,727, filed September 13, 1939.

Specifically, one factor which it is possible to determine by means of the present invention is the total surface per gram of the compressible fibrous material such as cotton, wool, etc.

Another factor which it is possible to determine by means of the invention is the density of the substance constituting the material.

When applied to fibrous materials such as raw cotton, for example, the invention provides a means for comparing the relative fineness of the fibers, as the term "fineness" is popularly understood. This characteristic is correlated to the factor which it is possible to really measure, namely the total surface area of the fibers per gram of material, and thus by determining the total surface area per gram of different samples of cotton, a general idea of the relative fineness of the fibers may be obtained.

In carrying out my novel method, I prefer to employ the apparatus disclosed in my said prior co-pending application, and in order that the invention may be readily understood, such apparatus is illustrated in the accompanying drawing, forming part of this specification, and in which:

Fig. 1 is a general view showing the apparatus in longitudinal section, parts being in elevation, and illustrating one step of my novel method; and

Fig. 2 is a fragmentary similar view, illustrating another step in the carrying out of the method.

Referring to the drawing in detail, the apparatus comprises a fluid conduit structure arranged in the form of a "bridge," having two pairs of arms E, S, and F, X. The free end of one arm of each pair is open to atmosphere as at G, while the other ends of one arm of each pair are connected together as at J, and the common junction connected to a source of fluid pressure illustrated conventionally as a bellows H.

This bellows is secured at its upper end to a platform L pivoted to a fixed support at N. Also pivoted to this support at N is an arm O having at its end a weight O'. This weighted arm can be turned about the pivot N from full line position to dotted line position as shown in Fig. 1. When in full line position, it tends to compress

the bellows and to force air under pressure down through the conduit J to the bridge structure above referred to. If, on the other hand, the weighted arm is thrown over to the dotted line position, it tends to expand the bellows, thus creating a partial vacuum and drawing air up from G through the arms of the bridge.

The arms E, F and S of the bridge consist of capillary tubes, which offer a known or determinable resistance to the flow of air. As illustrated in the drawing, two arms S and S' of different length are shown, and a rotary plug valve V is provided for operatively connecting either one or the other of these arms as desired.

The fourth arm of the bridge offers an unknown resistance to the flow of fluid such as air, and contains the sample of material to be tested. As shown, it comprises a cylindrical container into the opposite ends of which are fitted perforated pistons U and W, the former communicating with the conduit structure constituting the bridge and the latter communicating with atmosphere.

The arrangement illustrated in the drawing is for the purpose of measuring the fluid flow resistance of a mass of compressible fibrous material, such as raw cotton. This is contained within the cylinder X, and is confined between the pistons U and W. The piston W is provided with a rod or stem Y passing through a fixed guide and swiveled at Z' to the end of an adjusting screw Z working through a fixed support Z''. Thus the extent to which the sample of material in the cylinder X is compressed may be varied by turning the screw Z. A suitable scale, preferably including a vernier, may be employed at Y' to enable the extent of movement of the piston W to be accurately read.

Connected across the junction point R of the arms E and S, and the junction point T of the arms F and X of the bridge, is a pressure-responsive device shown as a manometer tube M, containing a suitable liquid. If the pressure at R and T are equal, then of course the liquid will stand at the same level in the two legs of the manometer, while any difference in pressure will be indicated by a difference in the level of the liquid.

When a difference in fluid pressure is applied to the two ends J and G of the conduit system, as by means of the bellows H, fluid tends to flow through the arms of each pair in series and through the two pairs of arms in parallel. Obviously the same quantity of fluid will flow through the arms E and S, and the same quantity will flow through the arms F and X. If the drop in

fluid pressure from the point J to the point R, at the junction between the arms E and S, is equal to the drop in fluid pressure from the point J to the point T at the junction between the arms F and X, then the pressure at R and T will be the same, and the system is balanced.

This balancing occurs when the resistance of E bears the same proportion to the resistance of S, as the resistance of F bears to the resistance of X. If E and F are, as shown, equal, then, when the system is balanced, the resistance of X is equal to the resistance of S.

In order to secure this balance, in which X and S are of equal resistance, the mass of material in X is compressed by means of the screw Z until equality is obtained, as indicated by the liquid in the manometer M.

Thus by virtue of the balanced system as above described, the exact pressure generated by the bellows H is immaterial, and it is even immaterial whether or not this pressure remains absolutely constant during the taking of a test. It will, of course, be understood, that in operation, the degree of compression is small, the resistance is relatively high, and the amount of fluid flowing through the apparatus per second is relatively small as compared with the capacity of the bellows.

When the above described balance is obtained, it is possible to express the resistance of the unknown arm X in terms of the resistance of E, F, and S.

If p is the pressure drop across the ends of a capillary tube of length l , having a radius r , and a cross-sectional area A , Q the volume of fluid flowing per second, and μ the viscosity of the fluid, Poiseuille's equation states that:

$$p = Q \frac{l}{A} \frac{8\mu}{r^2} \quad (1)$$

It has also been shown that if p is the pressure drop across a porous mass of finely divided material, of uniform cross-section A , throughout its length l , a the total surface area per cc. of the actual substance of the material exposed to the fluid, and f is the fraction of the total space which is occupied by the material itself (such total space being taken up by both the material and the voids between the particles thereof), then:

$$p = Q \frac{l}{A} \frac{9\mu}{2k} \frac{a^2 f^2}{(1-f)^3} \quad (2)$$

where k is some constant, approximately unity.

As above pointed out, it is obvious that the quantity of fluid flowing through E and S is the same, and the quantity flowing through F and X is the same. The first will be designated Q_1 and the second Q_2 .

Employing these designations, and using the subscripts 1, 2, 3 and 4 to indicate the factors corresponding to the arms E, F, S and X, respectively; and also assuming that the pressure drop across E and F is the same, and consequently that the drop across S and X is the same, Equation 1 above, can, under balanced conditions, be applied as follows:

$$p_1 = Q_1 \frac{l_1}{A_1} \frac{8\mu}{r_1^2} = Q_2 \frac{l_2}{A_2} \frac{8\mu}{r_2^2} \quad (3)$$

where p_1 is the pressure drop across E and F.

The ratio

$$\frac{Q_2}{Q_1}$$

can be obtained from the above Equation 3, thus:

$$\frac{Q_2}{Q_1} = \frac{\frac{l_1}{A_1 r_1^2}}{\frac{l_2}{A_2 r_2^2}}$$

This ratio depends upon the dimensions of the particular apparatus being used, and is therefore a constant which may be designated K .

Similarly, Equation 2 may be applied as follows:

$$P_2 = Q_1 \frac{l_3}{A_3} \frac{8\mu}{r_3^2} = Q_2 \frac{l_4}{A_4} \frac{9\mu}{2k} \frac{a^2 f^2}{(1-f)^3} \quad (4)$$

where p_2 is the pressure drop across S and X.

Obtaining the ratio

$$\frac{Q_2}{Q_1}$$

also from the above Equation 4, the two right hand members of Equation 4 can be written (cancelling out common terms:

$$\frac{Q_2}{Q_1} = \frac{\frac{l_3^3 \mu}{A_3 r_3^2}}{\frac{l_4}{A_4} \frac{9\mu}{2k} \frac{a^2 f^2}{(1-f)^3}} = K \quad (5)$$

The two right hand members of this expression form an equation from which p , Q and μ have been eliminated, thus showing that the result is true, regardless of the value of these factors.

From this:

$$K a^2 = \frac{l_3^3}{A_3 r_3^2} \cdot \frac{A_4 2k (1-f)^3}{l_4 9 f^2} = \frac{16 A_4 l_3 k (1-f)^3}{9 A_3 r_3^2 l_4 f^2}$$

The above equation can be simplified to read:

$$K a^2 = \frac{C (1-f)^3}{l_4 f^2} \quad (6)$$

where

$$C = \frac{16 A_4 l_3 k}{9 A_3 r_3^2}$$

In this expression, it will be remembered that l_3 is the length of the capillary tube S, A_3 is its cross-sectional area, and r_3 its inside radius. A_4 is the cross-sectional area of the cylindrical mass of material being tested at X. Hence, all of these quantities are constant for a given standard resistance tube and particular piece of apparatus.

However, Equation 6 cannot be solved in terms of known quantities, because it contains two unknowns, namely, a and f . I propose, however, to develop a second equation involving these terms, by securing another set of data, to obtain a new value of C . To accomplish this, I provide a second standard capillary tube, designated S' in Fig. 1, controlled by the valve V. By turning this valve clockwise 90° from the position shown in Fig. 1, the tube S will be cut off, and the tube S' connected to the arm E of the "bridge," as shown in Fig. 2. Having connected the tube S' , as described, the porous body of fibrous material in the cylinder at X is compressed longitudinally by means of the screw Z, also as shown in Fig. 2, thus increasing its resistance until a condition of balance, as indicated by the manometer, is again obtained.

The compression of the material produces a new value of f , which may be called f' , and a new value of l_4 , which may be called l'_4 , and although A_4 remains the same, the use of the different tube S' gives rise to a new value for C , which may be designated C' .

On the basis of Equation 6, therefore, since a

remains the same, a new equation can now be written, thus:

$$Ka^2 = \frac{C(1-f)^2}{l_1 f^2} = \frac{C'(1-f')^2}{l_1' f'^2} \quad (7)$$

Let m designate the total mass or weight of the sample being tested, and d designate the density of the actual substance of the material. Then, since f is the fraction of the total space $A_1 l_1$ which is occupied by the actual substance of the material,

$$f = \frac{m}{d A_1 l_1} \quad (8)$$

and

$$f' = \frac{m}{d A_1' l_1'} \quad (9)$$

Substituting these values of f and f' in the two right hand members of Equation 7, (omitting the left hand member), it will be obvious that it is possible to solve this equation for d , in terms of the two standard resistance tubes (embodied in the constants C and C'), the cross-sectional area and mass of the sample, (both of which remain constant for any given experiment) and the lengths l_1 and l_1' of the sample. All of these quantities are known or can be measured.

It will thus be seen that my novel process and apparatus makes it possible to achieve the remarkable result of measuring the density of the actual substance of a body of fibrous or other finely divided material by a purely hydrodynamical method.

With the value of d determined by the above method, or otherwise known, this value of d can be substituted in Equation 8, and the value of f thus becomes known. Hence, every quantity on the right hand side of Equation 6 is known, and since K is the constant of the instrument and can be measured, a can be determined from this equation. As already explained, a is the total surface per cc. of actual substance of the fibers making up the porous body of material, and this factor has a definite relation to the popular concept of "fineness."

It follows that the total surface per gram of material is a/d , where d is the density, as before.

Hence it is obvious that, by using a sample of predetermined weight and known density, the cross-sectional area of the container and other constants of the instrument being also known, and compressing the sample until the bridge is balanced as above described, the length of the compressed sample is the only variable in Equations 7 and 8, and it is possible to determine total area of the fibers per unit of mass simply by measuring such length.

While, in regard to fibrous material, I refer in the specification and claims to the density of the substance of the individual fibres, it will be understood that, in the case of fibres, which like cotton, contain an enclosed cavity or cell, I mean the density of the substance of the fibres including such cell.

I claim:

1. The method of determining physical factors related to the resistance to fluid flow offered by a confined mass of porous material which comprises first causing fluid to flow through said mass and determining its relative resistance, then varying the resistance to fluid flow offered by such mass and again determining its relative resistance, deriving an equation in terms of said relative resistances and one desired factor, and solving for that factor.

2. The method of determining physical properties related to the resistance to fluid flow offered by a confined mass of compressible porous material which comprises first causing fluid to flow through said mass and determining its relative resistance, then compressing such mass to vary its resistance to fluid flow and again determining its relative resistance, deriving an equation in terms of said relative resistances and the desired property, and solving for that property.

3. The method of determining values expressing physical characteristics related to the resistance to fluid flow offered by a given mass of compressible, porous material which comprises confining such mass in a form having a uniform cross-section and known length, causing fluid to flow through said mass and determining its relative resistance, in terms involving its length, the desired value, and an unknown quantity, then compressing said mass in such manner as to decrease its length while maintaining its cross-section unchanged, determining its new length and relative resistance in terms of such new length, the desired value, and the same unknown quantity, deriving an expression for the unknown quantity from each such determination, equating said expressions, and solving for the desired value.

4. The method of determining the density of the substance of the individual fibers constituting a sample of fibrous material, which comprises first measuring the resistance to fluid flow of a confined volume of such material of known cross-section and length, and deriving an expression containing the factor of density but involving an unknown quantity, then varying the length of the sample while maintaining its cross-section and mass unchanged and again similarly measuring the resistance which it offers to fluid flow, deriving a second corresponding expression containing the factor of density and the same unknown quantity, equating the two expressions to eliminate the unknown quantity, and solving the equation for density in terms of the other known factors.

5. The method of determining the aggregate surface area per unit mass of the fibers contained in a sample of compressible fibrous material, of which the density of the substance of the fibers is known, which comprises taking a sample of predetermined weight, confining such sample in an elongated form having a uniform and known cross-section, compressing the sample longitudinally until it has been reduced to a definite length, while maintaining its cross-section unchanged, causing fluid to flow through the compressed sample and determining the resistance it offers to fluid flow, relative to that of a known standard, and then measuring the length of the compressed sample and deriving an expression for aggregate surface area per unit of mass in terms of such length, cross-sectional area and density of the sample, and other known quantities defining its relative resistance.

6. The method of determining physical properties related to the resistance to fluid flow offered by a mass of compressible porous material which comprises confining such mass in an elongated form having a uniform and known cross-section and given resistance, causing fluid to flow through said mass, compressing said mass longitudinally to reduce its length and increase its resistance, determining the amount of such increased resistance, measuring the length of the compressed mass, and computing the value of

the desired property in terms of such length and other known quantities.

7. In the determination of the relative resistance to fluid flow offered by a confined mass of compressible porous material interposed in one arm of a fluid flow bridge consisting of four arms, another arm of which is constituted by a standard of known resistance, and having means for indicating when the flow through the two opposite sides of the bridge is balanced, the steps which comprise selecting and employing a mass of material of such volume and porosity that its resistance is relatively low and the bridge is initially unbalanced, and then progressively compressing such mass to increase its resistance until the bridge is balanced and the relation of the resistance of the mass to that of the known standard thus established.

8. Apparatus for determining the relative resistance to fluid flow offered by a mass of compressible porous material comprising a plurality of fluid conduits connected to form the four arms of a bridge, each offering a substantial resistance to fluid flow, one of said arms including an elongated container of uniform cross-section adapted to receive the material being tested, means for causing fluid from a common source to flow simultaneously through both sides of said bridge, means for indicating any differences in the fluid pressures existing at opposite points of the bridge, means for compressing the mass of material longitudinally in said container to increase its resistance, so that the bridge may thus be balanced, and means for indicating the extent of such compression.

KENNETH L. HERTEL