Development of A Filter Cake Permeability Test Methodology

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ABSTRACT

Permeability is an important characteristic of filter aid products. It can be tested by the liquid flowing through already formed cake approach (Method I) or by the cake filtration approach (Method II). Although in method I permeability is easily calculated, two test runs are required. This method also requires longer time compared to method II. Method II requires effective suspending of unfiltered suspension to prevent sedimentation during filtration. Calculation of Method II is also more complicated than Method I. To simplify test and calculation procedures, a new filter cake permeability test method was developed. Filter media resistance was also included in the new approach. Test results on Rice Hull Ash (RHA) filter aids from the new method repeated consistently, and correlated very well with results from tests based on the other two methods.

KEYWORDS

Permeability, permeability test, cake filtration, filter aids, Rice Hull Ash (RHA)

INTRODUCTION

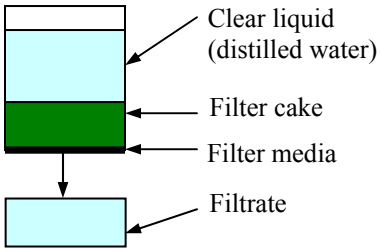
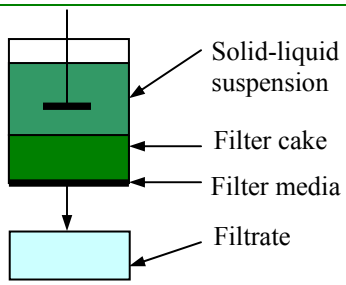
Permeability is a measure of rate of liquid flowing through a porous medium or a particulate filter cake. It is an important characteristic that filter aid manufacturers use for product specification, along with bulk density, particle size, solids retention, and other chemical and physical properties. Currently in the US and Europe, there has not been a standard filter aid permeability test method. Companies use various standards for filter aid product specifications.

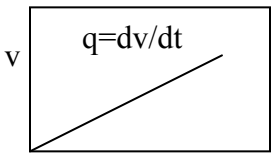
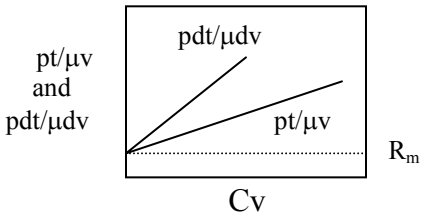
There are two methods in permeability determination: the liquid flowing through already formed cake approach (Method I) and the cake filtration approach (Method II). A detailed comparison of the two methods including test methods and fundamental basis is shown in Table 1.

The Method I approach is based on Darcy's Law (Darcy, 1856). It requires simple testing equipment, easy calculation (Table 1), and is normally used by most filter aid manufacturers. However, two runs of tests including cake formation, and liquid flowing through an already formed cake are required in this method. Furthermore, after a cake is first formed under a certain pressure, liquid (normally distilled water) must be poured into the filter carefully to avoid stirring

or damaging the already formed filter cake. Permeability determined by this procedure is dependant upon the pressure at which the cake is formed, the pressure during liquid flow through period, design of test procedures including how cake is formed, and how the liquid is poured on the top of filter cake. Filter media resistance is normally not included in the cake permeability calculation. With a substantial media blinding and increase of filter media resistance, an error will occur for calculation of cake resistance without considerations of media resistance.

Table 1 Comparison of Method I and Method II Permeability Tests

	Method I: Liquid flow through already formed cake	Method II: Cake filtration
Schematic Diagraph		
Test Method	(1) Cake formation under certain constant pressure or vacuum; (2) Clear liquid poured above already formed cake without damaging the cake; (3) Liquid flowing through already formed cake under a certain constant pressure or vacuum. (4) Volume of filtrate V against time, and final cake thickness collected for permeability calculation.	(1) Constant pressure filtration with an instrument to avoid sedimentation effect during cake formation; (2) Volume of filtrate against time, final cake thickness collected for data analysis.
Fundamental Basis	Darcy's law $q = \frac{dV}{Adt} = \frac{K\Delta p_c}{\mu L}$ (1) Δp_c is the pressure drop across cake. Neglecting filter medium resistance, Δp_c can be replaced by applied pressure p. Permeability equation is then given by: $K = \frac{\mu L dV}{pAdt}$ (2) With known p, V vs. t, L, A, and μ, cake permeability can be calculated.	The following equations are used to develop permeability calculation (Tiller, Li, 2002; Tiller, 1990): Two resistance model: $q = \frac{dV}{Adt} = \frac{p}{\mu(\alpha_{av}\omega_c + R_m)}$ (3) Material balance: $v = V/A = (\varepsilon_{sav}/\varphi_s - 1)L$ (4) $\omega_c = cV/A = cv$ (5) $c = \varphi_s/(1-\varphi_s/\varepsilon_{sav})$ (6) Volume vs. time: $pdt/\mu dv = (\alpha_{av}cv + R_m)$ (7) $pt/\mu v = \alpha_{av}cv^2/2 + R_m v$ (8) Average cake resistance and cake permeability: $\alpha_{av}K\varepsilon_{sav} = 1$ (9)

		With known p, V or v against t, φ_s, V and L at the end of filtration, ε_{sav} (from Eq. 4), c (from Eq. 6), and α_{av} (from Eq. 7 and 8) will be calculated. Permeability K is then calculated based on Equation (9).
Data analysis	 Permeability is then calculated based on Equation (2).	 According to Equations 7 and 8, slopes of the straight lines give the average specific resistance α_{av}. Permeability can be then calculated from α_{av} based on Equation (9).
Comments	1. Two runs of filtration tests; 2. Special attention on pouring liquid above cake to avoid cake damage; 3. Easy calculation; 4. Normally, filter media resistance is not included in calculation.	1. One run of filtration test; 2. Special instrument to suspend unfiltered suspension to avoid affect of sedimentation on filtration data; 3. Complicated calculation; 4. Filter media resistance is included.

The Method II approach is based on fundamental filtration theory (Tiller, 1990, 2002) assuming there is no affect of sedimentation during cake formation, and filtrate against time is a parabolic curve. An instrument to keep unfiltered slurry suspended to avoid sedimentation is usually installed in/on the filter cell. The volume of filtrate against time is collected, and analyzed based on the fundamental filtration theory to calculate the cake resistance and permeability as shown in Table 1. Both the equipment and calculations are more complicated than the Method I approach. However, for incompactible or low compactible material, once the cake is uniformally formed with little affect of sedimentation, the permeability results are quite reliable. This method is normally used in determination of filterbility of solid-liquid suspensions.

To simplify the test procedure and calculation method, a third cake permeability test method was developed. This method is based on Method I but with only one run of the filtration test. A company standard procedure is developed for determination of Rice Hull Ash filter aid products. Rice Hull Ash (RHA) in this study is produced from combustion of rice hulls for electricity generation (Filter Aids News, 2005). It is an interesting material with almost all properties required by a filter aid product such as porous and rigid particulate structure, appropriate particle size, shape, low bulk density, easy to be dispersed, chemically inert, etc (Rieber and Mayer, 1996; Mayer, 1997, 1998; Sun, 2001). Consistent permeability data on Maxflo^{TM} RHA filter aid was obtained based on this method. Comparison tests of the three methods on Rice Hull Ash filter aid yield relatively close results.

DEVELOPMENT OF A NEW PERMEABILITY TEST METHOD

Fundamental Basis

From Table 1, test Method I provides a simple and easy permeability calculation. However, two runs of filtration tests are required, and formed filter cakes are easily disturbed as clear liquid, normally distilled water is poured into the filter cell. There is one run of test in Method II, however, the calculation is based on the assumption that the cake is uniformly formed, and there is no effect of sedimentation on cake formation, which is difficult to obtain, even with assistance of the slurry suspending instrument. To simplify the test procedure and calculation, a third approach based on Method I but requiring only one run of test is developed.

The fundamental basis of the new test method is cake formation followed by flow through already formed cake in one filtration test. A typical volume of filtrate against time curve obtained from the new test method on RHA filter aid is shown in Figure 1. It can be seen that there are three regions during the one test run: "cake formation region" before 300 seconds, "transition region" from 300 seconds to 430 seconds, and a "flow through already formed cake region" when time is greater than 430 seconds. Volume of filtrate against time data during the flow through Darcy's law can be used to calculate cake permeability. Filter media resistance is included in the permeability calculation in the new method.

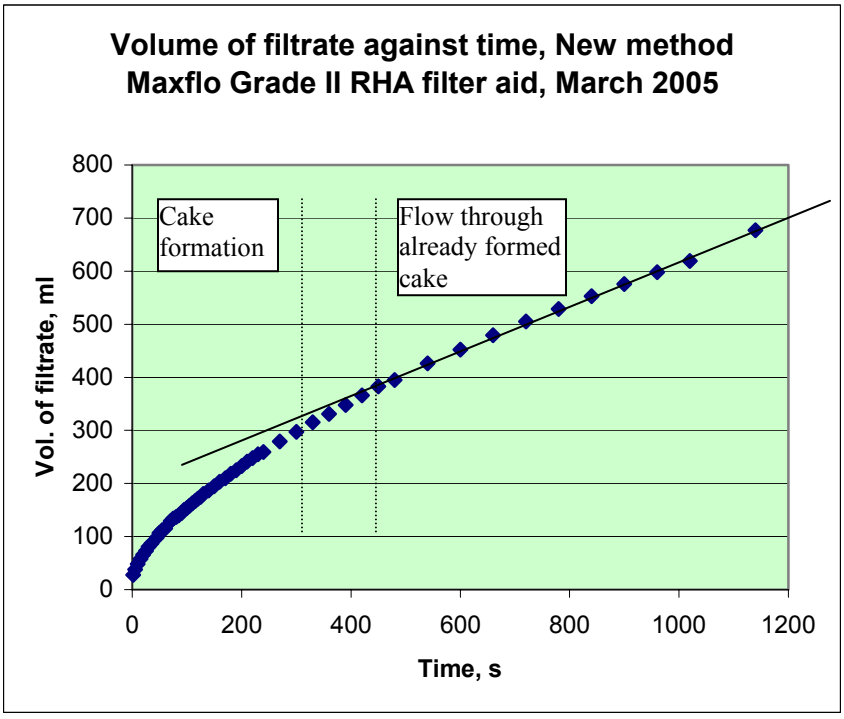


Figure 1. A typical volume of filtrate against time curve from the new method

Test Description

In the new permeability test method, it is important to use a sufficient amount of slurry and an appropriate solid concentration to provide adequate amount of liquid above the cake surface after the cake is formed under a constant pressure and gravity. The test system comprises of 3 inch ID (0.00456 m^2) filter cell with detachable bottom and top, a pressure regulator, and a digital balance as shown in Figure 2.

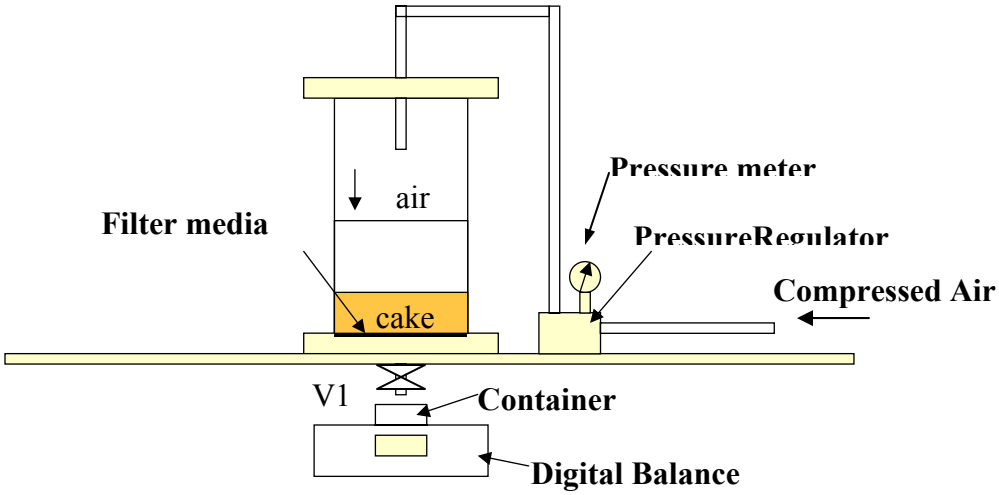


Figure 2. Pressure filtration test system

Filter medium resistance can be determined by a separate test of clean water flowing through filter paper only. Filter media resistance determined by this separate test is included in the permeability calculation.

Permeability Calculation

Permeability calculation is based on Darcy's Law for liquid flow through an already formed cake and a filter media. A simplified model is shown in Figure 3.

Total resistance R = Resistance of cake R_c+ Resistance of filter media R_m (10)

Total pressure p = pressure drop across cake Δp_c + pressure drop across filter media Δp_m (11)

Flow rate q = rate of flow through cake = rate of flow through filter media (12)

$$\text{Flow rate q=rate of flow through filter media} = K_m \frac{\Delta P_m}{\mu L_m} \quad (13)$$

Flow rate q=rate of flow through filter cake $= K_c \frac{\Delta P_c}{\mu L_c}$ (14)

In Equations (12), (13), (14) flow rate in $m^3/m^2/s$ can be obtained by the slope of the straight line region of the filtrate volume against time curve in Figure 1, divided by total filtration area. Media resistance K_m can be determined by a separate clean water flow through filter media only test. Cake thickness L_c and media thickness L_m can be measured. With known K_m, L_m and q, pressure drop across filter media Δp_m can be calculated based on Equation (13). Pressure drop across cake Δp_c can be obtained from Equation (11) with known total pressure p and pressure drop across filter media Δp_m. With known q, Δp_c, μ and L_c, permeability of cake can be then determined from Equation (14).

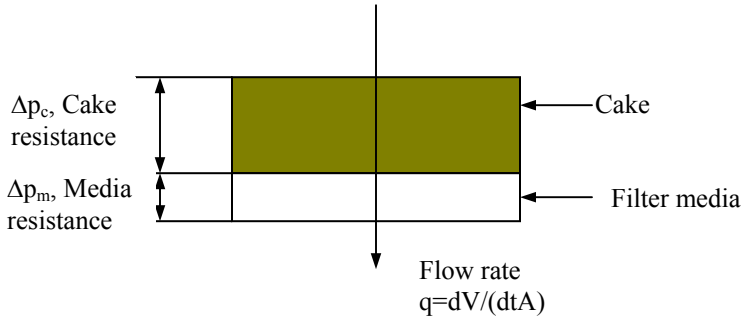


Figure 3. Flow through cake and filter media model.

PERMEABILITY TEST RESULTS OF RICE HULL ASH FILTER AIDS

Consistency of Permeability Results

Consistent test result is an important factor to evaluate a test method and procedure. Test method, test design, data analysis and interpretation, sampling procedure and operation procedure all affect consistency of test results. Results for three runs of permeability tests on three grades of Rice Hull Ash filter aid products Maxflo, Maxflo Grade I, and Maxflo Grade II are shown in Table 2. Good consistency results are obtained for all three grades of RHA filter aids products.

Table 2. Three Runs of Permeability Test Results Based On the New Method

RHA Products	Permeability, darcy		
	Run 1	Run 2	Run 3
Maxflo RHA filter aid	0.31	0.32	0.30
Maxflo Grade I RHA filter aid	1.15	1.21	1.14
Maxflo Grade II RHA filter aid	0.053	0.051	0.054

Permeability Results of the Three Methods

An interesting comparison test of the three permeability test methods was carried out and the results are shown in Table 3.

Table 3. Comparison of the Three Permeability Test Methods

Method	Permeability of Maxflo RHA filter aid, darcy
Method I	0.31
Method II	0.35
New Method	0.32

Although permeability results of the three methods are relatively close, there is some differences. Permeability determined by Method I is slightly lower than that from the New Method, which can be explained by error from Method I by ignoring filter media resistance. Result from Method II is higher than those of Method I and the New Method. This can be due to different cake structure formed in the Method II compared to cakes of Method I and the New Method.

SUMMARY

Fundamental basis for the "flow through already formed cake" method, "cake filtration" method to determine cake permeability are discussed and compared in this paper. A new and simplified filter cake permeability test method based on "cake filtration, followed by flow through already formed cake", is developed. Filter media resistance is also included in the permeability calculation.

While evaluating the new method on various grades of RHA and comparing with the other methods, consistent results indicated that the new method is reliable and suitable for determining permeability of filter aids for product quality specification purposes.

NOMENCLATURES

A	filtration area, m^2
K	permeability, m^2 or darcy, 1 $m^2 = 1.013\times10^{12}$ darcy
L	cake thickness, m
p	total pressure, Pa
Δp_c	pressure drop across cake, Pa
Δp_m	pressure drop across filter media, Pa
q	filtrate rate, $m^3/m^2/s$
Rm	resistance of filter media, 1/m
t	time, s
V	volume of filtrate, m^3
V	volume of filtrate per unit area, m
α_{av}	average specific cake resistance, $1/m^2$
ε_{av}	volume fraction of cake solids, -

φ_s volume fraction of solids in slurry, -
μ viscosity, Pa.s
ωc volume of cake solids per unit area, m

REFERENCES

Darcy, H. "Determination of the Laws of Flow of Water Through Sand", Appendix to Histoire des Fontaines Publiques de Dijon, p590-595, 1856, republished on *Fluid/Particle Separation Journal*, Vol. 2, 33-35, 1989

Filter Aids News, Agrilectric Research Newsletter, Vol. 1, No. 1, 2005

Mayer, E., R. Rieber, "Maxflo™ Filter Aids Conditioning Increases Capacity and Reduces Biiosolids Waste Volume", American Filtration & Separations Society Annual Conference, Minneapolis, MN, April, 1997

Mayer, E., P. Scholtyssek, "Membrane Press Produces Dry Biosolids for Outside landfarming", American Filtration & Separations Society Annual Conference, St. Louis, MO, May, 1998

Rieber, R., E. Mayer, "Self-flocculating Filter Aids", American Filtration & Separations Society Annual Conference, Calley Forge, PA, April, 1996

Sun, L., K. Gong, "Silicon-based Materials from Rice Husks and Their Applications.", Ind. Eng. Chem. Res. Vol. 40, 5861-5877, 2001

Tiller, F. M., and W. Li, Theory and Practice of Solid/Liquid Separation, Fourth Edition, 2002, University of Houston

Tiller, F. M., "Tutorial: Interpretation of Filtration Data, I", Fluid/Particle Separation Journal, Vol. 3, 85-94, 1990