The relationship of filter media 1st and 3rd bubble point and maximum pore size[1]

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ABSTRACT: This paper reports on the final results of work performed in connection with the Nonwovens Division Pressure and Pore Size Committee. The Committee was formed to study the relationship among isopropanol 1st Bubble Point, AC 394 3rd Bubble Point, and Maximum Pore Size testers or test procedures. For the filter nonwovens tested, it was shown that there was excellent correlation among the different test methods, and equations are developed that permit the conversion of one tester's results to another with a high degree of precision.

KEYWORDS: Alcohols, bubbles, equations, equipment, fabric, filters, media, nonwovens, pore size, propanols, separators, TAPPI, test equipment, test facilities, test methods.

The Nonwovens Division Pressure and Pore Size Committee was formed to determine if there is a relationship among the testing methods or procedures known as isopropanol (ISO) 1st Bubble Point, AC 394 (394) 3rd Bubble Point, and Maximum Pore Size. A series of nonwoven filter types having a range of test properties were obtained and distributed to the various participating committee members for testing[2]. Upon receiving the test results from the various individuals or companies, it was learned that there was a wide disparity in the number of test replications used. For example, Hollingsworth and Vose made 15 replicate tests, Ahlstrom and the Philadelphia College of Textiles and Science tested 5 replications and Donaldson had 3 Maximum Pore replications and 2 Frazier test replications. In addition, the testing conditions varied among the various companies. For example, Hollingsworth and Vose did their testing at 68°F and 50% RH, whereas the Philadelphia College of Textiles and Science used 70°F and 65% RH. The testing conditions for the other companies not mentioned were not stated in any of the correspondence, and therefore their testing conditions are not known. In spite of the wide range of testing conditions among the various testing laboratories, the test results are quite encouraging. With the exception of the air permeability test data, a summary of the nonwovens and test results obtained are summarized in **Table I**. Because the ISO 1st Bubble Point and the 394 3rd Bubble Point test results performed by Ahlstrom in Kentucky were not complete, no comparisons were made using these results. As can be seen, though, these values compare well with the tests performed at the Ahlstrom Tennessee facility. Likewise, no comparison was made on the P & G P8 707 sample since only one laboratory reported test results on this sample.

An initial report was given at the Nonwovens Filtration Committee meeting at the TAPPI 1993 Nonwovens Conference. At that time, it was recommended that Maximum Pore size results be given on the *y* axis and the other test methods be given as the *x* axis, with the equations obtained reported accordingly.

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[1]This work is the result of Committee Assignment 891204-02. Members of the Pressure and Pore Size Committee of the TAPPI Nonwovens Division: Ken B. Dema, Donaldson Co., Inc., chairman; J. Robert Wagner, secretary; Peter Brownell, Fram Corp.; Samuel D. Costanzo, Hollingsworth & Vose Co.; Philip T. Gay, Hollingsworth & Vose Co.; Michael L. Iveson, Ahlstrom Filtration Inc.; James W. Martin, Fram Corp.; William R. Ouellette, Procter & Gamble Co.; Frank Ludvik, James River Corp.; and Stephen H. Tse, James River Corp.

[2]Test procedures for Maximum Pore, ISO 1st Bubble Point, AC 394 3rd Bubble Point and Air Permeability as supplied by round robin participants.

I. Summary of test results

Sample	H &V Max. pore [µ]	D Max. pore [µ]	AT Bubble point, 1st bubble [ISO]	AK[a] Bubble point, 1st bubble [ISO]	AT Bubble point, 3rd bubble [394]	AK[a] Bubble point, 3rd bubble [394]
JR Blue 856	69.3	76.000	4.7		6.6	
JR White	64.0	64.000	5.5		7.4	
JR Tan 793	34.2	35.800	10.7		13.5	
A5	25.6	24.575	13.4	13.6	16.7	17.6
A12	40.9	39.600	8.8	8.9	11.4	11.4
A88	89.9	88.825	4.2	4.0	5.1	5.1
P & G P8 707[a]	284.2					

H & V = Hollingsworth & Vose Co.
D = Donaldson Co. Inc.
AT = Ahlstrom Filtration, Inc. (Tennessee)
AK = Ahlstrom Filtration, Inc. (Kentucky)

[a] No comparisons made

Initially, both Frazier and Kawabata air permeability tests were performed and excellent correlations were found for predicting Maximum Pore size, ISO 1st Bubble Point, and AC 3rd Bubble Point for the specimens tested. However, because it is known that this relationship will not be consistent and can give misleading results when the basic ingredients of the filter medium is varied, the equations relating air permeability to Maximum Pore, and 1st and 3rd Bubble Point will not be given.

Statistical comparison

The software utilized to make the comparisons has over 3000 possible equations that can be fitted to the data obtained. During computer processing, the different equations are arranged or "ranked" in order of the best to the least r^2 coefficient. Thus the equation having a "rank" of 1 would be the best fitting curve and also the one having the best r^2 correlation coefficient. However, because the equation having a rank of 1 is usually a rather complex equation or sometimes contained blips of peaks or valleys where no data existed, it was usually decided to select the most simple equation that still had a high correlation coefficient and did not contain such aberrations. The various curves or figures to be discussed include the equation, r^2 correlation coefficient, equation rank, and other statistics printed out when curve fitting.

In the first comparison made, the Donaldson Maximum Pore size values (Max. pore) in Table I were compared with the Hollingsworth and Vose, (H & V), Maximum Pore values. Because both of these are the same test method, one would expect the results to be the same within experimental error testing limits, and therefore a linear regression was used. The results obtained are given in **Fig. 1** and the equation is of the form:

$$y = \mathrm{a} + \mathrm{b}x \qquad (1a)$$

and with the coefficients Eq. 1a becomes:

$$y = 1.3394938 + 0.96065401\,x \qquad (1b)$$

where x is a given Donaldson Maximum Pore value and y is the calculated H & V Maximum Pore value. The r^2 correlation coefficient was 0.9858. Because the intercept was reasonably close to 0 and the slope almost 1, the Maximum Pore results obtained by the two laboratories are essentially the same.

Next, using the Ahlstrom Tennessee ISO 1st Bubble Point data, this was compared with the H & V Maximum Pore values from Table I. The equation selected using the guidelines previously discussed, is of the form:

$$y = -\mathrm{a} + \mathrm{b}x + \mathrm{c}/x \qquad (2a)$$

and with the coefficients Eq. 2a becomes:

$$y = -9.74963 + 0.58104992\,x + 388.13857/x \qquad (2b)$$

where x is a given Ahlstrom ISO 1st Bubble Point value and y is the calculated H & V Max. Pore value. The r^2 correlation coefficient of the above equation was 0.9772 or excellent. The resulting curve and statistical results are shown in **Fig. 2**.

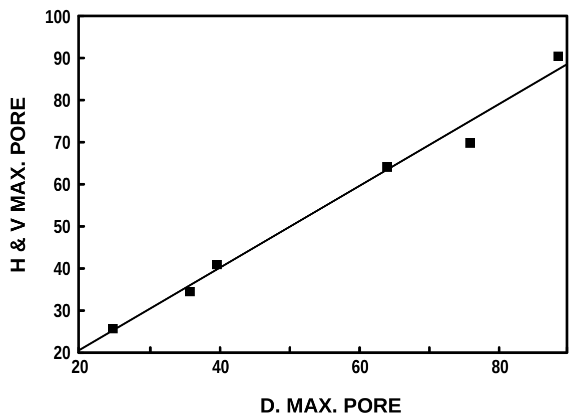
For additional comparisons, the H & V Maximum Pore values were used since H & V had 15 replications when performing their tests.

An equation relating the 394 3rd Bubble Point with Maximum Pore was determined using the Ahlstrom Tennessee values for the 394 3rd Bubble Point from Table I with the H & V Maximum Pore values. The resulting equation is of the form:

$$y = \mathrm{a} - \mathrm{b}x + \mathrm{c}/x \qquad (3a)$$

and with the coefficients Eq. 3a becomes:

1. Statistical and graphical comparison of Donaldson Maximum Pore Size and Hollingsworth & Vose Maximum Pore Size



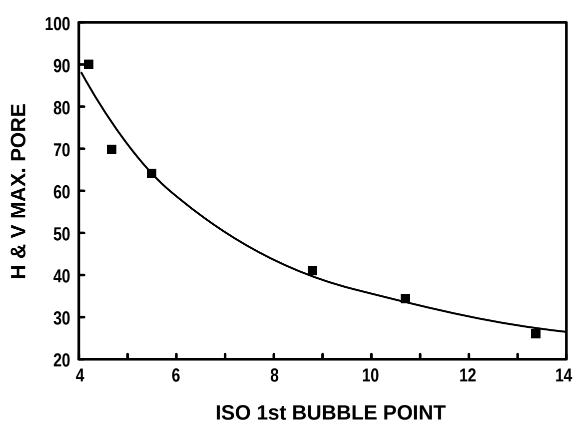
D Max. Pore vs. H & V Max. Pore May 3, 1993, 9:48 pm
6 Active X-Y points
X: D Max.Pore Mean: 54.8 SD: 25.2878281
Y: H & V Max. Pore Mean: 53.983333333 SD: 24.46674614
File source: Graph 1.PRN

Rank 1386 Eq. 1 y =a+bx

r^2 Coef. det.	DF Adj r^2	Fit std. err.	F-value
0.985835892	0.9763931533	3.2555610016	278.4039463

ParmValue	Std. error	t-value	95% Confidence limits	
a 1.339493804	3.423587672	0.391254419	-8.17754279	10.8565304
b 0.960654006	0.057574385	16.68544115	0.80060625	1.120701762

2. Statistical and graphical comparison of ISO 1st Bubble Point and Hollingsworth & Vose Maximum Pore Size



ISO 1st Bubble vs. H & V Max. Pore May 16, 1993, 10:07 pm
6 Active X-Y points
X: ISO 1st Bubble Point Mean: 7.883333333 SD: 3.7037368517
Y: H & V Max. Pore Mean: 53.983333333 SD: 24.46674614
File source: ISO.PRN

Rank 1303 Eq. 1016 y=a+bx+c/x

r^2 Coef det.	DF Adj r2	Fit std. err.	F-value
0.977158458	0.9428961449	4.7737898915	64.169822041

ParmValue	Std. error	t-value	95% Confidence limits	
a -9.74963098	35.28410856	-0.27631791	-121.206413	101.7071506
b 0.581049923	2.190360165	0.265275973	-6.33794291	7.500042759
c 388.1385726	119.9294809	3.236389999	9.300775649	766.9763696

$$y = 14.026858 - 0.7487155\,x + 404.86221/x \quad (3b)$$

where x is a given Ahlstrom 394 3rd Bubble Point and y is the calculated H & V Maximum Pore value. The r^2 correlation coefficient of the above equation was 0.9993 or almost a perfect fit. The resulting curve and statistical results are given in **Fig. 3**.

An equation relating the 394 3rd Bubble Point with the ISO 1st Bubble Point was determined using the Ahlstrom Tennessee 394 3rd Bubble Point and ISO 1st Bubble Point data from Table I. Because it was thought that the two should be a linear relationship the equation selected is of the form:

$$y = -\,a + bx \quad (4a)$$

and with the coefficients Eq. 4a becomes:

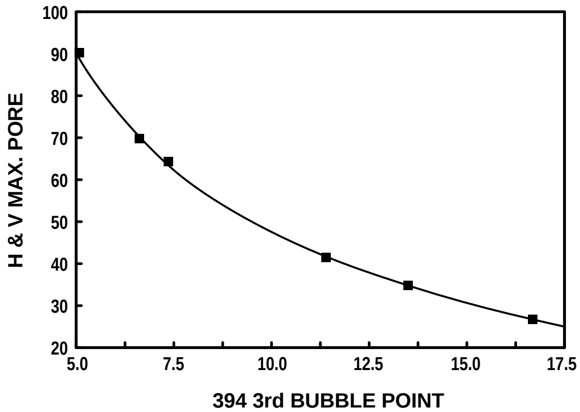
$$y = -\,0.41892483 + 0.82065155\,x \quad (4b)$$

where x is a given Ahlstrom Tennessee 394 3rd Bubble Point and y the calculated Ahlstrom ISO 1st Bubble Point value. The r^2 correlation coefficient of the above equation was 0.9951 or an excellent fit. The resulting curve and statistical results are given in **Fig. 4**.

Conclusion

It has been shown that there is a definite relationship among the ISO 1st Bubble Point, 394 3rd Bubble Point, and Maximum Pore test results. Test values from one type of tester or test procedure can be expressed in another tester's format with a high degree of precision, simply by using the equations that have been developed or their algebraic inverse.

3. Statistical and graphical comparison of AC 394 3rd Bubble Point and Hollingsworth & Vose Maximum Pore Size



394 3rd Bubble vs. H & V Max. Pore May 16, 1993, 10:31 pm
6 Active X-Y points

X: 394 3rd Bubble Point	Mean: 10.116666667	SD: 4.5021846549
Y: H & V Max. Pore	Mean: 53.983333333	SD: 24.46674614

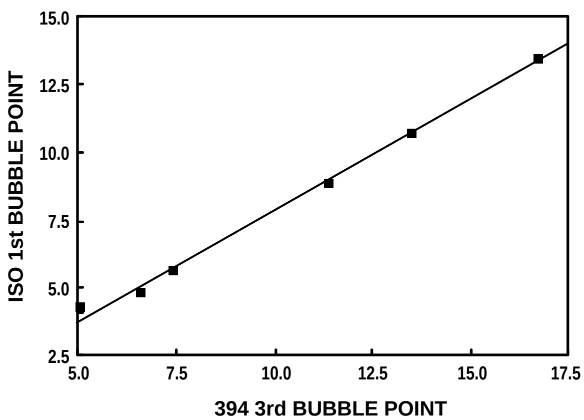
File Source: 3943RD.PRN

Rank 973 Eq. 1016 $y=a+bx+c/x$

r2 Coef. det.	DF Adj r^2	Fit std. err.	F-value
0.9992868931	0.9982172327	0.8434860621	2101.9714374

ParmValue	Std. error	t-value	95% Confidence Limits	
a 14.02685763	5.623283295	2.494424857	-3.73618311	31.78989836
b -0.74871549	0.281053538	-2.66396037	-1.63651807	0.139087099
c 404.8622103	24.14230056	16.76982727	328.6005948	481.1238258

4. Statistical and graphical comparison of AC 394 3rd Bubble Point and ISO 1st Bubble Point



394 3rd Bubble vs ISO 1st Bubble Point May 17, 1993, 9:20 pm

6 Active X-Y points

X: 394 3rd Bubble Point	Mean: 10.116666667	SD: 4.5021846549
Y: ISO 1st Bubble Point	Mean: 7.8833333333	SD: 3.7037368517

File Source: 3RDVS1ST.PRN

Rank 1479 Eq. 1 $y=a+bx$

r^2 Coef. det.	DF Adj r^2	Fit std. err.	F-value
0.9951394604	0.9918991007	0.2886937432	818.95389797

ParmValue	Std. error	t-value	95% Confidence Limits	
a -0.41892483	0.313138895	-1.33782432	-1.28940183	0.451552169
b 0.820651548	0.028676693	28.61737056	0.740934841	0.900368256

Recommendations

Consideration should be given to prepare a TAPPI Useful Method or Test Method for making conversions from one testing format to another. However, if it is decided to do so, then another round robin of tests should be made where all laboratories perform from 10 to 15 replications of each test. In addition, it would be desirable to increase the upper and lower range of filter test properties as well as the total number of different types of samples tested. Also, a careful plan for improved filter type, properties, specimen selection, distribution, and documentation of testing conditions, should be made. TJ

The assistance of various laboratory technicians who performed tests and other personnel, possibly not mentioned, is hereby acknowledged and appreciated.

Received for review Dec. 17, 1993.

Accepted Aug. 6, 1994.

Presented at the TAPPI 1994 Nonwovens Conference.