Multilayered sheets: the media of the future for automotive filtration applications?

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Laboratory tests indicate that multilayer filter papers can simultaneously increase efficiency and product life beyond that currently available from single-layer media.

Saturated paper for automotive filtration

Filter paper manufacture

The paper sheet is a network of cellulose or other specialty fibers formed on a paper machine from a suspension of these fibers in water. To find a filter paper for a certain automotive filtration application, the key factor is to find the right combination of pulps (furnish).

At the stage where the furnish is selected, most of the paper characteristics affecting filtration performance and to some degree mechanical strength already have been determined. Other factors affecting filtration performance will depend on factors directly related to the paper machine being used (i.e., fiber orientation, drying method, pressing, etc.). For the production of automotive filter paper, the most commonly used paper machines are those having flat fourdrinier, sigma former, or inclined-wire wet ends.

The base paper then is saturated with resins to produce the strength properties necessary for withstanding further processing into elements and the severe conditions of end use. The final filtration unit is typically a cylindrical cartridge with the paper in a pleated configuration which gives a large surface area within a given volume.

Engine filter paper applications

Filter paper provides a means to remove the greatest possible amount of contaminant from a fluid or air stream, while offering the least possible restriction to its flow. Each filter paper has an optimal filtering range, so much attention must be paid to choosing the right grade for a particular application. There are hundreds of different engine filter paper applications, from auto and heavy-duty air filters to oil and fuel filter paper, where the paper grade selected is dependent on the given end use.

Automotive filter paper is used in three different filtering locations: air, oil, and fuel. Each is unique to its position and requires a different range of filtration than the others. Obviously, all three carry out the same function of removing unwanted contaminants. This is accomplished with different requirements for efficiency, capacity/life, and initial pressure drop. Keeping these requirements in mind, filter paper is designed by using different fibers in a manner that provides low permeability for fuel, moderate permeability for oil, and high permeability for auto air filter paper.

In recent years, a new trend has developed. Due to the limited space available under the car hood, downsizing of filters is constantly demanded. This has led to new requirements for filtration characteristics: higher capacity/life and lower initial pressure drop, but not at the expense of efficiency. This demand has initiated research for a new high-performance media such as multilayer papers.

Quality

Testing filtration performance

The ideal filter paper design can be defined as one which provides infinite capacity/life at 100% efficiency and zero energy loss across the filter paper. Therefore, filtration performance, to a large extent, can be determined by efficiency and contaminant holding capacity/life.

Efficiency, which indicates how efficiently a certain type of contaminant has been removed by the filter paper from an air or oil stream, is normally expressed as a percentage. That percentage generally increases during the life cycle of the filter due to the buildup of a filter cake by the contaminant.

Contaminant holding capacity/life, which indicates for how long a certain type of contaminant has been added to the system before a pre-established pressure drop has been built up over the filter media due to the filter cake, normally is expressed in grams or minutes.

Figure 1 illustrates these two filtration curves. In the Multipass Test for oil paper grades (**Fig. 2A**), the efficiency values are normally related to a corresponding particle size of the contaminant. This can be done with a particle counter, where the number of particles upstream

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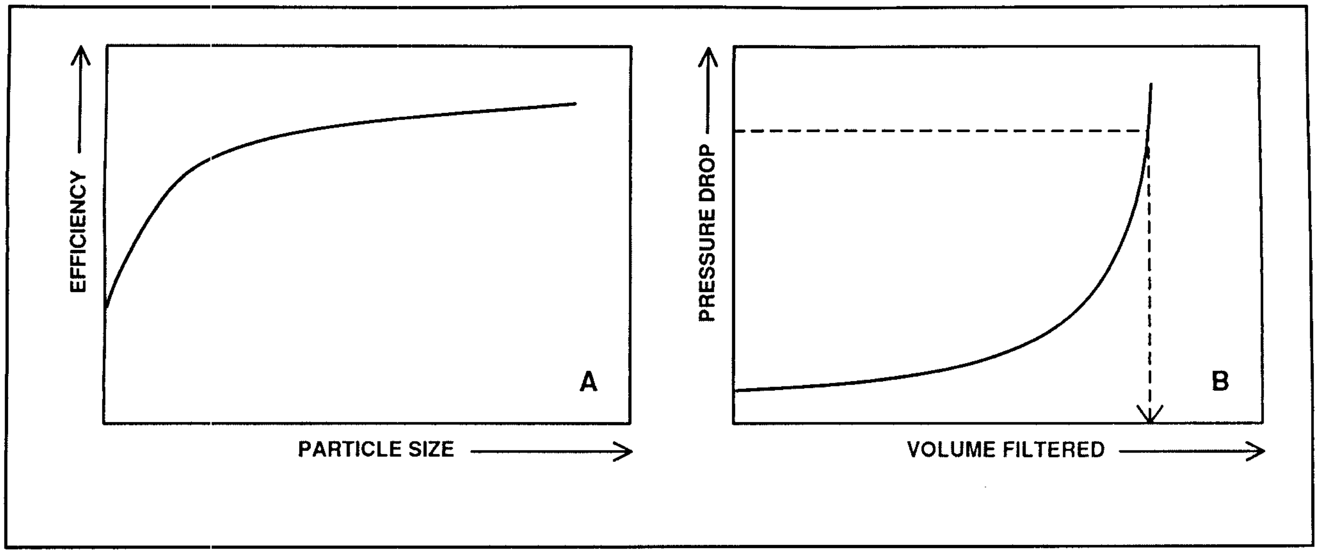
1. The Multipass Test (A) and the Single-pass Test (B) are two methods used to test the effectiveness of a filter paper.



and downstream of the test filter are counted. The upstream/downstream counts are referred to as "Beta ratios." In the Single-pass Test (**Fig. 2B**), the efficiency value for oil paper grades is measured gravimetrically. Both test procedures are carried out on flat sheets under carefully established test conditions. Some of the primary test parameters that must be selected are type of fluid, viscosity of the fluid, flow rate, contaminant type, and contaminant addition rate. Changing any of these parameters will have a direct impact on performance.

Performance tests for the media in air were carried out according to the Air Test stand set up shown in **Fig. 3**. The main components of this Air Test stand are: a rotating brush generator (for contaminant injection), a photometer, a filter holder, a dilution system, and an optical particle counter (on-line particle counting is controlled automatically by a computer).

For a given basis weight, the design of a "conventional" filter media is always a compromise between efficiency and life. Some of our results indicate that for multilayer media one does not always have to make this compromise, as both efficiency and capacity can be increased simultaneously.

Flow direction

One other important factor affecting performance is the direction of the flow through the sheet. Due to the two-sidedness of the media, filter paper has a readily observable *z*-direction asymmetry with a more permeable or "open" surface grading (felt side) to a denser, less permeable or "closed" bottom surface (wire side). For optimum performance on a "conventional" automotive filter paper, the filtration direction is always selected so that the felt side is the upstream side and the wire side is the downstream side. The test results for multilayer media show that, depending on how the pulp is layered, the filtration direction can be changed and still achieve improved performance.

Filtration mechanisms

Filtration mechanisms have been discussed earlier in various publications (*1-7*). According to these studies, filtration is accomplished by the following processes: direct entrapment or interception, adsorption, direct impingement, brownian diffusion, and cake filtration.

These theories on the filtration mechanisms carry a lot of important information. However, for a "practical" filter papermaker, it is difficult, even on a laboratory scale, to differentiate the magnitude of impact each of these mechanisms has on final performance. Extensive testing on automotive filter paper has shown that, in air filters, the surface filtration mechanisms tend to be dominant; in oil, the mechanisms which enhance depth filtration are dominant.

From a manufacturing standpoint, the most important thing is to be able to predict the filtration characteristics from the variables that can be measured and regulated in the production process itself. This is the key for tailoring the filtration performance for various applications. In other words, the manufacturer must know these relationships:

$$Y1 = f1(x1, x2, x3, x4, \ldots)$$
$$Y2 = f2(x1, x2, x3, x4, \ldots)$$

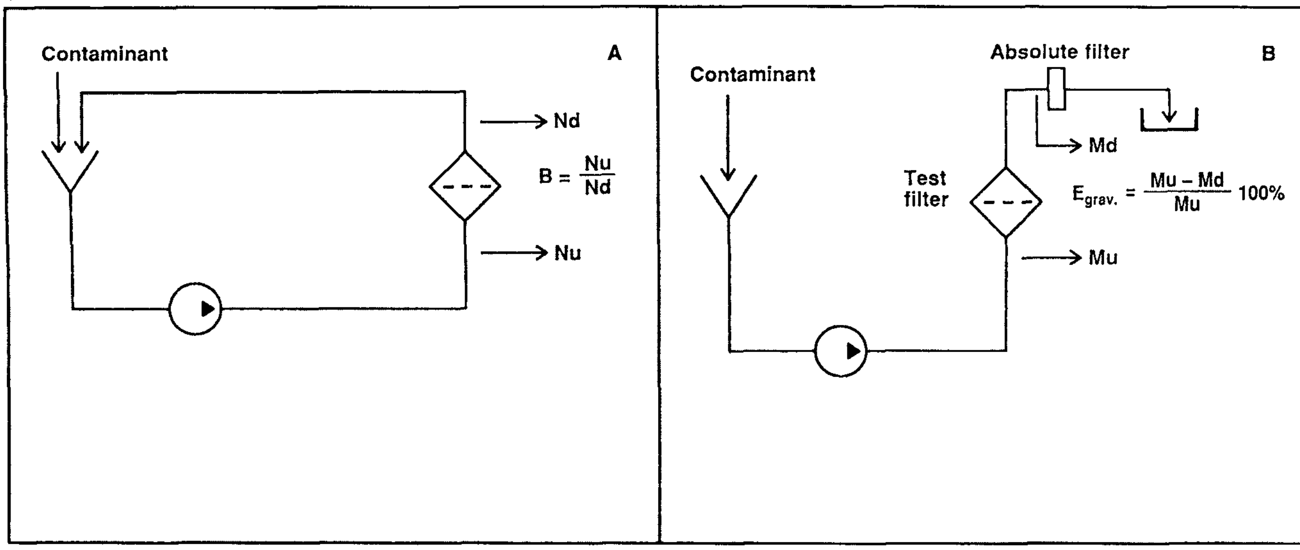
where

Y = performance characteristics (efficiency in air and oil, contaminant holding capacity in air and oil, etc.)

x = product variables (basis weight, caliper, permeability, bubble point, etc.)

The filtration mechanisms for multilayered media appear to change when compared to conventional single-layer media because a gradient of the pore size distribution is built into the media. The particle capture is fractionated so that the bigger particles are captured on the more permeable side and the smaller particles in the inner part of the paper, which progressively becomes less permeable. Thus, the effective filtration area is enlarged. Because of this, the filter cake requires more time to build up and become dense enough to block the paper.

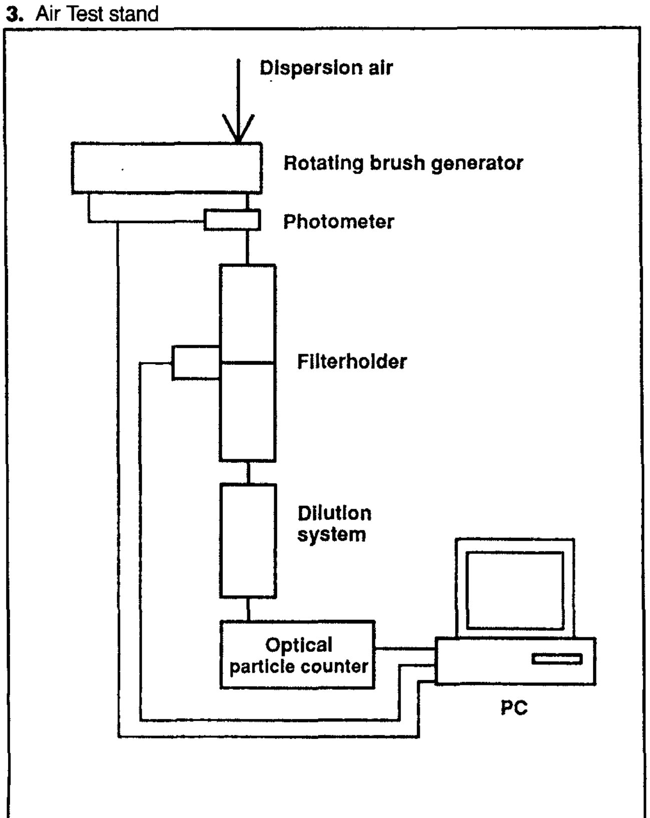
2. The Multipass Test for oil paper grades (A) relates efficiency to contaminant particle size. The Single-pass Test (B) measures efficiency gravimetrically.



I. Permeability properties of test pulp

Pulp type	*Frazier, ft³/min*	*3rd Bubble, in. of W.C.*
Mercerized southern pine	232	3.3
Standard southern pine kraft	56	5.3
Southern hardwood	37	8.0
Eucalyptus	23	12.0

3. Air Test stand



Multilayer trials

Test objectives

The main objectives of our multilayer trials were:

1. Find out what effect layering the media has on filtration performance. Does the number of layers significantly affect the result, and, if so, what should the optimum number of layers be in terms of performance?
2. Find out if "reversing the pulps" has an effect on filtration performance. Can the layer with the most open pulp be placed first on the wire side (which means faster drainage and thus production speed); then can we reverse the "filtration direction," making the wire side the upstream side, without losing filtration performance?

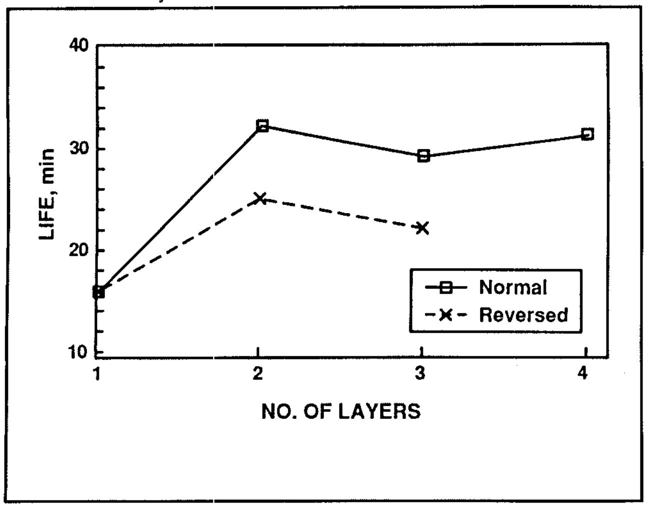
In **Table I**, the types of pulps that were used for the trials are illustrated. The numbers are based on lightly pressed 60-lb handsheets. The 3rd Bubble is a modification of the standard Bubble Test for pore size which is used by our company.

Laboratory trials

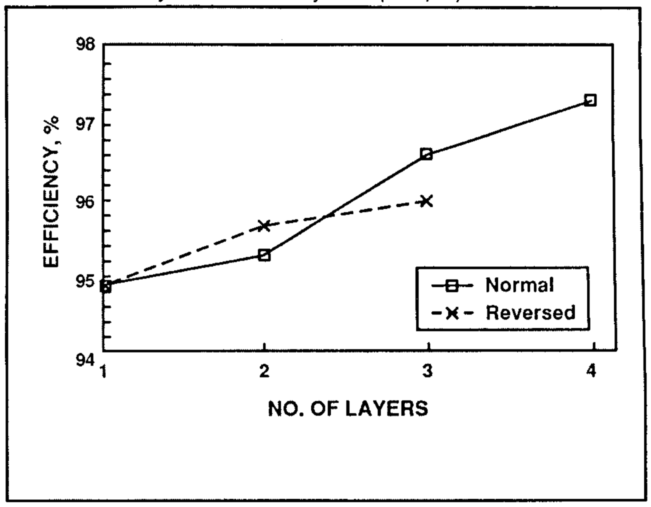
The laboratory trials were carried out on a centrifugal screen former. The dynamic test conditions for this instrument pretty well resemble actual machine conditions for drainage and fiber orientation. The former consists of a drum, a drilled cylinder, a wire, and a scoop which is used for removing the water from the drum. The sheet is formed with a nozzle that moves vertically and distributes the fibers evenly on the wire while the cylinder is spinning. Wire/jet speed ratios can be controlled and were held at approximately 1. The consistencies were in the 0.1% to 0.3% range.

The following types of sheets were produced: control, 2-layer/2-layer reversed, 3-layer/3-layer reversed, and 4-layer. The control sheet was a single-layer sheet made under the same conditions as the multilayer sheets so we'd have a fair comparison of the filtration performance between the multilayer sheets and a conventional single-layer sheet. Our goal was to have similar basis weights

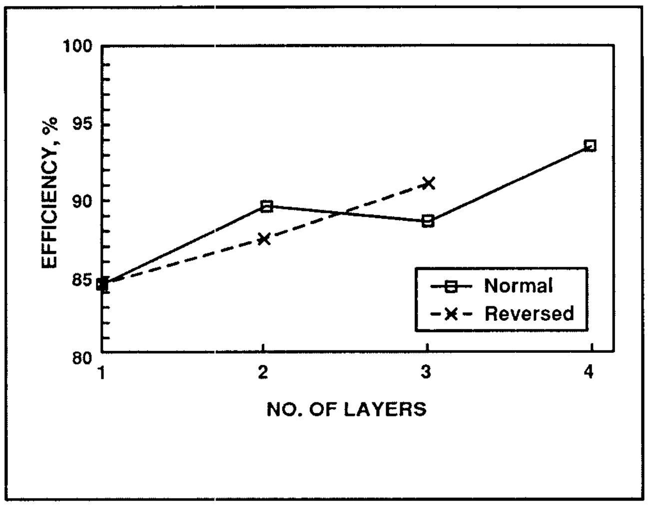
4. Number of layers vs. life in air



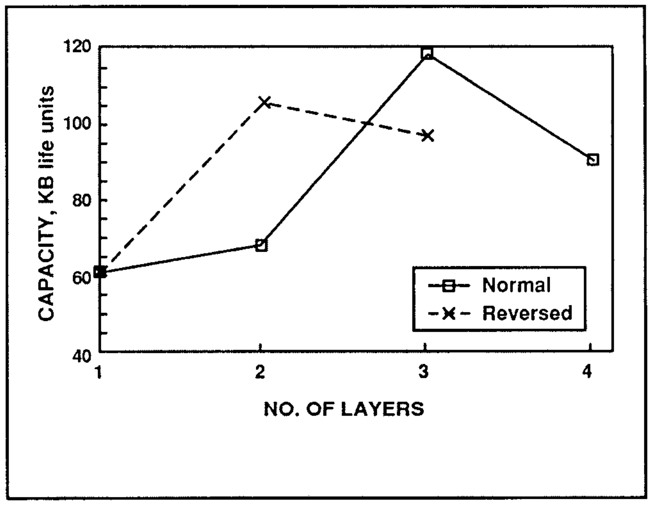
5. Number of layers vs. efficiency in air (at 2 μm)



6. Number of layers vs. single-pass efficiency in oil (10–20 μm)



7. Number of layers vs. capacity in oil



and Frazier permeabilities for all the sheets, since these parameters largely determine the applications of the automotive filter paper grades. At the same time, the pulps in the layers were chosen in a way that the sheets were gradually "closed up," creating a permeability gradient through the sheet.

Test results

The physical properties of the sheets we produced are illustrated in **Table II**. The pore sizes were measured with a Coulter Porometer.

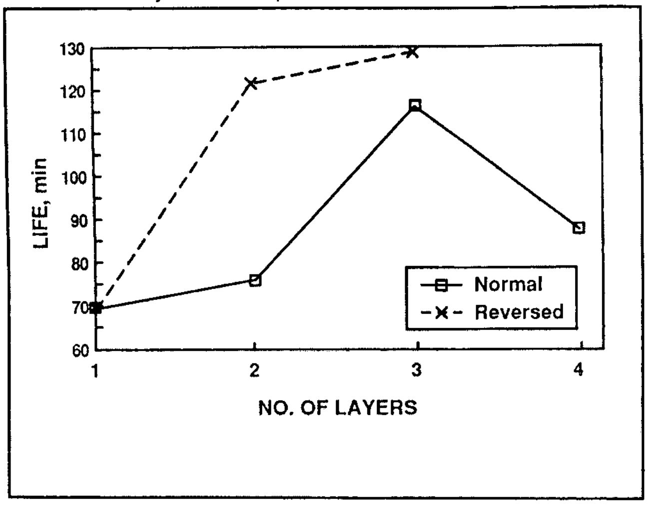
Our results show that when the number of layers increases, the pore size distribution becomes more narrow. Prior to the performance tests, the sheets were saturated with phenolic resin. The performance results for both air and oil are shown in **Figs. 4–10.**

The life in air doubled when going from the single to the 2-layer media, and the life for the 3-layer and 4-layer media decreased in comparison to the 2-layer media (Fig. 3). Also, when layering pulps in the reversed direction, the filter life increased. Earlier experience had shown that, when tested in air where surface filtration mechanisms tend to be more dominant, a rough surface often gives improved performance. One possible explanation why the reversed media did not perform as well as the media layered in the normal direction could be that in the reversed case the very smooth wire side became the upstream filtration side.

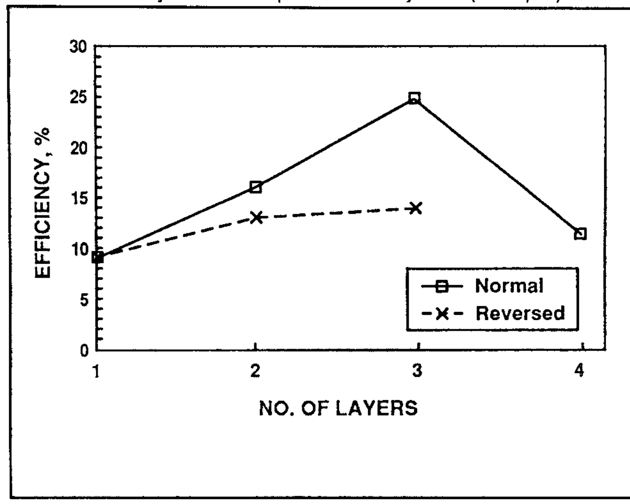
The efficiency in air was measured in the 1.2-μm to 29-μm range. In Fig. 4, the results are illustrated at 2 μm and 3 minutes after the start of the testing. The measuring point was chosen in the initial part of the life cycle because it is easier to distinguish major differences in efficiency values between the media. After 5 minutes, the efficiencies for all media already had climbed to values above 99%. At 2 μm, it is easier to get statistically accurate readings. Again, the efficiencies in air for the multi-layered media improved in all cases over that of the single-layer control sheet.

The results of the tests in oil are illustrated in Figs. 5-9. The Single-pass efficiency values for all the layered media were higher than the value of the single-layer sheet (Fig. 5). In Fig. 6, the capacity increased simultaneously. The KB life is a capacity test developed by Ahlstrom Filtration Inc. Interestingly, the media with the layering direction reversed performed very well, especially in the

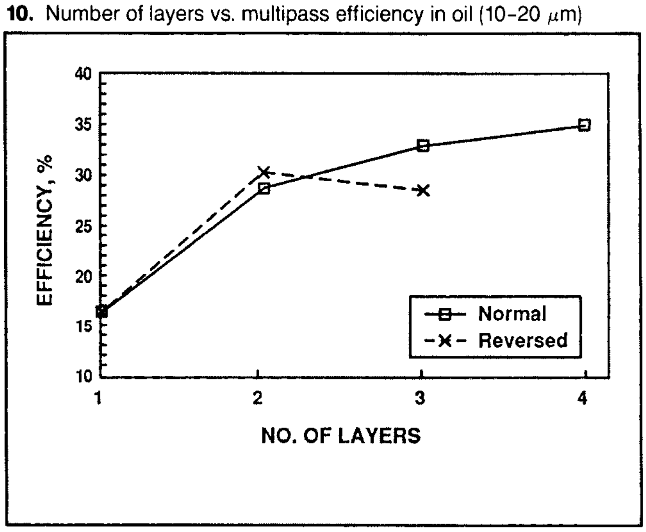
8. Number of layers vs. multipass life in oil



9. Number of layers vs. multipass efficiency in oil (5-10 μm)



10. Number of layers vs. multipass efficiency in oil (10-20 μm)



2-layer case. Apparently this is related to the fact that in oil, where depth filtration mechanisms tend to be dominant, the smooth surface on the wire side does not have a negative impact. In other words, the overall result is more dependent on the characteristics within the sheet than on the surface characteristics.

Finally, the multilayer media was tested according to the Multipass Test (Figs. 7-9). The life values of the test came out very similar to the capacity of the KB life test, with the media layered in the reversed direction performing better than the media layered in the normal direction (Fig. 7). Again, all the multilayer media performed better than the single-layer sheet, and a drop in performance could be seen when going from 3-layer sheets to 4-layer sheets. This drop could well be a consequence of the 4-layer sheet being slightly tighter (lower Frazier value) than the rest of the sheets (see Table I).

The multipass efficiency numbers for various particle size segments are illustrated in Figs. 8 and 9. Once again the multilayer media performed better than the single-layer media.

Similar trials have been conducted on a pilot-scale inclined-wire former (at line speeds typical for the production of filtration papers). The same general trends were observed, although the magnitude of relative performance improvements with multilayer samples was not as significant as observed with the centrifugal screen former trials. Clearly, more work must be done to identify the important product design and process variables before the promising laboratory results can be transformed into a commercial product.

Comments and conclusions

The results of these laboratory trials clearly show that there is potential for an improved product in wet-laid multilayer media. The filtration performance improved significantly in both air and oil when compared to single-layer media. The results also show that performance can be improved when the layering direction is reversed. This should have a positive effect on the dewatering characteristics on the paper machine and thus the production speed. Wet-laid multilayer media could provide a new degree of freedom in tailoring filtration products to meet future performance needs.

These results also indicate that a considerable performance benefit can already be achieved with two layers. This is especially important when looked at from the process standpoint. A wet end with three or four layers would create a completely different cost structure compared to a single- or double-layer wet end in an environment where numerous grade changes and flexibility are required. In any case, multilayer media cannot be produced overnight. Going from a conventional single-layer wet-end unit to a multilayer wet end requires a capital investment by the paper manufacturer.

From an economical standpoint, the multilayer concept could mean a need for smaller filtration areas than that required for single-layered media. In this application, money could be saved because the filter manufacturer would have the option of making smaller filtration elements. Multilayers may also reduce the portions of expensive specialty pulps and synthetic fibers required to achieve the desired results for a given product. It could also be a less expensive option than the laminates used today

II. Physical properties of raw paper

Paper property	*Control*	*2-layer*	*3-layer*	*4-layer*	*2-layer reversed*	*3-layer reversed*
Basis weight, lb/3000 ft^2	110.9	113.6	112.4	113.2	114.7	114.2
Caliper, mils	33.3	35.7	34.5	35.0	35.0	33.9
Frazier, ft^3/min	29.2	27.0	27.0	24.0	28.0	26.1
3rd Bubble, in. W.C.	7.1	7.2	7.0	8.5	7.6	8.7
Pore-size, μm						
Maximum	76.9	52.0	49.6	48.7	55.6	48.5
Minimum	11.0	9.4	9.8	9.5	10.0	9.7
Mean	19.8	15.4	15.4	14.7	16.3	14.9

for various filtration applications and that today, for the most part, must be produced in at least two separate steps.□

Literature cited

1. Dickenson, C., Filters and Filtration Handbook (2nd edn.), The Trade and Technical Press, New York, 1987.
2. Bell, J. R. and Cove, M. G., Filtration & Separation (9): 418(1978).
3. Jelley, T., 1986 Wet End Operations Seminar Notes, TAPPI PRESS, Atlanta, p. 375.
4. Magill, D. G. Jr., 1986 Nonwovens Conference Proceedings, TAPPI PRESS, Atlanta, p. 17.
5. Ostreicher, E. A., Fluid Filtration, Vol. II, ASTM STP 975, Philadelphia, 1986.
6. Schroeder, H. G., Simonetti, J. A., and Meltzer, T. H., Fluid Filtration, Vol. II, ASTM STP 975, Philadelphia, 1986.
7. Hoffman, C. S., 11th Technical Nonwovens Symposium, INDA, New York, 1986.

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