Practical comments on paper machine drainage

Arnold F. Giles

Since fiber mat buildup is related to time and frequency, a higher frequency is used to prevent mat buildup.

As a forming fabric and drainage equipment manufacturer, my involvement with "drainage" is in the interaction of the forming fabric, drainage equipment, stock flow, and the machine.

For many years drainage has been misunderstood. Twenty years ago Foster P. Doane, Jr. stated that "drainage and formation by the fourdrinier are still misunderstood" (*1*). Nine years later at the 18th International EuCePa Conference in London, I presented a paper which focused on the continuing confusion concerning drainage (*2*). Even today "drainage" is still very much misunderstood by suppliers and users.

The major reason for this confusion is due to the need of those in our industry to take a complex process and attempt to express it simply by its action alone. For instance, many express drainage by the action of the fabric's ability to drain. This is taken to such an extreme that many even shorten it to cubic feet per minute (CFM) or drainage index (DI). Drainage is a complex process and should be expressed as such.

Erroneous beliefs concerning drainage include: "This fabric is too closed, so we need more drainage" or "This fabric is too open, so it drains too fast." In reality, it is more likely that the exact opposite is true in each of these cases.

The drainage ability of a fabric referred to as CFM is only appropriate when either air or water flows through it. Water flow is directly proportional to air flow or CFM (400 ft^3/min = 2.03 m^3/s air = 570 L/min water).

CFM does not control drainage on a paper machine. This can be demonstrated by running the same fabric first top side out and then inside out. If the structure's top and bottom are different (as they normally are), then the drainage will also be different—yet the CFM will be identical.

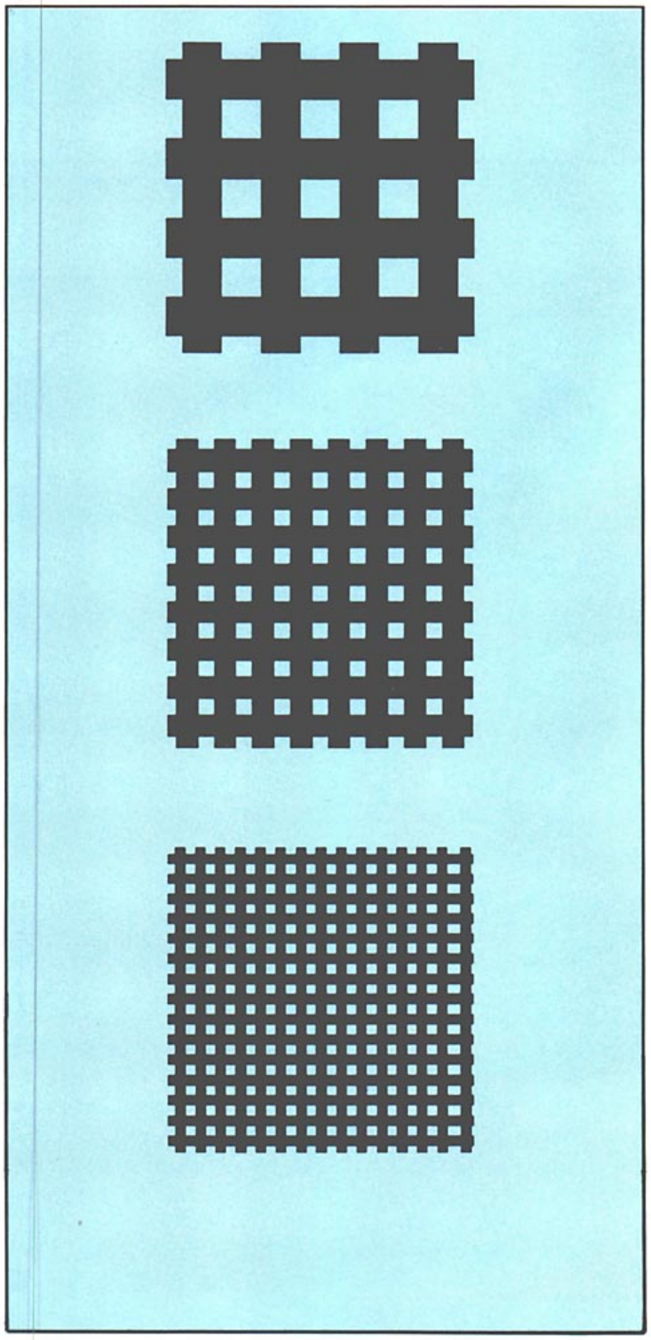
All three structures in **Fig. 1** have the same open areas and the same CFM, yet each will drain differently from the other.

Fiber mat buildup and how it occurs is the greatest contributor to drainage. It is controlled by:

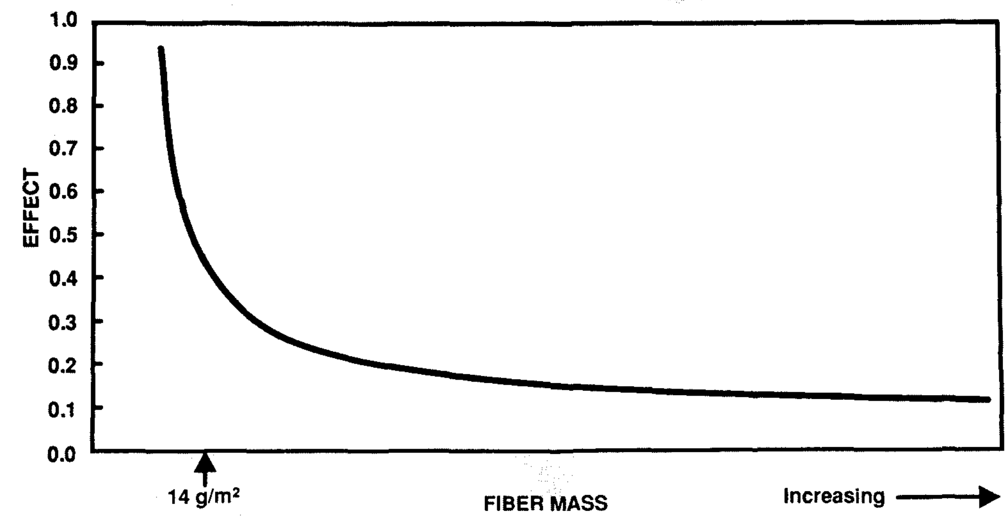
1. Fabric structure
2. Fiber length
3. Machine conditions such as forming board, foils, jet angle, initial drainage, etc.

Giles is the applications manager for Huyck Formex Co., Box 471, Wake Forest, N.C. 27587.

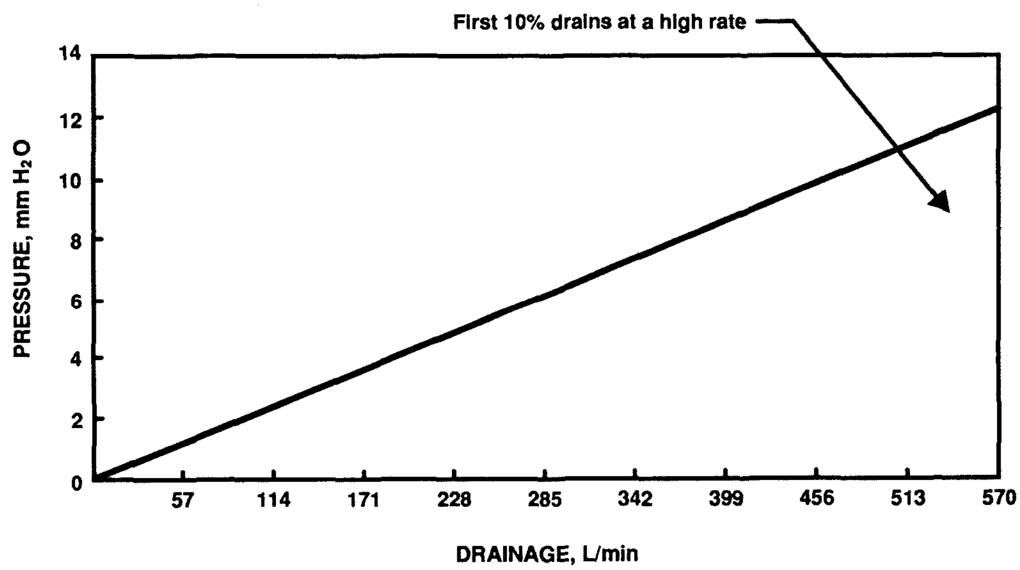
1. These structures have the same open areas but will drain differently



2. Effect of air permeability on total drainage



3. Initial drainage is at a rate proportional to the fabric air permeability



4. CFM.

CFM does play a small part in the control of drainage but not in the way you might think.

Many studies have shown how the interaction of the buildup of a fiber mat affects drainage (**Fig.** 2). Air permeability of fabric has a large effect, up to about 14 g/m^2 sheet weight. This can be seen on critical drainage machines making lightweight sheets like suction breast roll tissue machines. Above 14 g/m^2, the drainage on a paper machine does not appear to be so dependent on available fabric openness.

CFM is a measurement of flow at a pressure differential of 12.5 mm H_2O. A slice opening of 12.5 mm that gently lays this water onto the fabric with no disturbance or outside forces causes the same pressure differential. As the water flows through, the thickness and the pressure decreases towards zero. The flow with reducing pressure can be charted (**Fig. 3**).

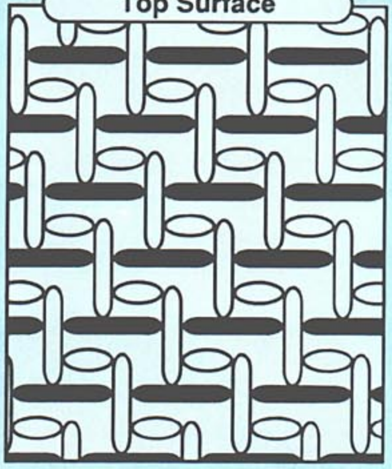
An average fabric with an air flow of 2 m^3/s converts to about 570 L/min with water at 12.5 mm. The average flow rate over the period is 285.5 L/min.; so the elapsed time is 2.6 s, which is a long time in paper machine terms.

Drainage elements create even higher forces than those presented in the previous example. The initial jet impact may cause a pressure differential of 10 times this figure. Drainage of water through the forming fabric is proportional to the pressure differential.

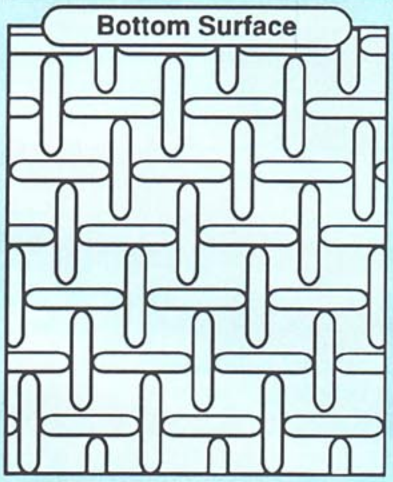
If we revert to the 14-g/m^2 fiber mat referred to earlier and examine the speed at which this mat builds, we find

4. Fabric with nonuniform hole size (Ratio 2.2:1)

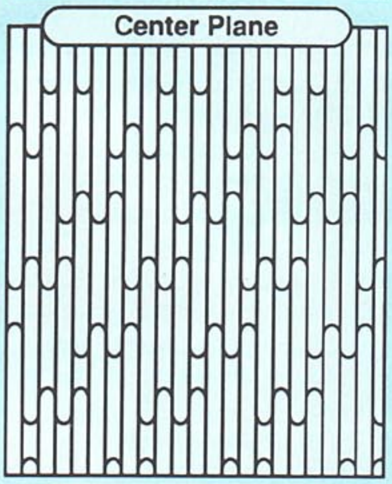
Top Surface



Bottom Surface



Center Plane



Fabric Description

TAPPI — Scale : 15:1

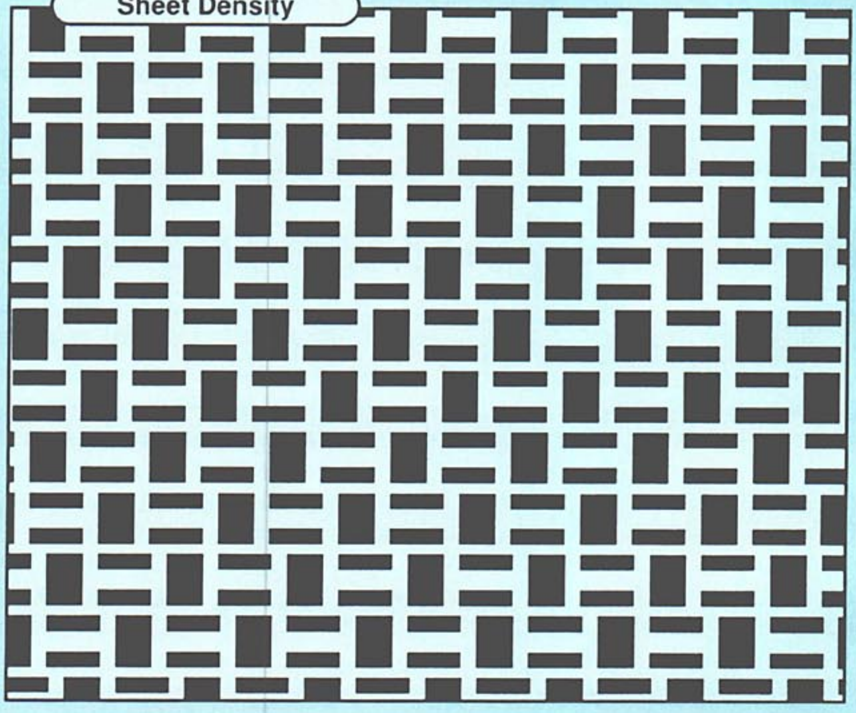
Mesh : 150 x 120
MD diameter(s), mm : 0.17
CD diameter(s), mm : 0.20 0.23 0.13

Open area : 43.24%
No. of holes : 2571/in.^{2}
MD support length : 42.86 in.^{2}
CD support length : 62.86 in.^{2}
Support ratio CD/MD : 1.47
FSI : 112.4

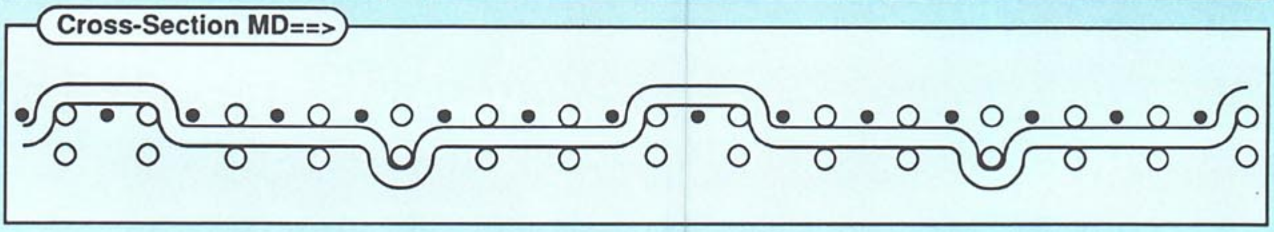
Warp coverage : 100.39%
CP open area : 28.29%

Hole no.	Length, mm	Width, mm	Area, mm^2	Open area, %
1	0.505	0.338	0.171	52.91
2	0.153	0.507	0.077	35.98

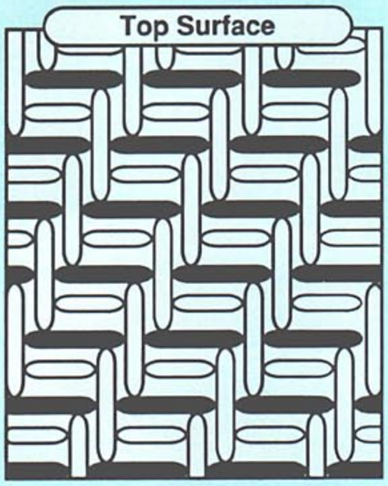
Sheet Density

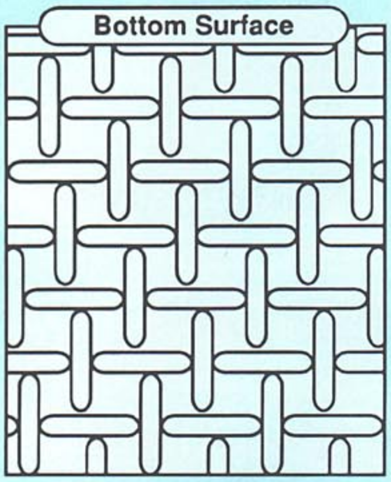


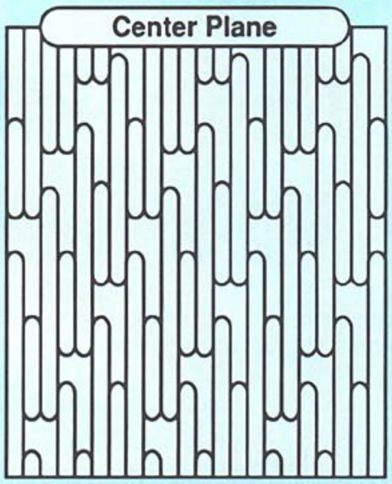
Cross-Section MD==>



5. Fabric with more uniform hole size (Ratio 1.2:1)







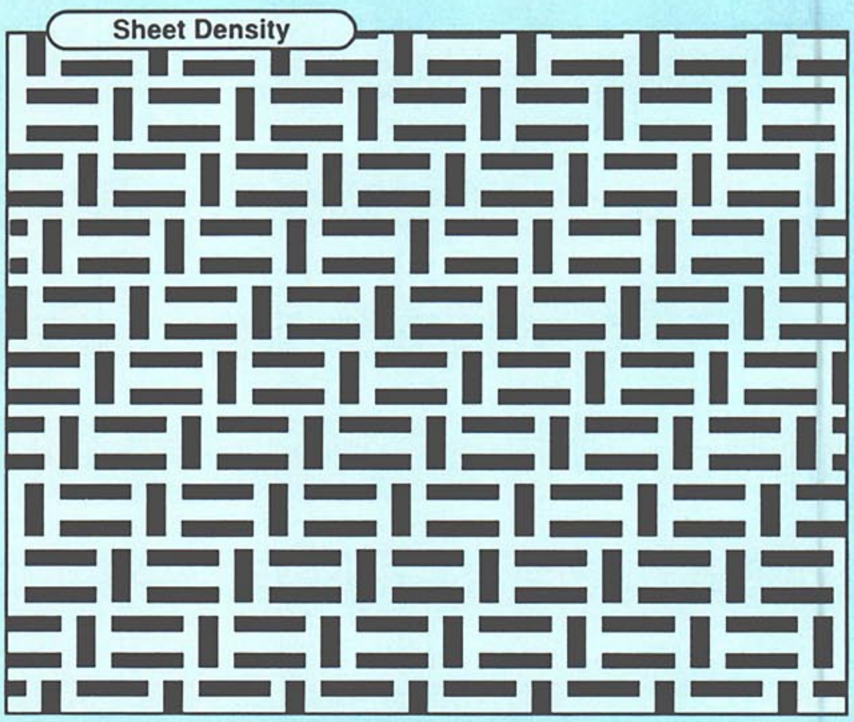
Fabric Description

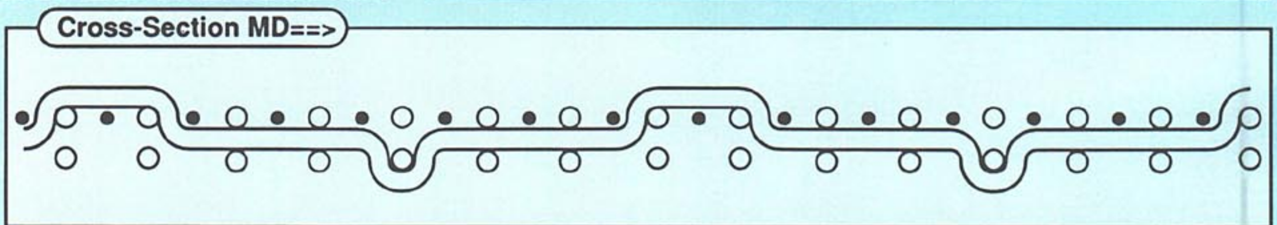
TAPPI 1 — Scale : 15:1

Mesh : 150 x 120
MD diameter(s), mm : 0.17
CD diameter(s), mm : 0.20 0.23 0.13

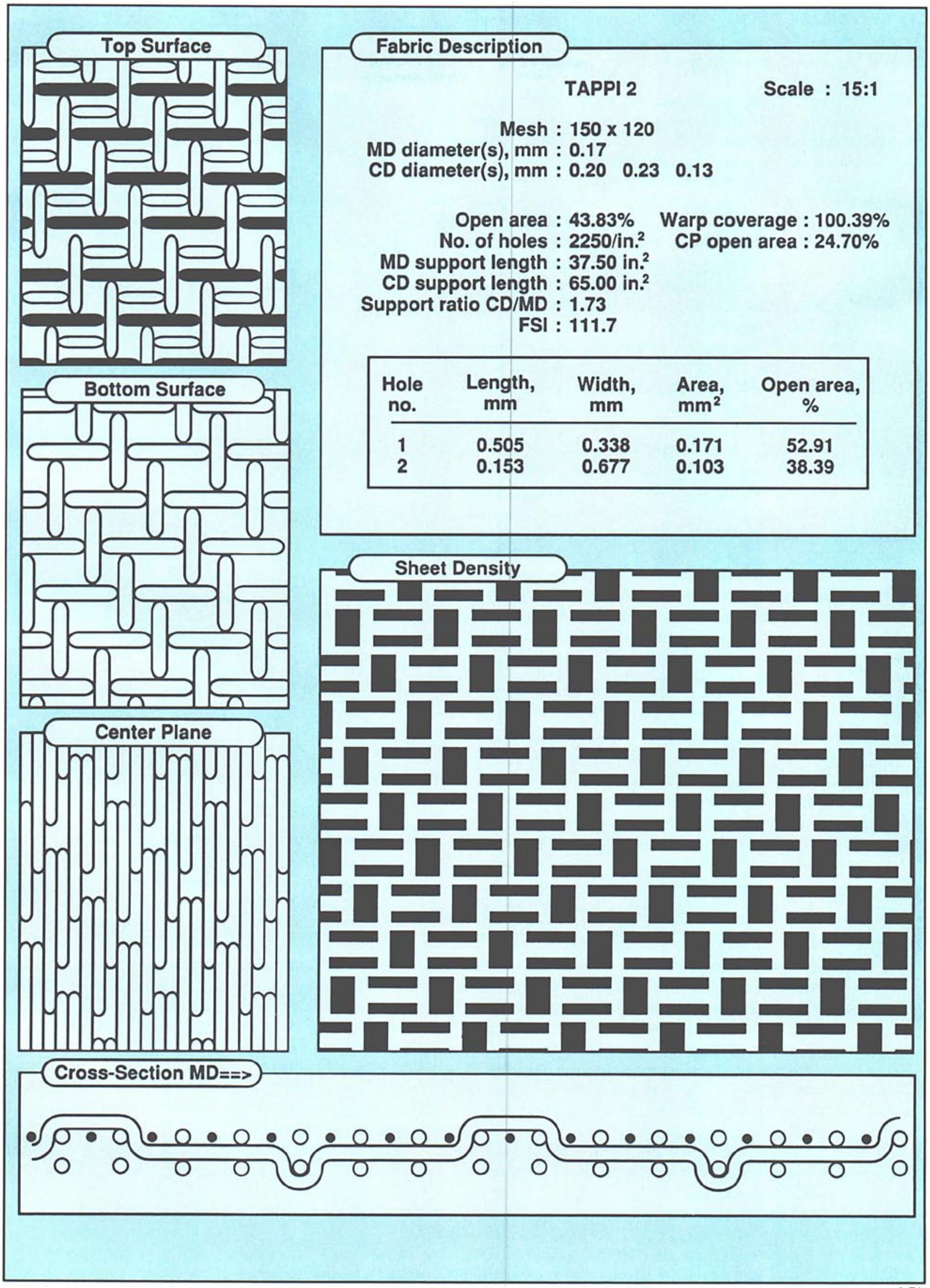
Open area : 38.74% — Warp coverage : 100.39%
No. of holes : 2571/in.^{2} — CP open area : 28.29%
MD support length : 42.86 in.^{2}
CD support length : 68.57 in.^{2}
Support ratio CMD/MD : 1.60
FSI : 120.0

Hole no.	Length, mm	Width, mm	Area, mm^2	Open area, %
1	0.505	0.169	0.085	39.61
2	0.153	0.677	0.103	38.39





6. Again, fabric with nonuniform hole size (Ratio 1.7:1)



Hole no.	Length, mm	Width, mm	Area, mm^2	Open area, %
1	0.505	0.338	0.171	52.91
2	0.153	0.677	0.103	38.39

that 14 g/m^2 is 10% of a 140-g/m^2 sheet. This suggests that 10–15% of the stock flow is needed to create this drainage reducing mat. We can assume that the initial drainage is at a rate proportional to the fabric air permeability as illustrated in Fig. 3.

In the quoted example of 2 m^3/s with an impact factor of 10, the initial 10% would drain in 0.0135 s or 135 mm at 600 m/min. If the impact factor is higher, as it often is, the time factor could be considerably shorter.

The buildup of a fiber mat that controls further drainage explains one typical fourdrinier phenomenon. By preventing early drainage, the dry line often moves toward the slice. With heavy early drainage, the dry line moves toward the couch. The latter is often referred to as "sheet sealing." A more appropriate term would be "fabric sealing."

Similar effects can occur by altering the fabric drainage rates. By replacing a single-layer fabric with a multi-layer, the dry line moves toward the headbox. This can be caused by (a) improved retention and (b) delayed early drainage. The single-layer fabric would have had air permeability of about 3 m^3/s, whereas the multi-layer would have had only about 2 m^3/s.

Fiber mat buildup is also dependent on fiber length in relationship to fabric surface structure. As a general rule, fibers of various lengths are uniformly distributed as these come out of the headbox. A mat is built by the bridging effect of the fibers over the holes in the fabric top surface.

If the fabric has uniform hole shapes, then a uniform buildup occurs. But fabrics are not often like this. Some have surface holes that vary in size up to a ratio of 2:1 or more. **Figures 4–6** show three multilayer fabrics of identical mesh and yarn diameters but of different weave patterns. Notice the variation in top surface hole size. In these cases, the smallest hole will bridge first and restrict drainage. The bigger, less restricted holes will absorb the remaining drainage causing a mass distribution on a micro scale that matches the exact pattern of weave, hole shape, and size (*3*).

Application engineers are becoming so proficient at the technique of sheet examination that the fabric design, mesh, and weave pattern can often be read directly from the paper sheet surface. On twin-wire machines where the proportion of sheet weight to fabric is less, this effect is more evident.

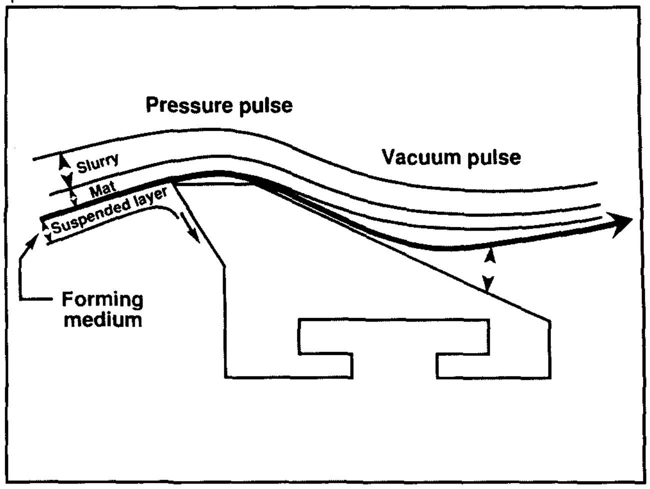
One solution to this early mat buildup is to prevent it from occurring. If a drainage delaying fiber mat is built in a short distance at high speed, then we need to find a way to redistribute it before that can occur.

If 150 mm at 900 m/min takes 0.001 s, then mat buildup could occur at a frequency of 100 times/s or 100 Hz. With no mat to restrict drainage, the first 10% of total slice flow occurs in 0.001 s, which then forms the mat. If this mat is disturbed at a frequency greater than the mat forming frequency, it cannot form and fibers remain in suspension. Thickening occurs due to the natural filtering action of the fabric. Under these conditions, drainage is rapid and retention slightly less.

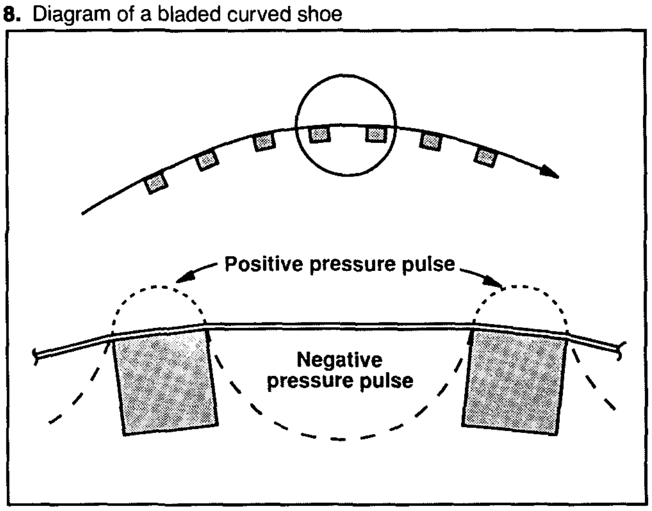
So how do we create this high-frequency turbulence (excitement) of the stock? All drainage elements cause a pressure pulse followed by a vacuum pulse as shown in **Fig.** 7. Some are more effective than others.

If these elements are positioned at uniform spacing, a harmonic pressure-vacuum frequency can be set up. With a typical foil blade, the drainage effect is far greater than the pressure effect. Drainage is not desirable, but it will occur anyway. We must find a way to create a pulse frequency greater than the mat forming frequency to prevent fiber mat buildup.

7. Drainage elements causing a pressure pulse followed by a vacuum pulse



8. Diagram of a bladed curved shoe



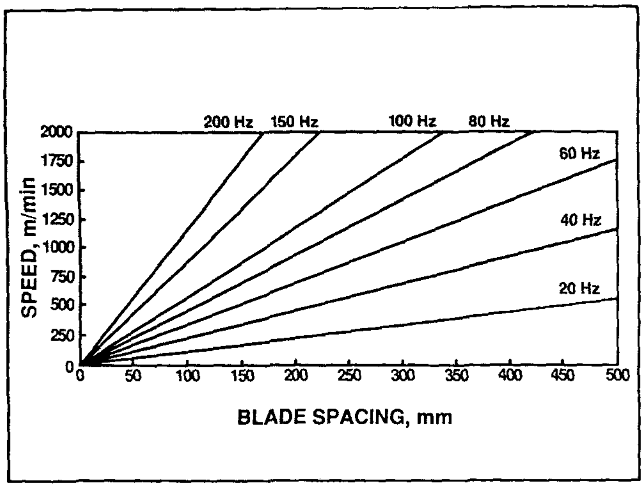
We can adopt some knowledge from modern twin-wire machines concerning this drainage problem. The "Big 3" manufacturers report that bladed curved shoes used very early in the table is effective. I agree 100% with this principle, but a curved shoe is not a curve. It is really a series of straight lines bending around the fixed blades as shown in **Fig.** 8.

Pressure points occur at each bend. Because the space between has no pressure (some machines have vacuum), this creates the cyclic pressure-vacuum action (harmonic) that was referred to earlier.

The blades on these curved shoes are spaced at intervals that give far higher pulse frequency for a given machine speed than the numbers referred to earlier. The frequency of turbulence is in some cases in the range of 200 Hz (**Fig. 9**).

Simple fourdriniers have problems of their own. If we set out to achieve the points mentioned earlier, then the

9. Pulse frequency chart



10. Modified hydrofoil blade

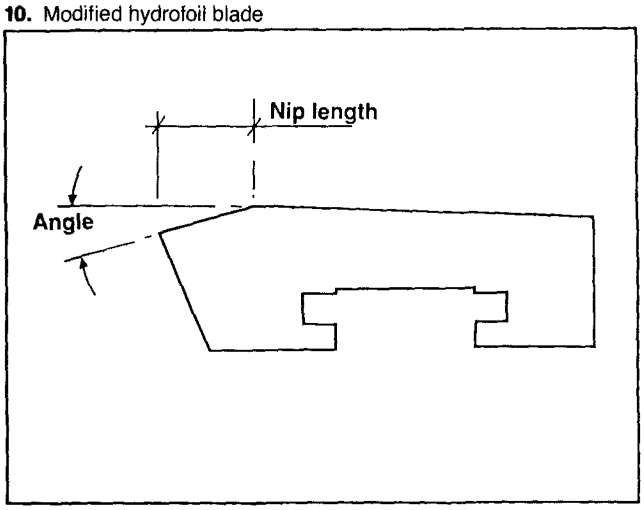


table may be far too long. "Can't get the water to the dandy" will be the complaint.

There are ways to put back into the sheet water that has been removed. This transfers more water down the table, easing the problem.

Hydrofoil blades with an ingoing nip (**Fig. 10**) have been known to help in this case. The amount of water put back is dependent on two factors:

1. Nip length
2. Angle.

The longer the nip length for any given angle, the more water that can be trapped. The higher the angle, the less water re-enters the sheet.

This ingoing water does two things:

1. Returns water to the sheet, allowing more time for turbulence to continue down the table
2. Refluidizes the sheet, helping to lift the fiber mat from the fabric.

Correct blade spacing under these conditions can cause high-frequency turbulence (excitement) of the furnish. Without mat buildup, good formation and controlled drainage will occur.□

Literature cited

1. Doane, Jr., F. P., Paper Trade J., 154(52): 32(1970).
2. Giles, A. F., 1979 EuCePa Conference Proceedings, EuCePa, p. 23.
3. Danby, R., Pulp Paper Canada 90(2): T45(1989).

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