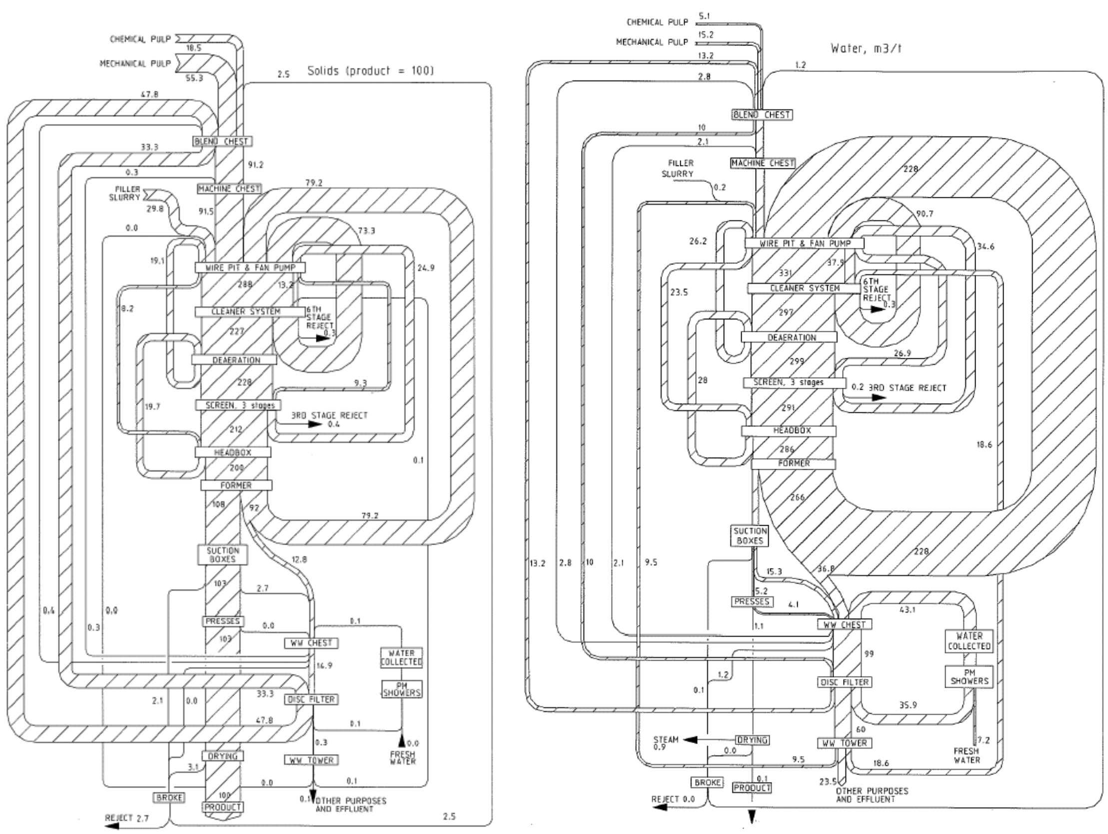
Papermaking

PAPERMACHINE - FORMING

1. Introduction

Papermaking is essentially the process of removing water from the pulp. The figures below show the stock and water Sankey diagrams for the flow around a typical papermachine system. These material balances can change significantly depending on the grade that is being made.



(a) (b)

Figure Sankey diagrams showing (a) stock flows and (b) water flows

The relative flows of the short circulation and a long circulation is clearly seen in these diagrams. Most of the flow is in the short circulation. We can also see that for this machine there is a lot of stock recirculating in the short circulation loop.

2. Headbox

The function of the headbox is to distribute the papermaking stock uniformly across the width of the wire section. The papermaking stock pumped in a pipe is converted to a uniform rectangular flow with absolutely the same flow rate and flow direction across the wire width. The headbox consists of a manifold distributor, flow stabilization elements and slice.

The manifold distributor is a tapered header which converts the pipe line flow into a rectangular flow with same velocity, quantity and jet thickness across the width of the wire section. The manifold distributor design is very important to maintain a constant static pressure along the cross machine direction. A recirculation valve is provided at the other end of the manifold distributor

Based on the design of the headbox, flow stabilization elements are present inside the headbox. These elements prevent the fibers from flocculating and settling by producing turbulence. Depending on the type of headbox these elements may be rolls, tubes or plates with even holes. Flow stabilization in headbox improves paper formation.

The headbox slice is also known as the nozzle and consists of a top lip and a bottom lip. The distance between the top lip and the bottom lip is known as slice opening. Slice opening controls the stock velocity and the angle of impingement of stock on the wire. The slice opening is crucial for paper formation and dewatering on wire. The bottom lip is stationary whereas the top lip is adjustable. A number of slice arrangements are available depending on the headbox type and the grade of paper to be manufactured

The major functions of the head box are:

- Further flow straightening (rectification)
- Streak elimination
- Floc dispersion
- Stock acceleration to machine speed

Types of Headboxes

The headbox serves several purposes: (1) Provide a uniform and stable jet with a constant MD velocity with no lateral (CD) components, (2) To create controlled turbulence to disperse flocs and create a uniform suspension and (3) To accelerate the fluid up to a high speed for fast paper production.

Pulp is dispersed by the shear created in wake turbulence. With the high velocities possible in hydraulic headboxes, high levels of shear can be attained, and therefore good pulp dispersion is possible. However, wake turbulence decays quickly, resulting in pulp re-flocculation. In most paper machines this occurs to a considerable extent before the headbox jet reaches the forming zone.

One major type of headbox is called an “air pad” headbox. Here stock flows through two or three slowly rotating perforated rolls. Wake turbulence from these rolls disperses the pulp and creates mixing to eliminate streaks from the tube bank. These headboxes have a free surface, with pressurized air above. The air cushion provides a dampening effect on pressure fluctuations in the stock flow entering the headbox. The air pressure is controlled to set the pressure in the headbox. The jet speed leaving the headbox is determined entirely from the height of the free surface inside the headbox. Usually around 10 inches of head on machines running at 500 m/min.

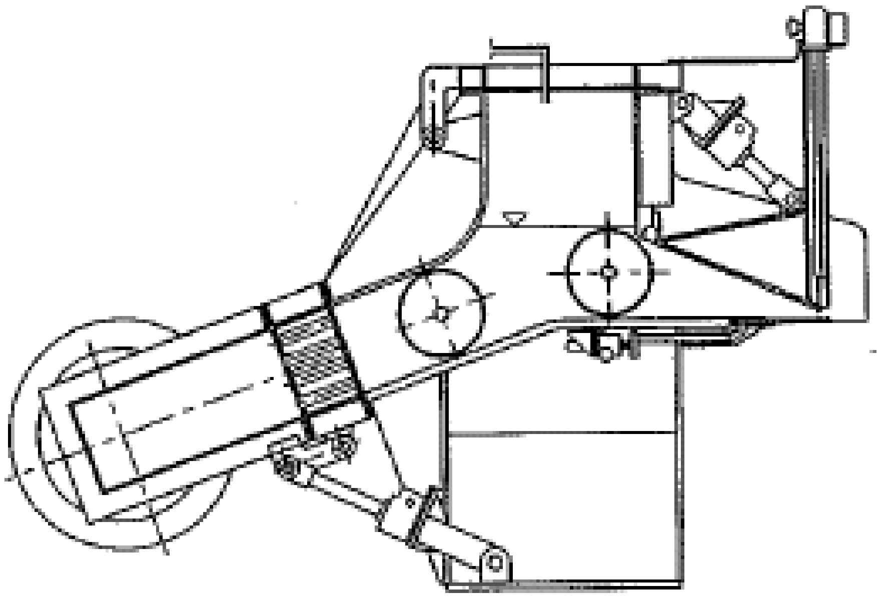


Figure: Air Cushion or Air Pad headbox

Air-cushion headboxes are used in moderate speed papermachines.

Another newer type of headbox is the hydraulic headbox shown in Here stock is fully enclosed (no air pad). Hydraulic headboxes were designed for twin-wire forming where small slice geometry was required to produce a free jet in the gap between the wires. The headboxes are available with or without a stabilization chamber. The stabilization chamber consists of a tube bank and is present between the chamber and the slice. This tube bank is also known as turbulence generator although its main function is to improve the velocity profile in the cross direction.

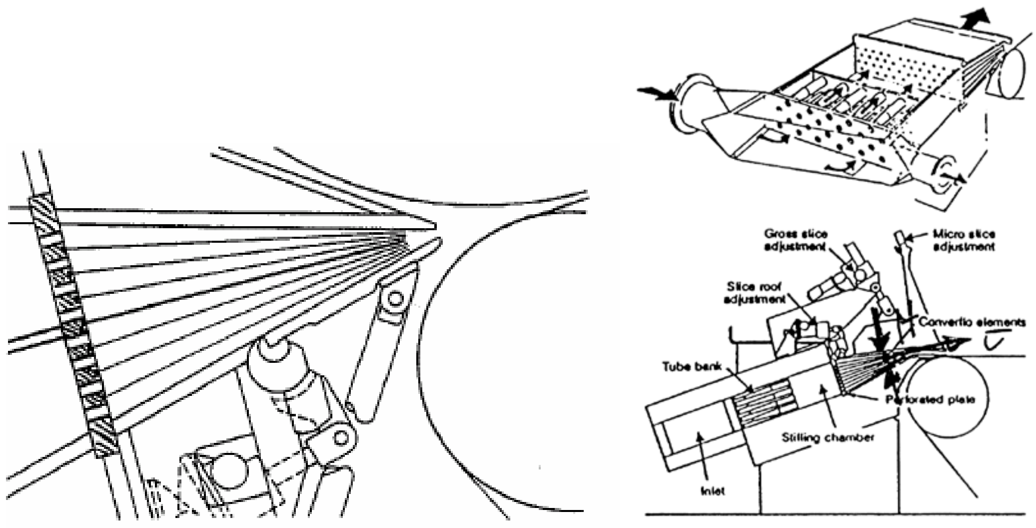


Figure: Beloit convertflo hydraulic headbox.

This tube bank has relatively large sudden expansion to generate turbulence and break up the flocs in the flow and evenly distribute the stock on the wire. Beloit inserted flexible vanes to reduce the large scale turbulence that could cause large scale unevenness in the paper.

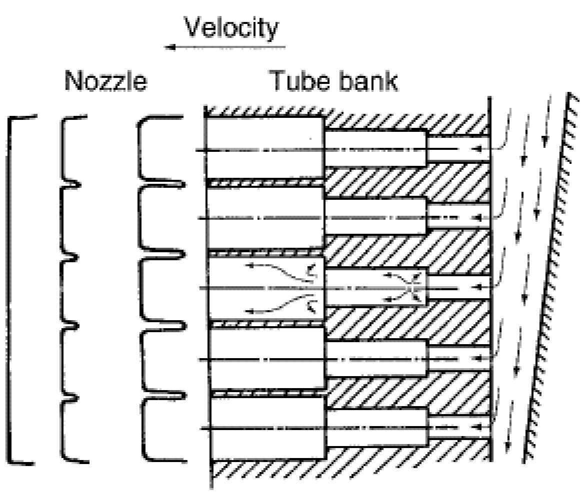


Figure: Step diffuser headbox

Another example for the hydraulic headbox is the step diffuser headbox in which the equalization chamber is absent. In the tube bank an increase in area takes place through a sudden expansion of the pipe diameters. The final section has a square cross section to permit close packing. The tubes are places vertically one above the other, eliminating the problem of basis weight streaks.

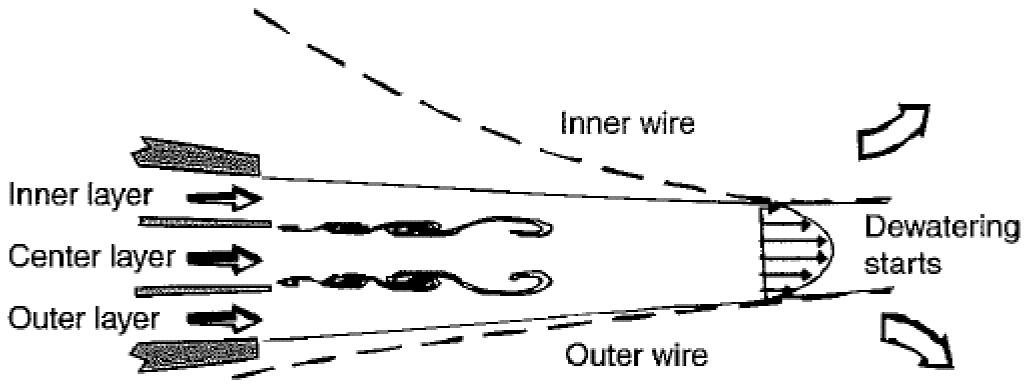


Figure: Multi-layer Headbox

It is possible to make multi-layered sheets of paper using multi-layer headboxes. In a multi-layer headbox different stock can be put together for the top, middle and bottom. Of course this requires separate CD distributors for each layer. The bending stiffness as well as the thickness along the vanes is important. This type of headbox is used to manufacture tissue papers and specialty boards.

The head box has a slice that serves to deliver the jet through a rectangular well-defined opening which is not deformed by changes in temperature and pressure. The shape of the slice is controlled to deliver even basis weight across the machine. The slice is converging (often 20-30 degrees) and the opening can be regulated both along the whole machine width and locally. Other requirements include high rigidity, polished surface and lip adjustment.

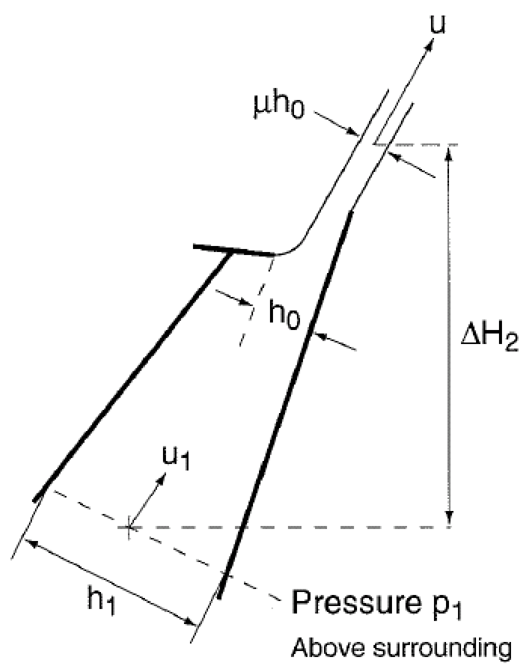


Figure Headbox slice lip.

Paper is sold on the basis of weight. Basis weight is the defined as the weight of paper in grams, per square meter area (g/m^2). Basis weight for writing and printing paper ranges from 60 g/m^2 to 90 g/m^2. Newsprint 45 g/m^2 to 50 g/m^2. Boxboards and corrugating medium ranges from150 g/m^2 to 450 g/m^2. Coated papers range from as low as 30 g/m^2 to 250 g/m^2

Uniform basis weight is necessary for the efficient runnability of paper machine. Basis weight is controlled in paper machine by scanners placed after calenders. These scanners measure the basis weight, moisture and caliper profile continuously along the cross-machine direction (width) of the sheet during production time.

The scanner sends signal to the machine chest thick stock pump to vary the flow based on the basis weight set point. Modern scanning systems perform statistical analysis on standard deviation or variance in the cross-machine and machine direction. This reflects the operational stability of the paper machine. The scanner collects the data from a number of points in the cross-machine direction.

Individual slice screws placed across the width of the headbox control cross-machine direction basis weight and profile. Position indicators for these slice screws indicate the slice profile. Remote control of the slice screws makes automatic control of the slice opening profile possible, based on the basis weight profile recorded at the dry end of the machine.

Dried fibers accumulated on the slice lip will cause fixed streaks which are detrimental to paper quality. Unstable basis weight profile is caused by hydrodynamic sources behind the slice area. Plugged holes in the manifold distributor can cause larger instabilities. The manifold inlet and outlet pressure should be same to produce a uniform cross-machine direction basis weight profile. Special care should be taken a the edges to produce stronger edges. Over adjustment of slice screws should be avoided to cause deformation in the slice lip.

3. Formers

The forming section of a paper machine is designed to produce a particular grade of paper with a limited dewatering capacity. The basis weight, speed of the machine and the grade to be manufactured determines the type of forming section to be used. It is designed to produce maximum dewatering with minimum fiber losses and good formation. The cost of dewatering in the forming section is lower than all the other sections of the paper machine for per unit of water drained. The type of paper machine is named after the forming section used. The press and the dryer section remain the same for most of the paper machines. Fourdrinier paper machine is the most widely used for producing writing, printing, copier, newsprint, etc. Most of the newer machines are a modification of Fourdrinier machine

Fourdrinier Formers

The fourdrinier forming section is a horizontal table consisting of a breast roll, forming board, table rolls, foils, wet suction boxes, dry suction boxes, dandy roll, lump breaker roll and couch roll. Auxiliary rolls like tension rolls, return rolls, guide rolls, showers and doctor blades are present to ensure smooth running of the forming section. The forming fabric known as ‘wire’ is an endless finely woven belt which runs between the breast roll near the headbox and the couch roll at the other end. The couch roll is provided with most of the drive power required to turn the wire along with the returning roll. However, due to the increasing width and speed of the paper machine the fourdrinier machine was incapable of providing the dewatering capacity.

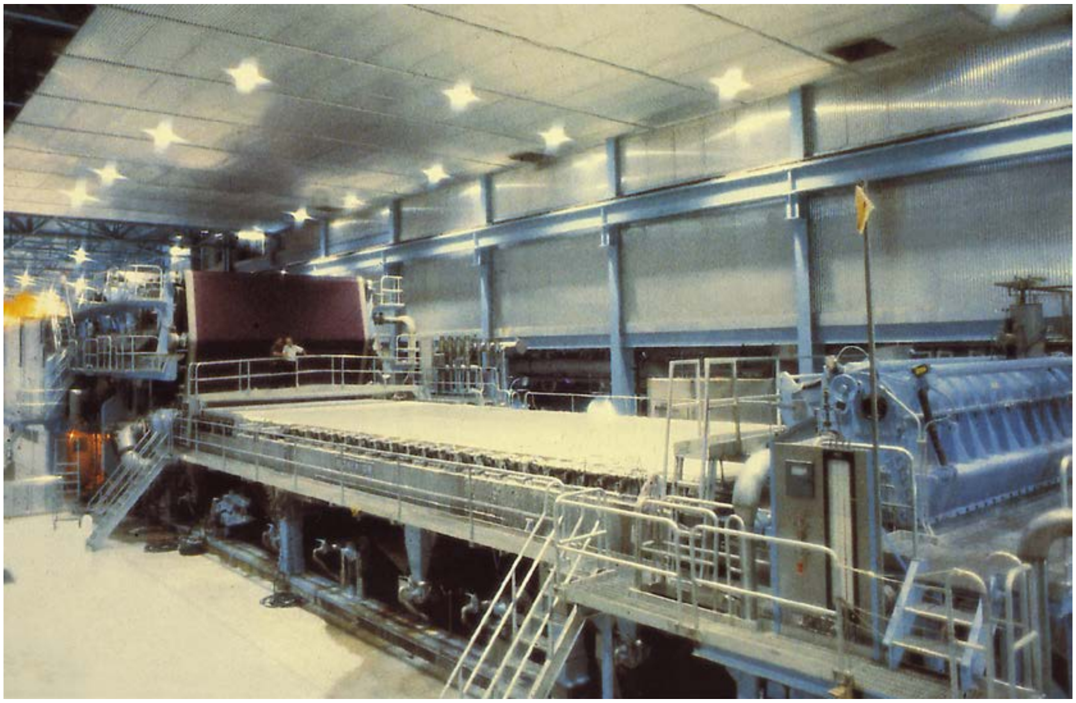


Figure: Fourdrinier papermachine

The fourdrinier paper machine is a horizontal table consisting of a solid breast roll near the headbox and a couch roll at the other end. The wire rotates between the breast roll and the couch roll. A forming board is placed after the breast roll to support the wire as the stock meets the wire. Drainage elements which aid in removing water are placed between the breast roll and the couch roll. These drainage elements are table rolls, foils, wet suction boxes, and dry suction boxes. Vacuum is applied in wet suction and dry suction boxes to provide the force to draw water from the sheet as it consolidates.

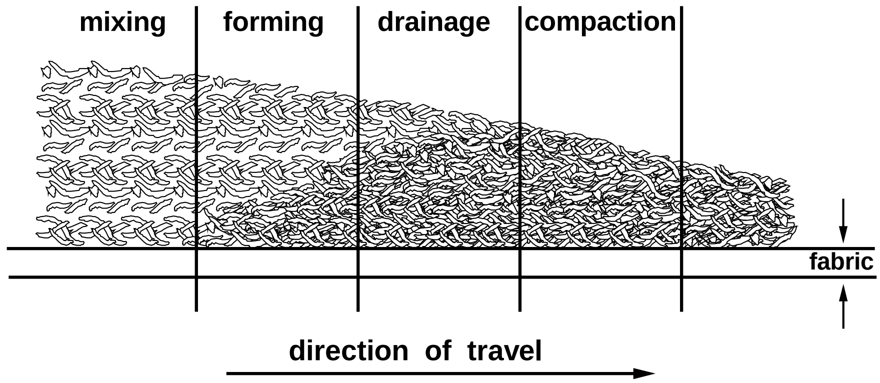


Figure showing the four stages of forming

The breast roll is the first component of the fourdrinier paper machine. It is a solid hard rubber covered roll which supports the wire when the stock meets the wire. The function of the breast roll is to turn the wire at the headbox end of the section and takes the entire tension load of the wire. The breast roll is not driven and is rotated by the wire. Doctor blades are provided on the breast roll to prevent the fiber lumps and water from following the roll. In tissue paper manufacturing the breast roll is supplied with vacuum to help in dewatering.

The forming board is installed to get rid of the sagging wire between the breast roll and the first table roll or hydrofoil. The space between the first table roll or hydrofoil and the breast roll is critical for paper formation. The earliest forming boards were single slatted and were mainly used to support the wire. However with the increasing width of the paper machine slotted type forming boards with three to six slats are used. Some forming boards also use a light vacuum to regulate the initial drainage

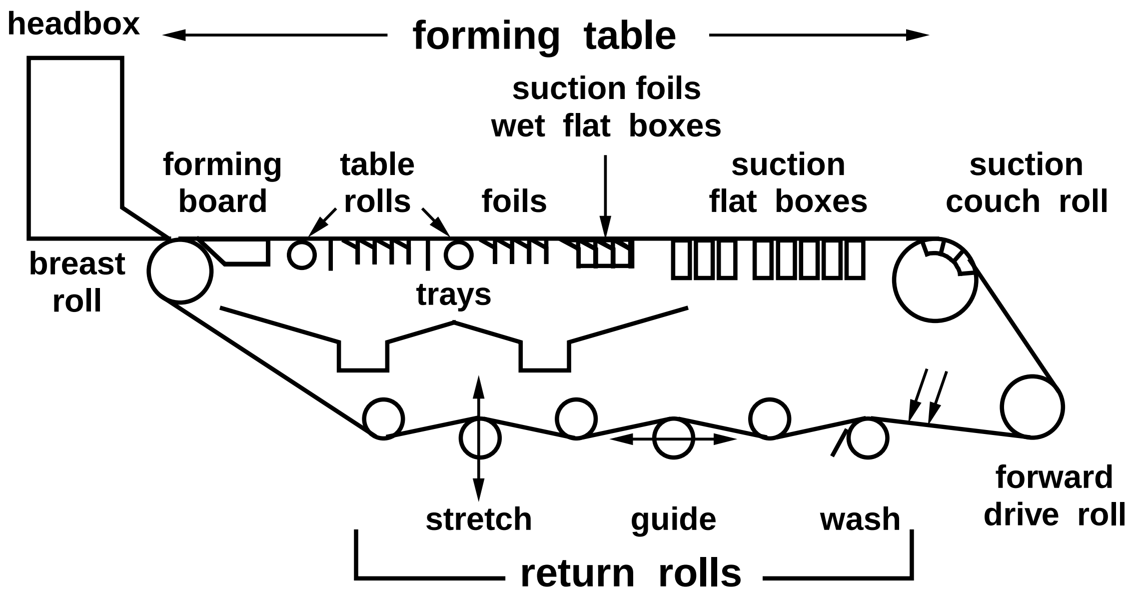


Figure Schematic of Fourdrinier papermachine showing drainage elements

The forming board is followed by drainage elements installed to remove water and induce turbulence into the sheet for good formation. The first drainage element used is the table rolls. Table rolls rotate by the tension of the wire and create turbulence. The table rolls must be straight, rigid and dynamically balanced, to prevent from disrupting the formation. A table roll creates a suction pressure in the downstream expansion zone between the wire and the roll. This suction helps in water removal. The magnitude of the vacuum depends on the diameter of the table roll. However, the suction will also create a slight deflection in the wire. The greater the diameter the greater the vacuum and the greater is the deflection. A film of water accompanies the table roll on its return at high speeds and splashes into the wire at the nip. This disturbs the formation. Increasing paper machine speeds required large diameter table rolls which disrupted the formation. Therefore, table rolls are replaced by stationary drainage elements in modern high-speed machines.

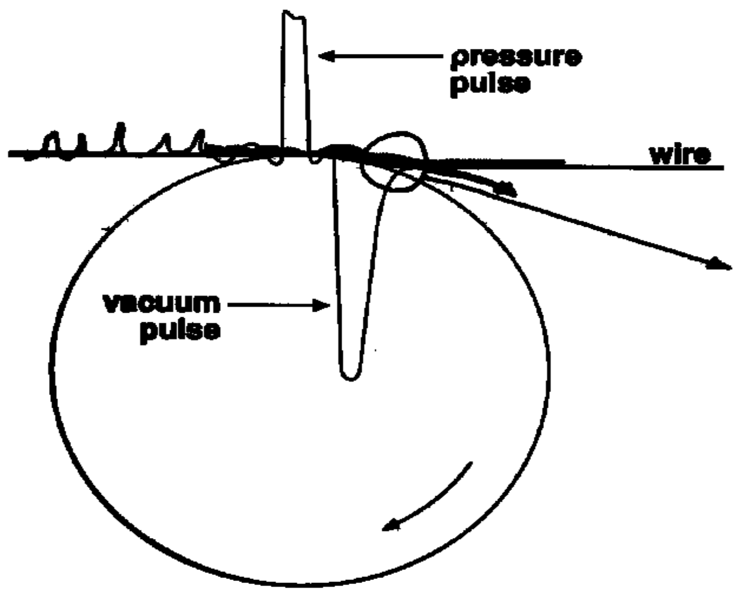
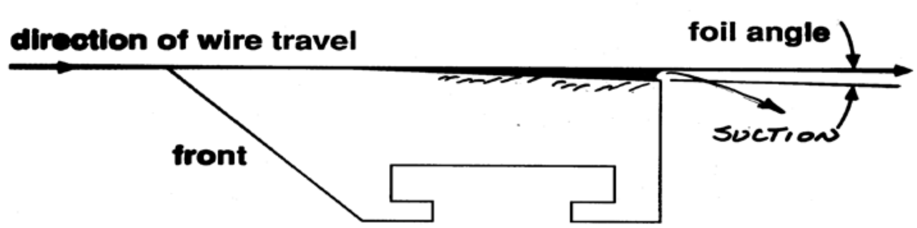


Figure showing the pressure caused by a table roll.

Hydrofoils have replaced table rolls in high-speed paper machines having very short forming zones. The advantages of hydrofoils are easy regulation of drainage, gentle turbulence, more drainage, good formation at low consistencies, better retention of fines and fillers, and reduced vacuum in wet suction boxes. The disadvantage of hydrofoil is poor formation in absence of microturbulence and the selection of proper material for durability and low coefficient of friction which is very costly. Hydrofoil consists of two parts: top surfaces called the flat surface which is parallel to the wire provides the support to the forming wire and the trailing surface which is inclined to the wire at an angle forms a divergent nip. The divergent nip is the important part, which generates the vacuum and dewaters the sheet. Blade angle and length of the divergent nip are the main parameters which determines the performance of the hydrofoil blade such as turbulence, drainage and fines retention. Hydrofoils are available with different blade angles. The blade angles used vary from zero degrees to seven degrees.



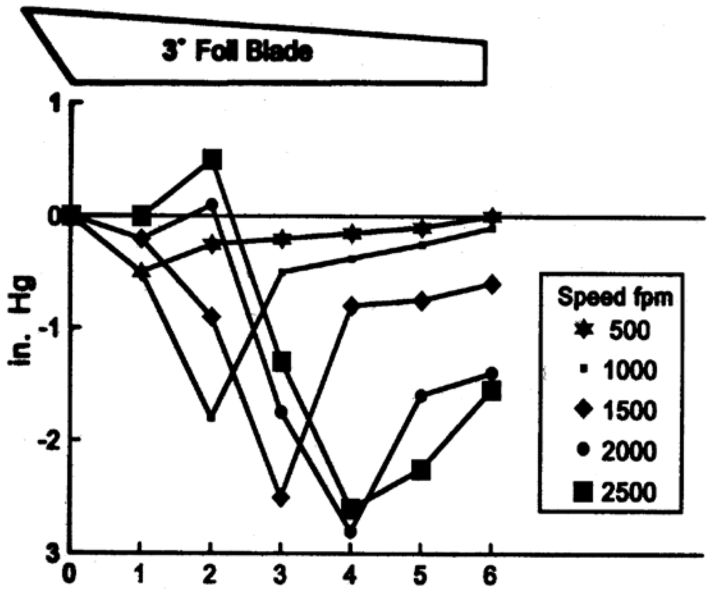


Figure showing a foil blade and the associated pressure produced.

The paper made with hydrofoils shows improved formation, less flockiness and a more even distribution of fibers. Paper properties like porosity, roughness and two sidedness improve. Water spots are absent in contrast to the sheets produced from table rolls. However other sheet properties like caliper, tear and opacity remain practically unchanged.

Wet suction boxes or vacuum foil units are extension of foil technology where the foils are enclosed in a vacuum box. A fan or a pump generates the vacuum. The amount of vacuum applied is low. Two or six wet suction boxes can be placed in the wire section. The vacuum draws the water and air inside the box. The air is separated from the water using barometric legs. The white water flows downwards and the air moves upward towards the vacuum header. The vacuum is gradually increased from the first box near the breast roll end towards the couch roll end. The increase in vacuum increases the drag load on the drive. As the wire contacts the foils in the suction box the foils get worn out due to friction. Proper selection of material is required to reduce wear on both the wire and the foils. Wet suction boxes are slotted to increase the open area

High vacuum boxes or dry suction boxes are flat covers containing circular holes or slots which increase sheet concentration by using vacuum to draw the water from the sheet. The vacuum levels in the dry suction boxes range from 15-40 kPa. Three to five dry suction boxes are used on the fourdrinier table and are placed after the dandy roll and before the couch roll.

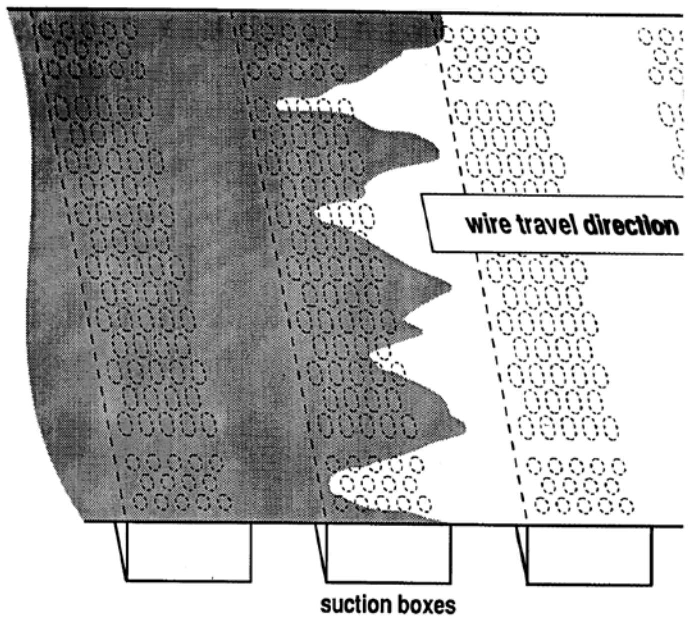


Figure shing the placement of the suction boxes.

A dandy roll is a wire covered open roll of cylindrical design and evens out the paper surface. It is placed on the wire at a position where the concentration of the sheet is around 2%-3% and improves web formation by introducing shear in the stock. The dandy roll is not a dewatering roll and the concentration of the stock remains the same on the upstream and downstream sides of the roll. Watermark can also be incorporated using the dandy roll. The dandy roll also reduces two sidedness of the sheet. However, it is not possible to use dandy rolls at a higher speeds due to marks in the wet web and difficult to maintain cleanliness of the roll. The twin-wire can be considered to be an extension of a dandy roll

Couch roll is the final stage of dewatering in the fourdrinier paper machine. Most machines use suction couch roll to get a web dryness of 18-20% leaving the former section. The increase in the dryness increases the tear in the wet web enabling to apply more pressure in the press section. The couch roll is the main drive of the wire in some machines, however, when a turning roll is present the couch roll acts as a helper drive and the wire turning roll the principal drive. Water removal in the couch roll is through a suction box inside the roll. The water flows out of the system through the couch pan. The design of the pan is such that the water does not enter the sheet on its return. The perforations in the couch roll are kept clean by showers. The sheet from the couch roll is transferred to the press section by means of a pick-up roll in slower machines and a suction pick-up in high –speed machines.

Twin Wire formers

With the increasing machine speeds the forming section of a fourdrinier machine became longer and problems with a unstable liquid surface increased. The drainage of paper form one side increased the two sidedness. To overcome this problem, a top wire was used in addition to the bottom wire of the fourdrinier thus enabling two-side dewatering. Twin-wire forming increased dewatering capacity, more symmetric paper product, lower basis weight variability, better formation and lower linting. There are a variety of twin-wire formers which use different forming principles.

Twin-wire roll forming is used to produce printing paper. The stock jet is injected into the nip between the two wires wrapping a rotating roll. Dewatering takes place from both outer and inner wire. The latter water is kept in the open roll surface and released after the inner wire has been removed from the roll. The drained water is thereafter led to the wire pit. The water passing through the outer wire is also led to the wire pit. Roll formers do not produce sheet with top levels of formation, however, they give a higher retention values which eliminate the use of retention aids.

In a twin wire former, the jet from the headbox is captured between two moving fabrics and dewatered on both sides

Some obvious advantages are:

- higher dewatering capability (needed for faster machines)
- less two-sidedness.
- avoidance of free surface instabilities
- improved formation

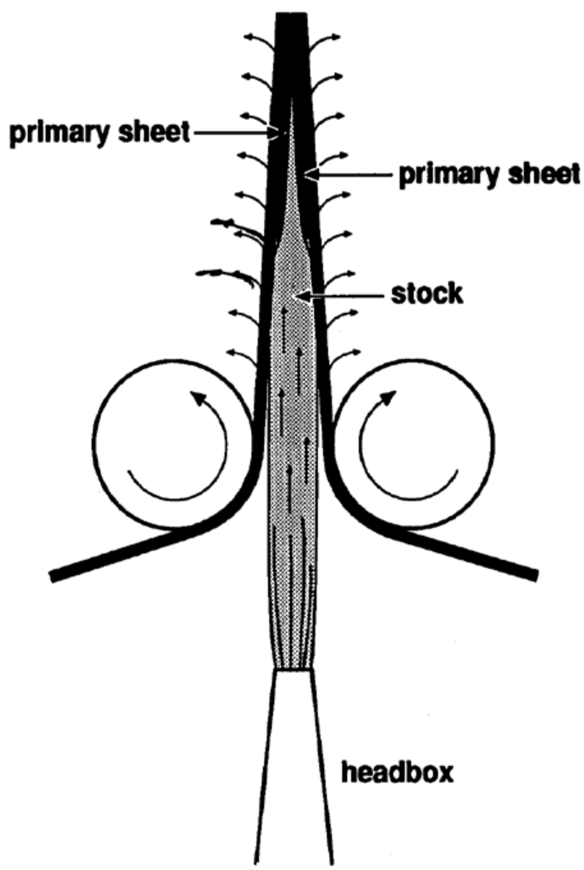


Figure: Twin Wire former

Roll Formers

In this case, the jet is captured in a wedge between to fabrics passing around a rotating roll, as shown in Figure 2. Pressure is created by imposing a curvature upon a fabric under tension.

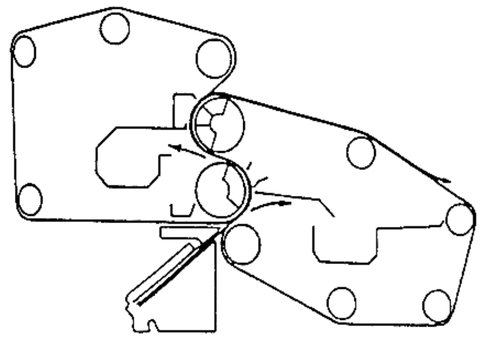
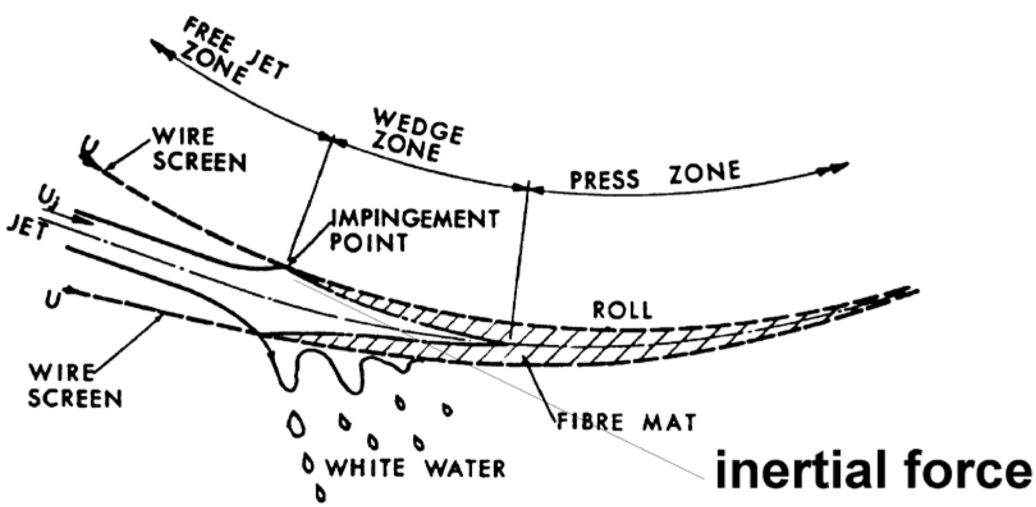


Figure: Roll former

As in the case of Fourdrinier forming, there is an initial pressure from the jet inertia. The angles of impingement between the jet and fabric are in the range 5-10 degrees as a result of the wedge geometry.



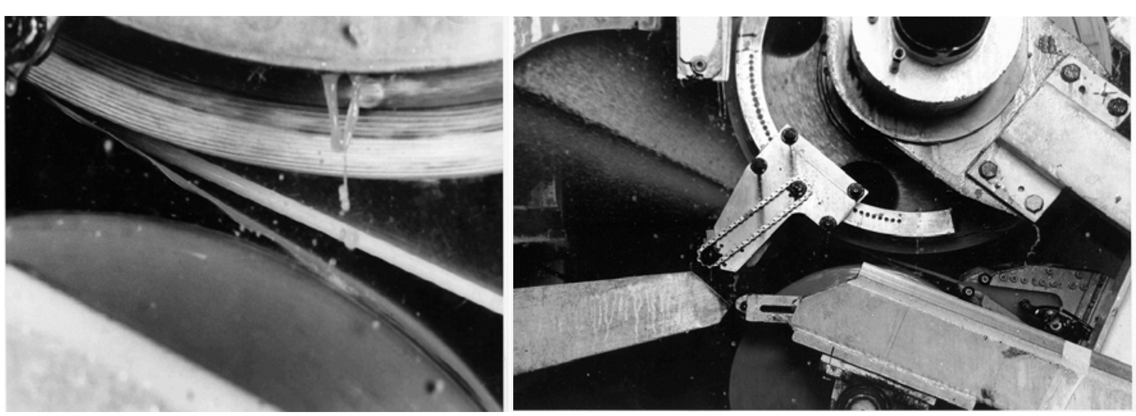


Figure: Point of impingement and the forming roll spray

The influence of jet to wire speed ratio in roll forming is illustrated by the energy balance (Bernoulli equation) shown below. This equation assumes that no energy is added to or taken away from the jet by the fabric. As shown, to meet this condition, the jet speed must always exceed the fabric speed. However, because the jet is a real fluid with viscosity, this velocity difference introduces shear, which transfers energy from the jet to the fabric, and therefore strictly speaking, the Bernoulli equation can only approximately represent the case of jet impingement in roll forming.

Roll formers generally produce poor formation but very good retention of fines and filler. This is attributed to the “gentle” drainage pressure imposed.

Jet to Wire Speed Ratio for Roll former:

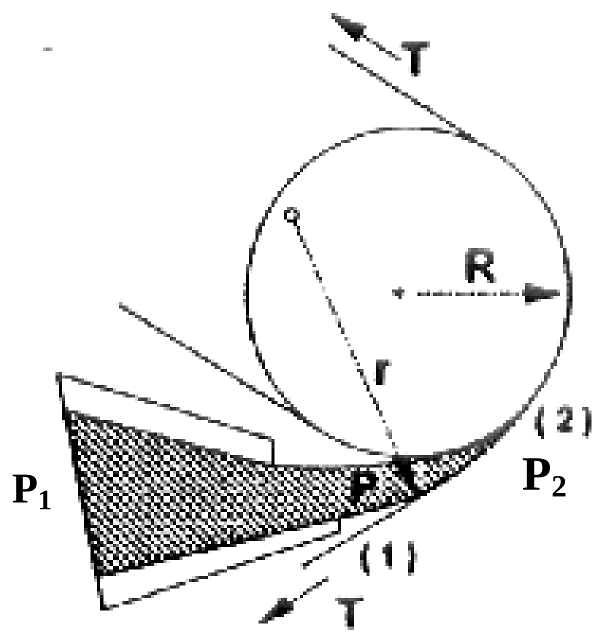


Figure Forming roll pressure

Bernoulli Equation:

$$\frac{u_1^{\ 2}}{2}+\frac{P_1}{\rho}=\frac{u_2^{\ 2}}{2}+\frac{P_2}{\rho}$$

If we assume that the suspension velocity is equal to the wire velocity at point 2 then

$$\frac{u_1^{\ 2}}{2}=\frac{u_2^{\ 2}}{2}+\frac{T}{\rho R}$$

Where T is the tension per unit width

$$\frac{u_{jet}}{u_{wire}}=\sqrt{1+\frac{2}{\rho u_{wire}^2}\frac{T}{R}}$$

$$\frac{u_{jet}-u_{wire}}{u_{wire}}=\sqrt{1+\frac{2}{\rho u_{wire}^2}\frac{T}{R}}-1$$

To minimize the difference and produce a random sheet of paper, you need to minimize,

$$\frac{2}{\rho u_{wire}^2}\frac{T}{R}$$

(Roll) Blade Formers

Blade formers have vertical stationary elements mounted on both the sides of the wires initially opposing each other but later positioned in a staggered mode. A curved slotted forming shoe placed on one side of the wires. The basic principle of dewatering is same to that of roll forming. The radius of curvature for the wire was obtained by placing the shoe element in that curvature to produce the necessary dewatering pressure. This radius of curvature is larger than that of the roll former and produces lower dewatering pressure than roll former which in turn improves formation.

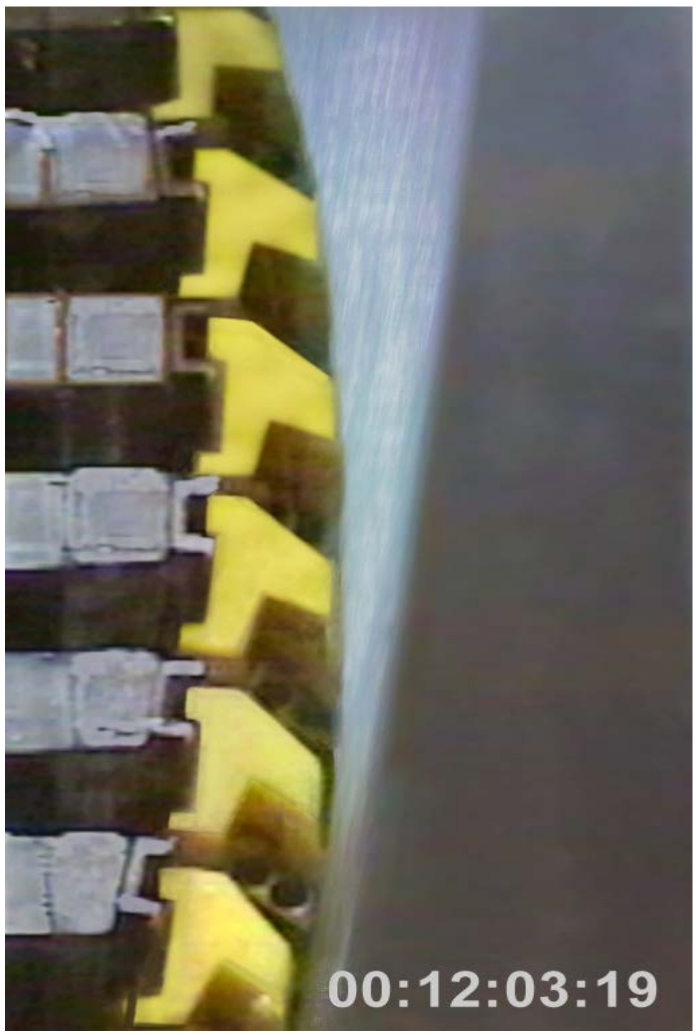


Figure Blade drainage

Roll blade forming is a combination of dewatering blades, forming rolls, and blade shoes (forming shoes). If a blade shoe is designed as a curved surface with parallel slots, pressure pulses will be generated due to the wire deflections at the blade edges. Different combinations of blade and roll formers are used. Some twin-wire formers use blades followed by a blade shoe and roll dewatering. Others use initial roll dewatering followed by blade shoes. However flow instabilities in the roll nip cannot be avoided. The formation of the sheets produced from these formers was low. To avoid these flow instabilities hybrid formers were developed.

Hybrid formers are twin-wire formers in which a fourdrinier forming is followed by a twin-wire forming. These type of formers are used for producing printing papers and base paper for coating. The initial forming takes place on a fourdrinier table consisting of a breast roll, forming board, hydrofoils and vacuum foils. At this time the drainage takes place at only one side of the wire. A top wire is placed after the vacuum foils where vacuum is applied to draw water from the sheet through the top wire. Hence two way drainage is achieved lowering the two sidedness. The top wire returns back and the sheet follows the fourdrinier wire to a dry suction box and couch roll. The hybrid formers can have roll, blade or roll/blade or adjustable blade dewatering following the Fourdrinier wire. Hybrid formers produce good formation and symmetrical sheet structure.

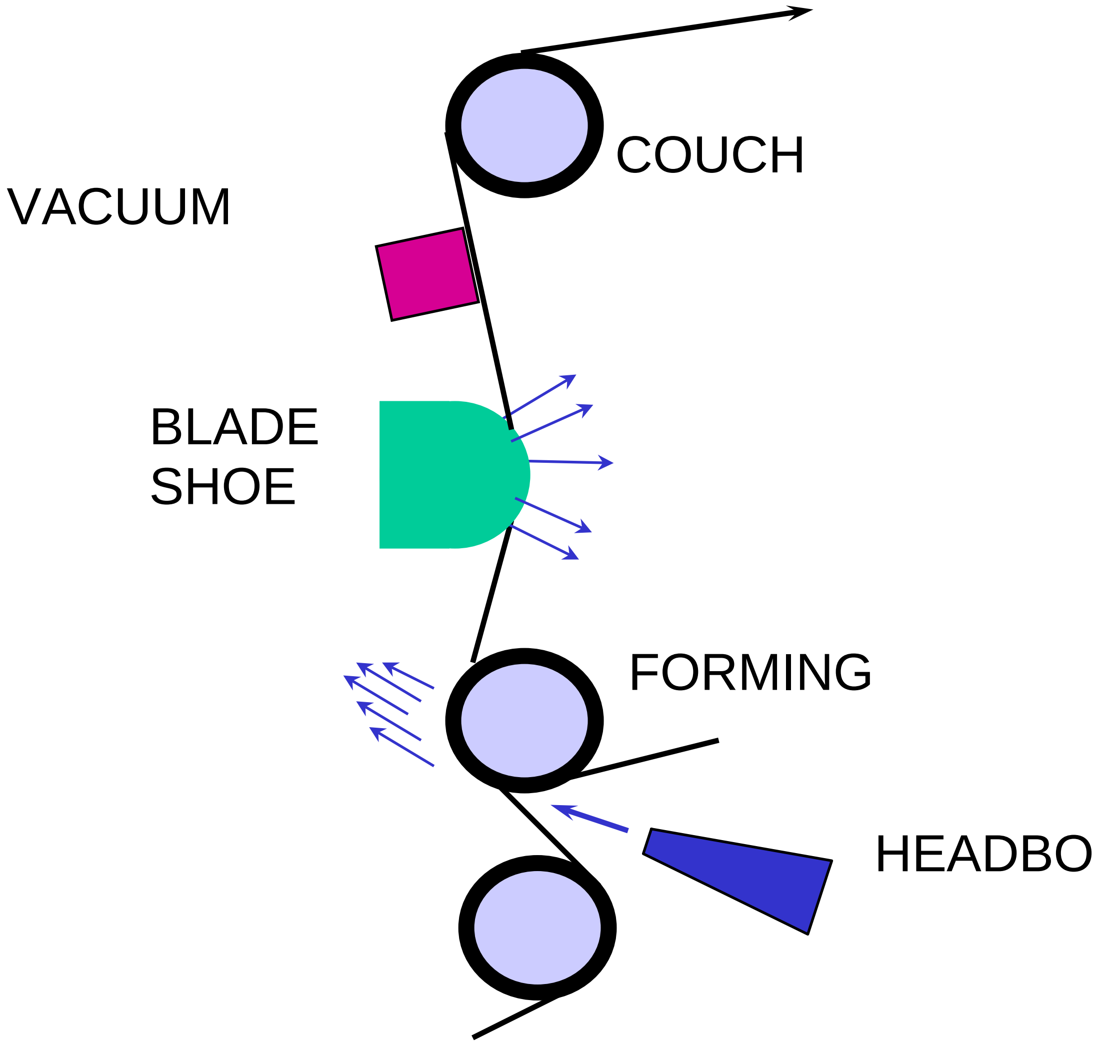
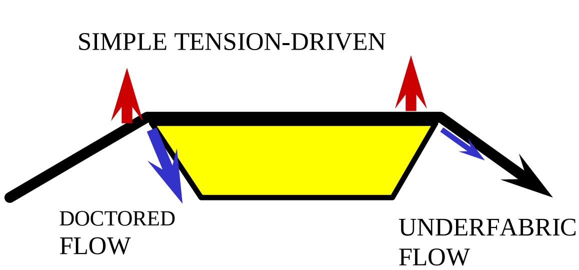


Figure showing the dewatering elements of a gap former



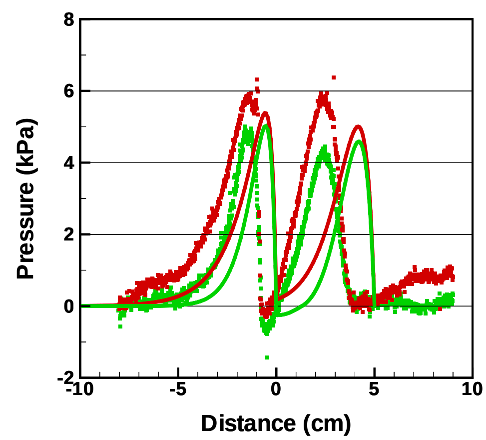


Figure showing blade and measured pressure profile.

Figure: Experimental pressure measurement over blade

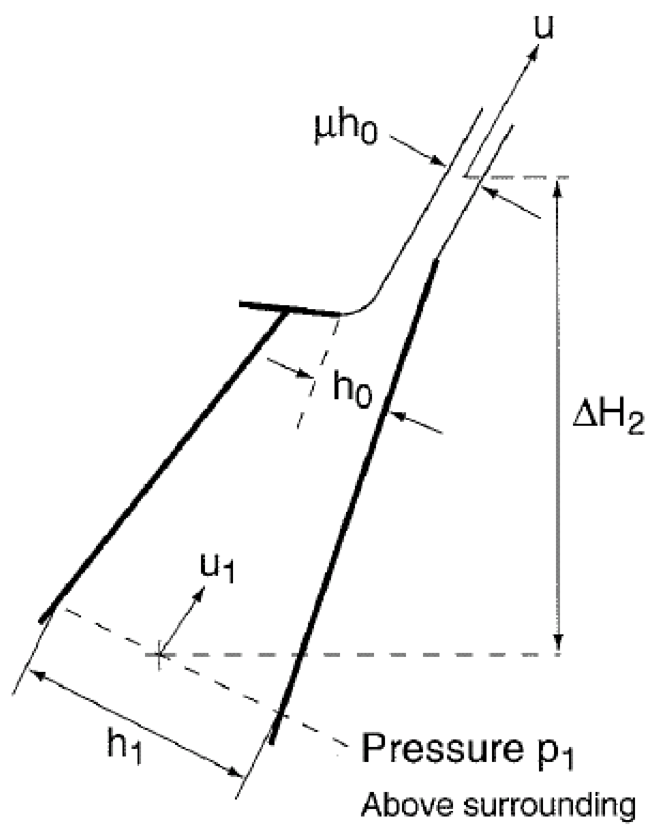
Calculating Jet Velocity

Stock is accelerated up to the machine speed in the headbox. This is accomplished in a converging section, and then by a very sharp contraction called a ‘slice” from which the stock emerges as a free jet.

Jet velocity is governed by headbox pressure. It is typically measured from this pressure using the Bernoulli equation.

The jet thickness and jet velocity determine the flow rate discharging from the headbox. The jet thickness is determined by the slice opening and its geometry. The slice creates a “vena contracta”, which causes the jet thickness to contract to a smaller value than the slice opening. This is commonly described by a “contraction coefficient” shown below. The jet pressure falls to zero at the vena contracta.

Both the jet contraction coefficient and its angle of outflow can be estimated from hydrodynamic potential flow theory.



Mass Balance:

$$u_1 h_1 = \mu h_0 u$$

$$u = \frac{u_1 h_1}{\mu h_0}$$

Momentum:

$$\frac{P_1}{\rho} + \frac{u_1^{\,2}}{2} + \rho g h_1 = \frac{P_0}{\rho} + \frac{u^2}{2} + \rho g h_0$$

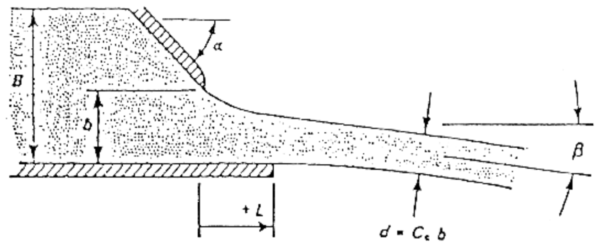
Note: $P_0 = 0$

$$\frac{P_1}{\rho} + \frac{u_1^{\,2}}{2} = \frac{u^2}{2} + \rho g \Delta H_2$$

Substituting and simplifying yields:

$$u = \left(\frac{2g\left(\frac{P_1}{\rho g} - \Delta H_2 \right)}{1 - \left(\frac{\mu h_0}{h_1} \right)^2} \right)^{\frac{1}{2}}$$

Appendix: Vena-Contraction coefficient



$$C_c = \left[\frac{a_0 - a_1 Y}{1 - a_2 Y}\right] \cdot exp\left[-\left[\frac{a_3 - a_4 Y}{1 - a_5 Y}\right] X^J\right] + \left[\frac{a_6 - a_7 Y}{1 - a_8 Y}\right] \quad (1)$$

$$\beta = \left[\frac{b_0 + b_1 X - b_2 Y + b_3 Y^2 - b_4 XY + b_5 XY^2}{(1 - b_6 Y)^2}\right] \cdot exp\left[\frac{-b_7 - b_8 X + b_9 Y + b_{10} XY}{(1 - b_6 Y)}\right] \quad (2)$$

where X = L/b and Y = b/B and

$0 \le X \le 5.0$, $0 \le Y \le 0.95$ for $\alpha = 45°$, $\alpha = 90°$

$0 \le X \le 5.0$, $0.7 \le Y \le 0.90$ for $\alpha = 10°$

range of validity of equations

Equations to calculate C_c and ß from X and Y for three slice angles α (10°, 45° and 90°)

Formation

During the forming process fibres are stochastically deposited onto the moving wire. The resulting wet web of fibres has a non-uniform mass distribution that affects the strength and optical properties of the paper.

This basis weight variation is referred to as the 'formation' of the paper and is easily seen by the naked eye in almost all papers.

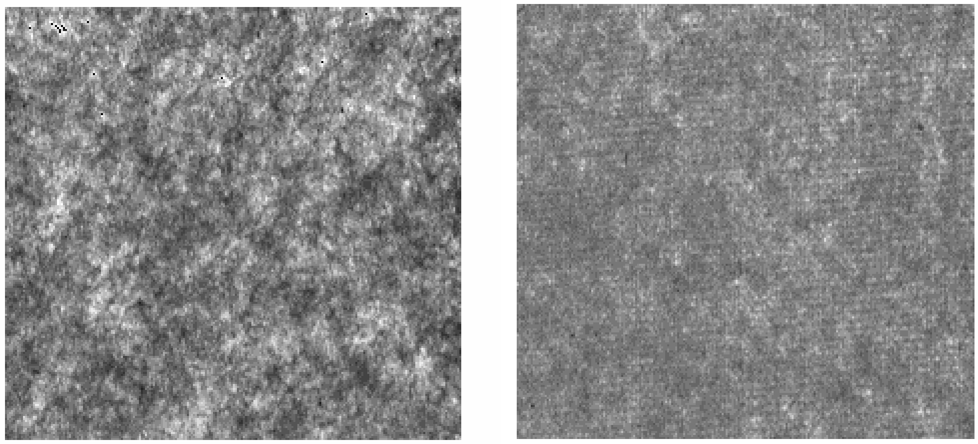


Figure. Two pictures of paper using transmitted light showing good formation (left) and bad formation (right).

The basis weight variation is due to the random nature of depsotiing a thin layer of fibres onto a surface and due to the incomplete disruption of ‘flocs’ that form in the fibre suspension. It can be said that they are due to the:

1. randomness of single fibre distribution
2. fibre interactions
3. flocculation
4. hydrodynamics forces both turbulent and ‘self healing effect’.

Turbulence is used to create a more random sheet. However, even a perfectly random sheet will have basis weight variations.

The ‘self-healing effect’ or ‘hydrodynamic smoothing’ is where more fluid flows through the low basis weight regions in the sheet bringing more fibres to that low basis weight region and creating a more uniform sheet that is better than random.

Formation effect many paper properties. Some of the most important are:

1. Print unevenness
2. tensile strength
3. cockling (waviness of paper surface)

Formation is measured using beta radiation absorption or light absorption. The advantage of beta-radiation is that it can be relatively independent on fibre type where as optical measurement rely strongly on fibre type and the treatment of the fibres (for example by refining). This means that the formation measurements must be often calibrated.

The most common measurement is the specific formation, which is the standard deviation of baiss weight, σ_b, divided by the square root of the basis weight.

$$f_N = \frac{\sigma_b}{\sqrt{b}}$$

Note that the units of specific formation are in units of square root of basis weight.

Coefficient of variation is also used which is dimensionless

$$COV(b) = \frac{\sigma_b}{b}$$

Purely random networks

The theory starts with Corte and Kallmes (1960). IF every fibre randomly and independently is laid down on top of each other then you get a Poisson process.

The number of fibres in an area, A, is then given by

$$N = bA / l_f \omega_f$$

Or wif we know the mass of a fibre is

$$m_f = l_f \omega_f$$

Then

$$N = bA / m_f$$

For a poisson distribution, the variance is N (note the variance equals the mean) and the standard deviation of basis weight is then

$$\sigma_b = \sqrt{N} m_f / A$$

Therefore the specific formation of a purely random sheet of paper is:

$$f_N = \sqrt{m_f / A}$$

Where A is interpreted as the square of the resolution in the measurement (size of inspection window).

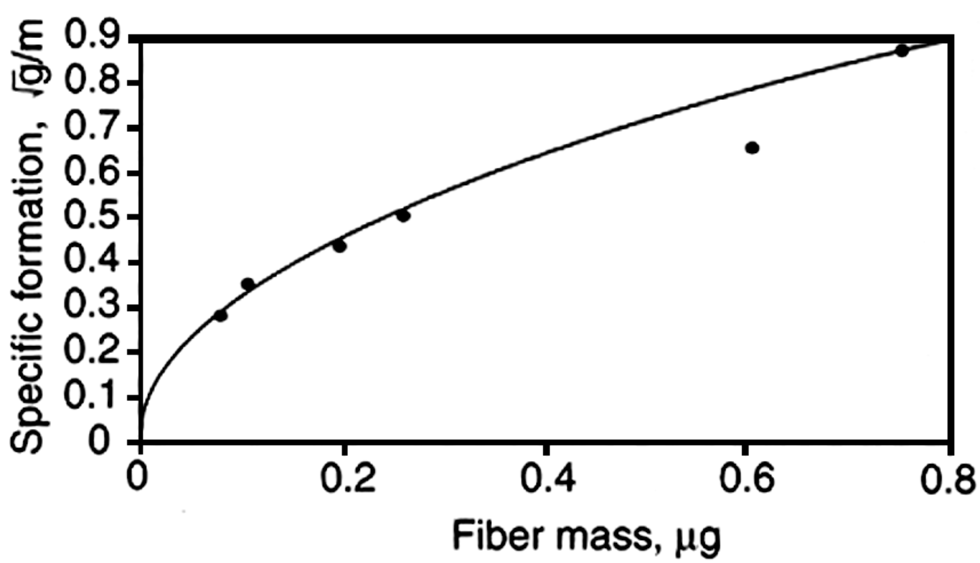


Figure 19. Specific formation, f_N, against the average fiber mass, m_f, in handsheets formed at low consistency[29]. The solid line shows a square-root behavior.

For paper sheets formed in a handsheet former (nearly pure random sheets) we see that the only variable affecting formation is fibre mass. Note that this analysis assumes that the fibres are all the same length and have the same mass and the sheet is isotropic (no orientation).

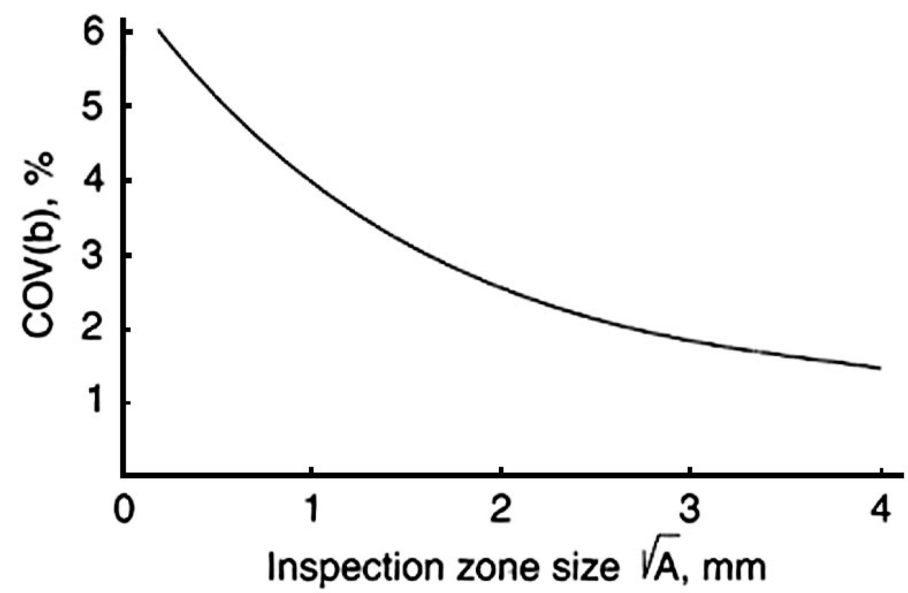


Figure 20. Coefficient of variation of basis weight, *COV(b)*, in a random fiber network of basis weight 100 g/m^2 against the size $\sqrt{A}$ of square measurement window for fibers of length 2 mm, width 20 µm, and coarseness 0.2 mg/m[31].

This analysis also shows the importance of inspection window size (spatial resolution). The figure above shows how the formation will appear to improve if you use a large inspection zone. This is important to realize when comparing 2 different measurements of formation that use different techniques.

Formation has been shown to be increase exponentially with crowding number, defined as,

$$n_{crowd} = \pi C l_f^2 / 6\omega_f$$

High values of N give ppor formation. Kerekes and Schell showed that a possible threshold number is approximately N_{crowd} =60 for the start of flocculation that leads to formation problems.

Formation on the papermachine

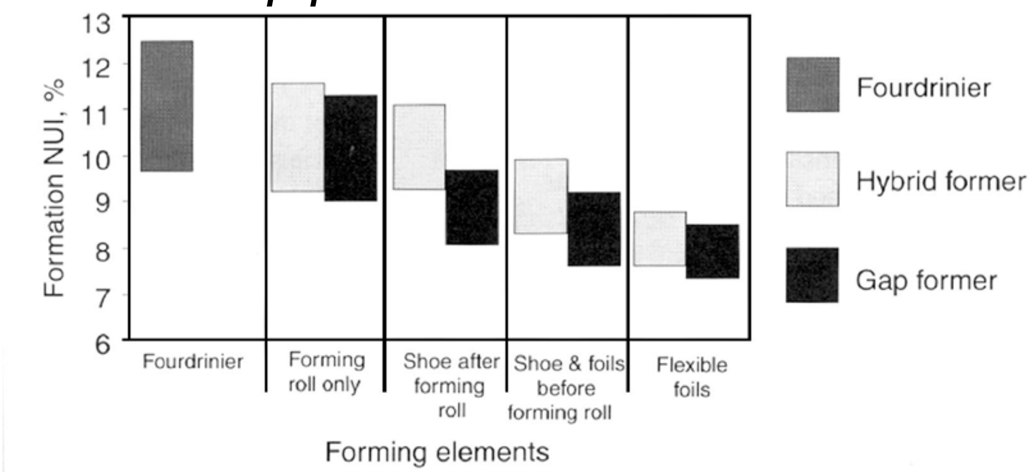


Figure 21. Typical formation levels of woodfree printing paper grades on different formers. Formation is measured with an optical instrument where high readings indicate poor formation[35].

The above figure shows approximate values of formation through the forming profcess for three different types of papermachines.

One of the main papermachines variable that can affect formation is the jet to wire speed ratio. If the ratio is 1 the fluid matches the speed of the wire and there is relatively little shear imposed on the suspension and the fibres are able to flocculate and create poor formation.

If the jet to wire speed is not 1 then shear induces turbulence that breaks up flocs and the formation can improve. (See figure below).

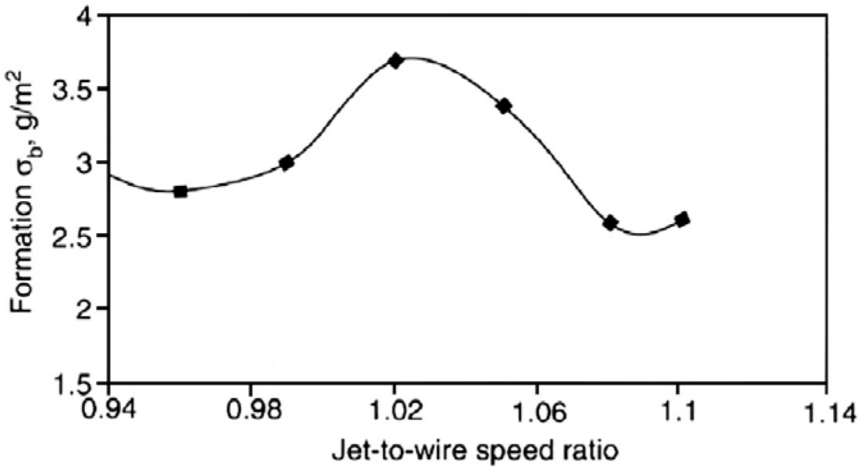


Figure 23. The effect of jet-to-wire speed ratio on formation (σ_b) on a gap former.

Effect on properties

The variation of basis weight impacts many of the important paper properties as we said in the introduction.

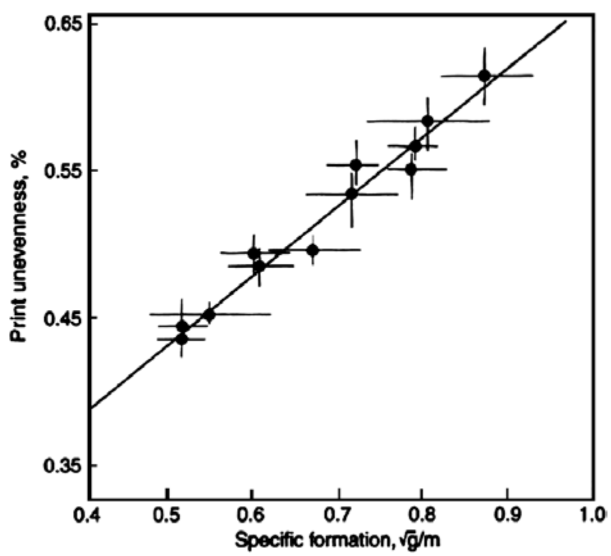


Figure 26. Correlation between specific formation, f_N, and print unevenness (standard deviation of print density relative to paper brightness) when formation varies on one machine with constant stock composition[39].

The figure above shows how print unevenness is a clear function of specific formation. The variation of basis weight means that the force imposed on the paper by the printing plate is non uniform. The high basis weight areas carry more of the load then the low basis weight areas of the paper.

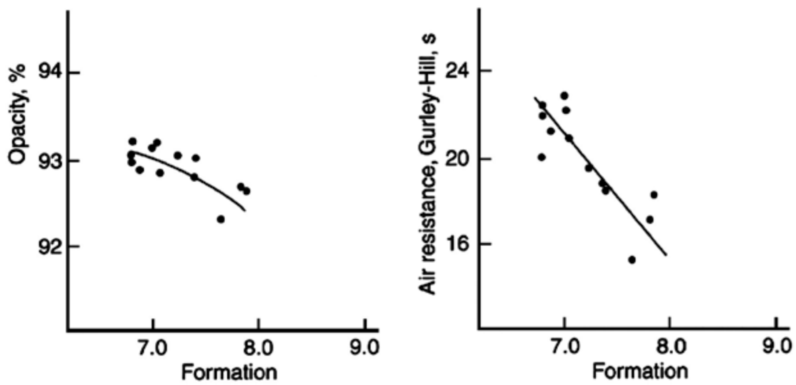


Figure 27. Apparent effect of formation (measured with an optical tester) on opacity and Gurley air permeability. Altering stock consistency produced the changes in formation[40].

Any property that is non-linearly related to basis weight will be affected by formation. For example, fluid permeability and opacity. Both are very large at low basis weight. Figure 27 (above) shows how air resistance and opacity are adversely affected by poor formation.

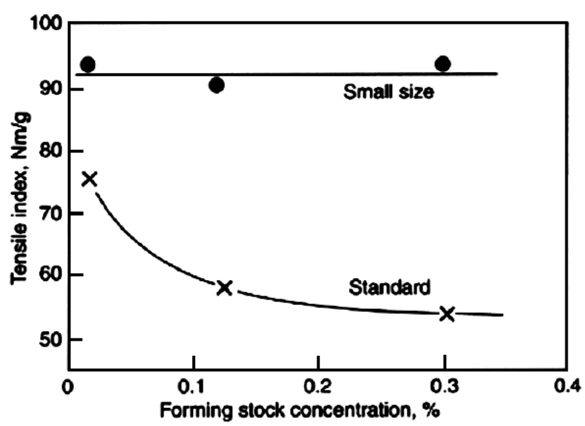


Figure 40. Tensile index vs. forming stock concentration for standard specimens using strip width 15 mm and small specimens with a narrow 3-mm waist[56].

Tensile strength also decreases with poor formation. Figure 40 shows that as the consistency of forming increases, which decreases formation, the tensile strength decreases.