Evolution and development of headbox systems for specialty nonwoven formers

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The design of headbox systems has changed over time to make the process more controllable and to improve product properties.

The ultimate goal in the evolution and development of headbox systems has been the improvement of the physical properties of the products produced on these specialty nonwovens formers. To understand the interactions of the design of the headbox system and the resulting control of physical properties, we should first establish the intermediate link—the process functions of the headbox system. The effect on the process and ultimately on the product properties of the design of the headbox system can then be seen.

To illustrate the applications of these principles, this article examines the history and some steps in the development of these headbox systems. The last topic discussed is the current headbox system design recommended for today's specialty nonwovens formers and the fundamental principles of this design.

Functions of headbox systems and process physical properties

The five primary process functions of headbox systems are listed below with the product properties affected by these functions.

Distribute stock uniformly across machine width

Normally, the first process function in the headbox system is to spread the stock flow from the fan pump across the width of the headbox. Various systems have been used, based on different principles of operation. These systems will be discussed as a part of the historical review.

The product property directly affected by this stock spreading function is cross-machine direction basis weight uniformity. Maintaining uniformity becomes more difficult as the width of the machine increases and as the basis weight of the sheet is reduced.

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Provide uniform flow of stock into forming zone

The second function is the constant and regulated metering of stock flow into the forming zone. The product property affected by this function is the machine direction basis weight uniformity.

Provide microturbulence of stock into forming area

This is a primary continuing process concern of the stock system and the headbox system. In order to form a uniform sheet, the fibers must remain separated and in uniform suspension in the stock slurry from the time of mixing through the fan pump and into the forming zone. The method used to accomplish this is to create microturbulence in the stock slurry and prevent the development of laminar flow and still ponds.

Many product properties are affected by the level of microturbulence and the resulting dispersion. Some of these are small area weight uniformity, formation, directionality, density, and filtration properties.

Control stock velocity entering and through forming zone

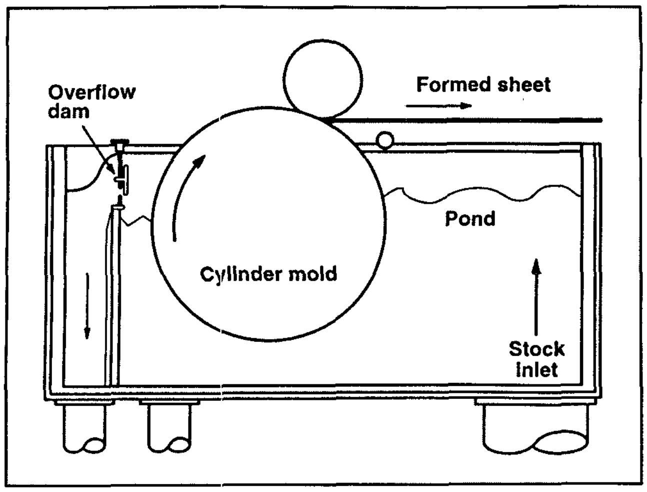
An important process function of all wet-lay forming process headboxes is the control of the stock slurry velocity into the forming zone, both for standard papermaking and high-dilution nonwovens processes. The control of the stock velocity *through* the forming zone is a major difference between the papermaking process and the nonwovens wet-lay process. The control of this area, with the control of the drainage through the forming fabric, is the focus of much process development work on specialty nonwovens/high-dilution forming equipment.

Product properties which are affected by control of the stock velocity are directionality of physical properties and other formation criteria.

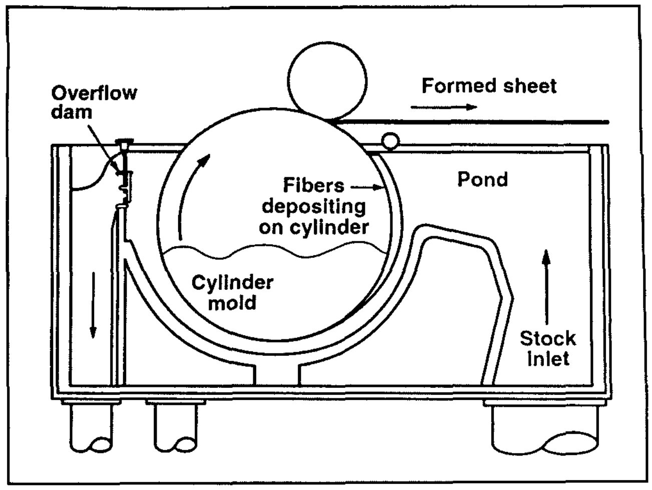
Reduction and control of macroturbulence

In the generation of turbulence for dispersion and formation purposes, we want to generate microturbulence (small area turbulence). In doing this, we often create macroturbulence (large area turbulence). The macroturbulence or large area turbulence may cause shifting streams and currents in the stock flow to the forming zone, which results in nonuniform formation. The reduction and control of stock flow macroturbulence while maintaining

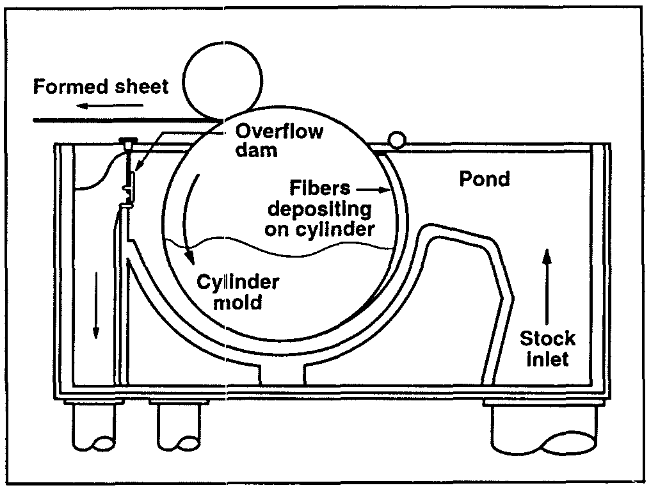
1. Basic cylinder vat former



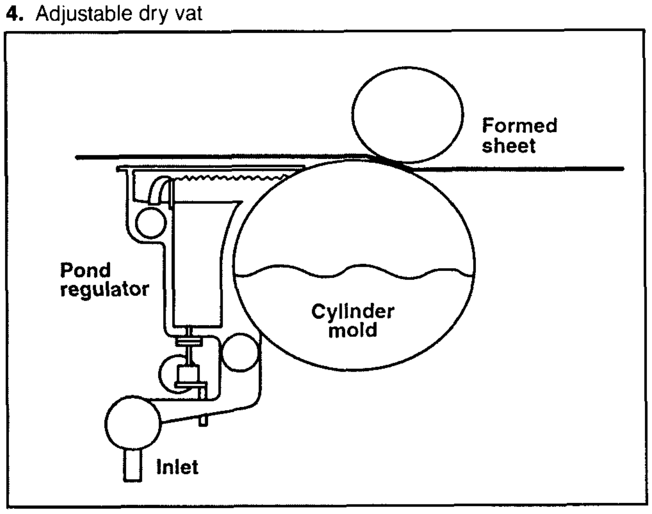
2. Uniflow vat



3. Counter flow vat



4. Adjustable dry vat



microturbulence is a major process concern in recent developments of high-dilution forming elements.

The product properties affected by macroturbulence are uniformity of cross-machine direction and machine direction sheet properties.

Evolution and history of Sandy Hill nonwovens headboxes

The specialty nonwovens forming elements developed by Sandy Hill come from two separate directions. The first, and more evolutionary, started with the original cylinder or vat formers and led to the Rotoformer and the Sigmaformer. The second development, the inclined wire Deltaformer, comes from the fourdrinier. The principles of pond formation from the cylinder former headbox developments are shared with the inclined wire Deltaformer.

Cylinder formers

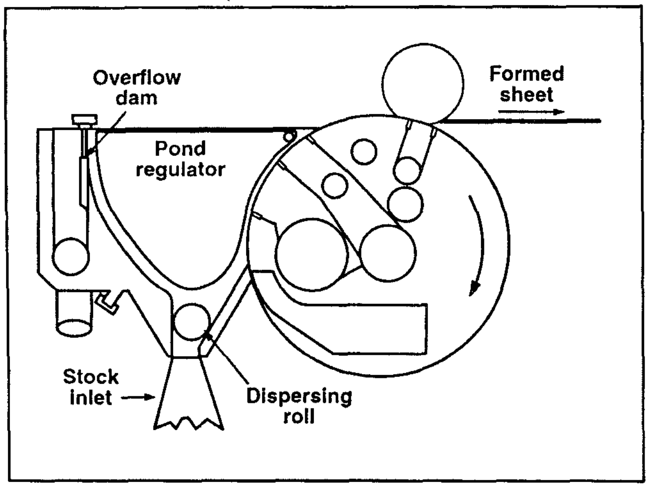
Improved formation was obtained over the basic vat former with the "uniflow" vats and "counter flow" vats. The progression of cylinder formers is illustrated by comparing the basic cylinder vat shown in **Fig. 1** to the uniflow vat of **Fig. 2**, which greatly reduces the volume of the static pond for improved dispersion and formation.

The counter flow vat shown in **Fig. 3** increases stock turbulence by rotating opposite to the direction of flow. The major problem with this design is the highly directional orientation of the fibers in the sheet.

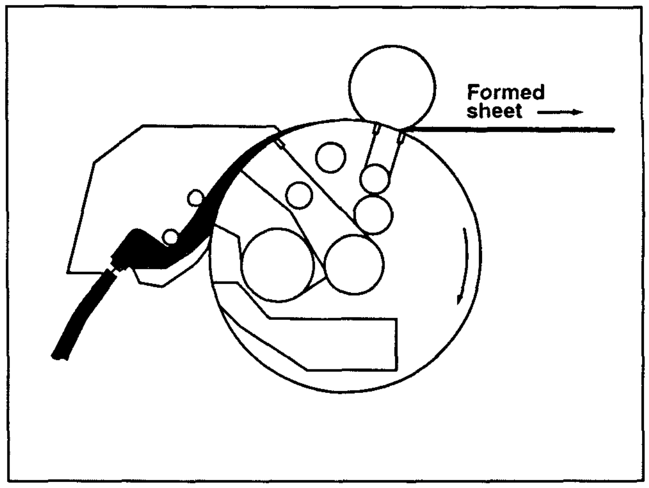
The adjustable dry vat in **Fig. 4** illustrates a further reduction of pond volume and the addition of control of stock velocity. The adjustable dry vat improved sheet formation control and uniformity by accurately controlling the stock velocity through the forming zone. This was one of the first true applications of the theory of stock velocity control in the forming zone.

The "Adaptaslice" headbox illustrated in **Fig. 5** was developed as a pressure forming headbox for cylinder vat machines. The production rates of the pressure formers were limited by the headbox pressure that could be developed in the headbox without problems of "spouting" or spurting at the exit slice, which disrupted the formed sheet with the resulting turbulent flows. Further increases in capacity were obtained by adding suction to the forming cylinder to increase the drainage rates of the dry-vat and Adaptaslice machines.

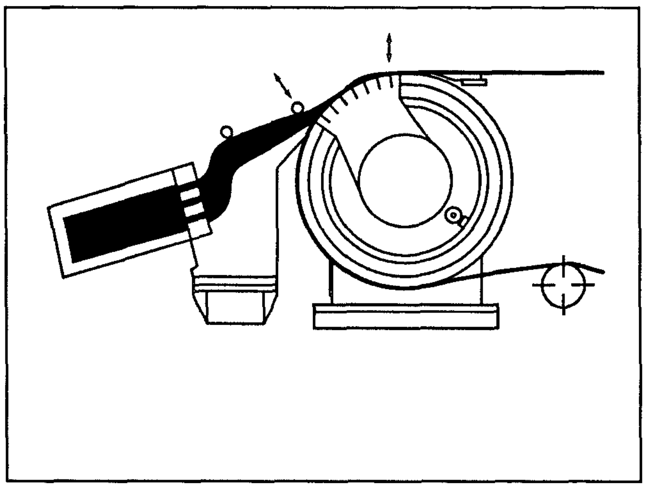
5. Rotoformer with Adaptaslice headbox



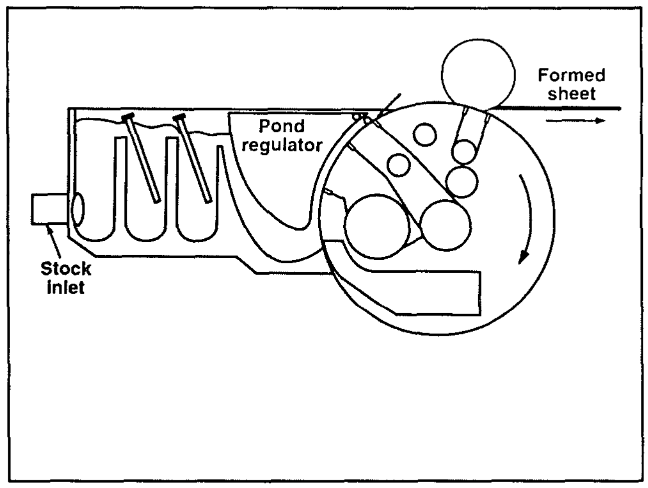
6. Basic Rotoformer



7. Sigmaformer



8. Overflow dams in early Rotoformer headbox



The Sandy Hill "Rotoformer," shown in **Fig. 6**, is an example of a further development of a suction forming machine. The Rotoformer featured a headbox with dispersing roll for added turbulence, two overflows to increase flow velocities, and a pond regulator for control of the stock velocity in the forming zone. A rear overflow was normally provided, as on paper headboxes of the era, to allow for recirculation of the unused stock. A second overflow (the lip overflow) was provided on the Rotoformer pond regulator to permit higher stock flow rates in the forming zone for better formation, as previously discussed for the counter flow vat. The pressurizing device on the Rotoformer headbox permitted adjustment of the pressure inside the forming zone to ensure that the desired stock velocity was achieved, similar to the Adaptaslice. Rotoformers have been supplied with an Adaptaslice headbox, as illustrated in Fig. 6.

The most recent cylinder based former, designed to accommodate increased stock flow volumes, is the Sigmaformer, shown in **Fig. 7**. Here the suction former is augmented by a fourdrinier table for additional drainage.

Cross-machine distribution systems

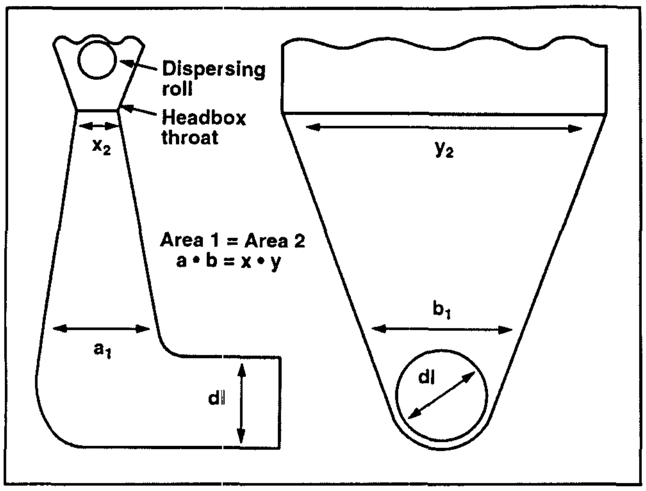
Cross-machine flow distribution in these early machines was often accomplished by one or more overflow dams from a pond fed by a single stock pipe which distributed the stock flow across the width of the machine. This is illustrated in **Fig. 8** by an early Rotoformer design. The drawback to this design was the long dwell times and slow stock velocities in the various ponds of the headbox.

Headboxes of these machines were characterized by provisions for stock recirculation. The purpose of this was to maintain high stock velocities in the piping system and headbox system to prevent flocking while providing for varying production rates and different products. The cost, maintenance, and control accuracy of the variable speed drives available at the time encouraged the use of constant speed motors and flow control valves to control the stock flow. This was detrimental to some synthetics and long fiber nonwovens.

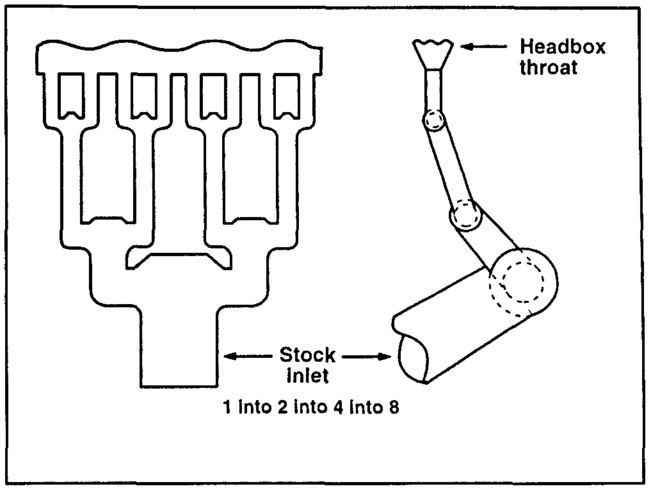
In order to reduce the stock volume in these ponds, cross-machine flow distribution systems were fitted and the ponds and dams eliminated. Some of the early systems used were the "fishtail," "Bertrums" header (or 1-into-2-into-4, etc.), and various manifold systems.

The basic fishtail design illustrated in **Fig. 9** is based

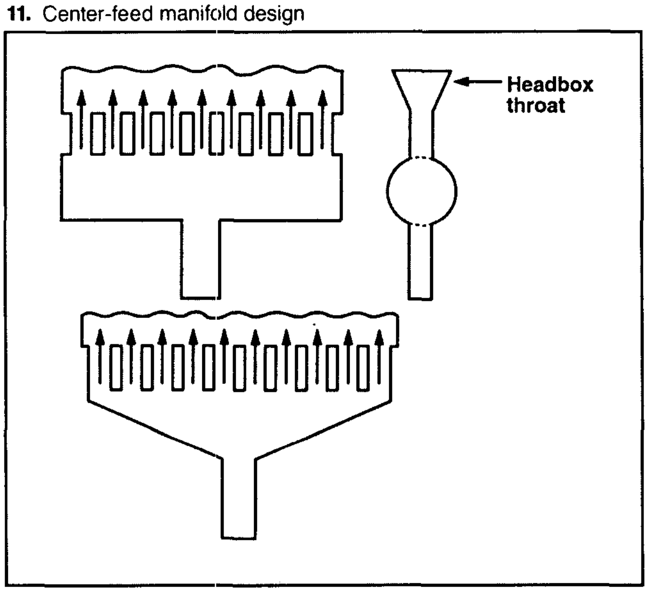
9. Fishtail or beaver tail inlet header



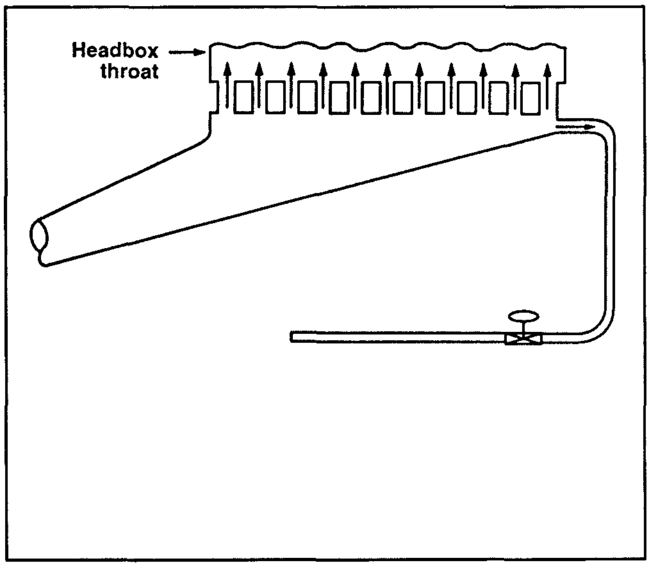
10. Bertrums header



11. Center-feed manifold design



12. Tapered flow distribution header or manifold



on the principle of stock flow entering the bottom of the header, well below the headbox level, from a round pipe. The design principle is for the area of the rectangular cross-section to remain constant while changing from the width of the pipe diameter to the width of the headbox. Two physical design principles helped improve the uniformity of the flow spreading. First, a small angle of divergence is utilized to prevent high flow in the center. Second, the force of gravity as the flow is pushing upward, pushing against the head of stock above, spreads the flow outward.

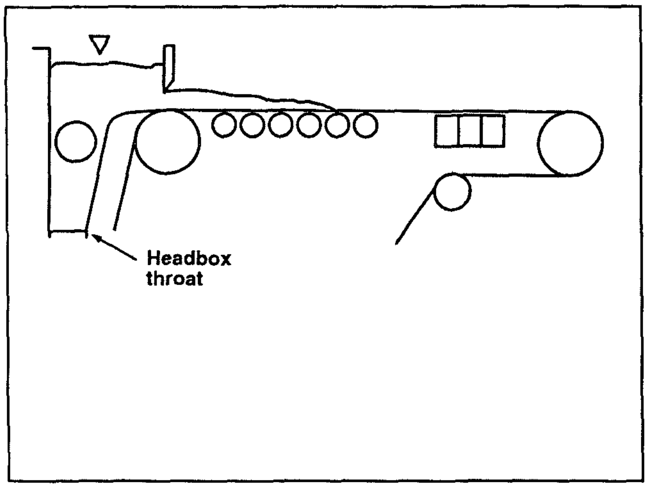
For wide machines, the depth of the header and the required vertical or horizontal space below and behind the headbox could become excessive. At times, two or more of these have been used side by side to reduce the depth (length) of each fishtail. This required an additional splitting of the stock flow prior to entering the fishtail. A disadvantage of this design is the large volume and relatively low stock velocities, leading to flocculation.

The Bertrums header, shown in **Fig. 10**, split the main stock flow from one pipe into two. The resulting pressure drop from diverting the flows helped to divide the flow equally into two pipes. Each of these was then in turn split into two equal flows, until the desired number of pipes and width was reached. Major disadvantages of this design were a limited effective range of stock flow volumes and the excessive space requirement, resulting in large stock volumes. Some nonwovens machines used a Bertrums header to feed four fishtails for a wide machine. This also resulted in large stock volumes and extended stock dwell times.

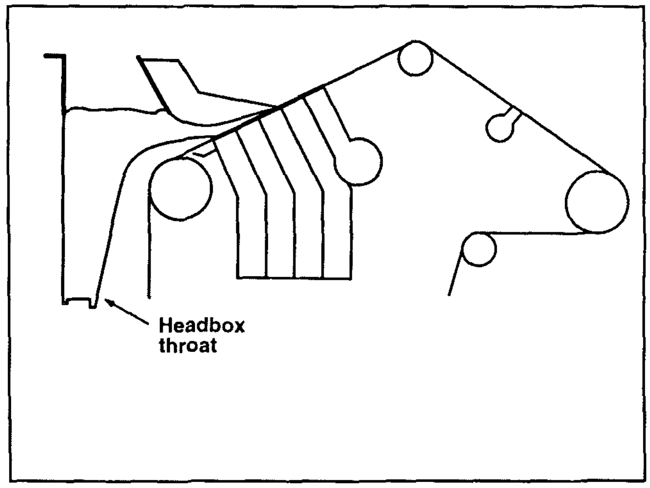
As variable speed drives for pumps became more economical and available, the need for headbox systems to operate over a wide range of stock flow rates intensified. Various header designs were developed, including center-feed manifolds, as shown in **Fig. 11.**

The tapered flow distribution manifold, shown in **Fig. 12**, was developed for wide paper machines and adapted to the nonwovens/high-dilution former headbox. The design principle is to maintain the velocity of the stock as the section reduces, balanced against the water volume leaving through the tubes or holes in the perforated plate.

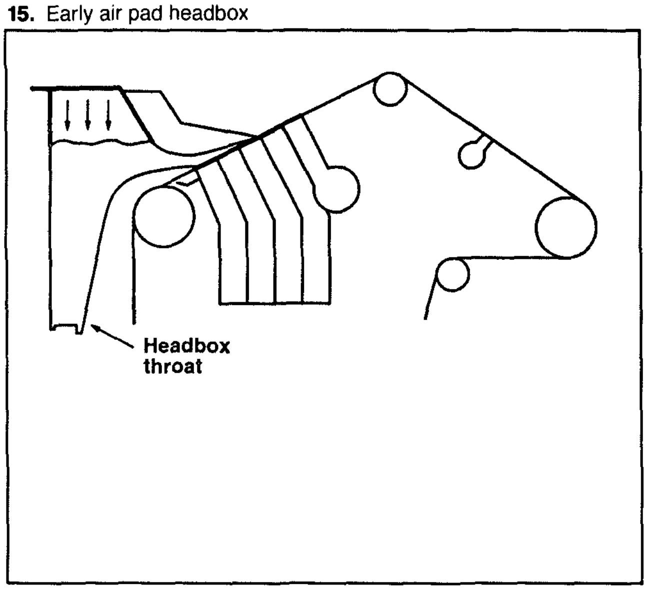
13. Open headbox fourdrinier with dispersing roll



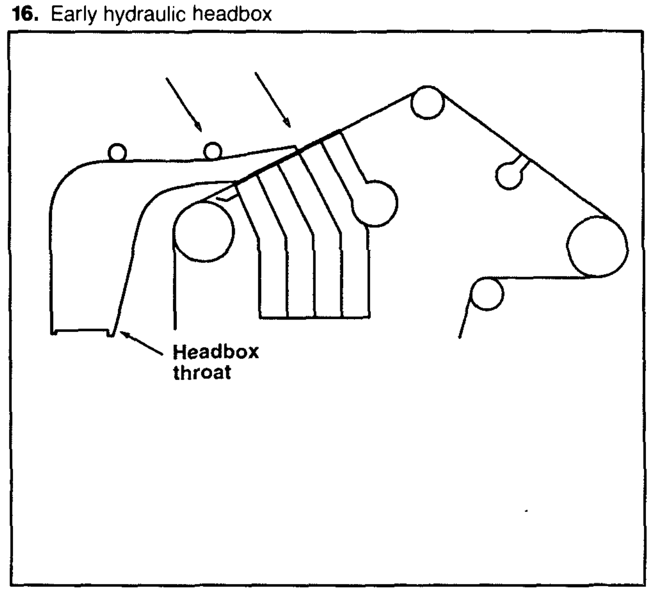
14. Deltaformer open headbox for inclined wire formers



15. Early air pad headbox



16. Early hydraulic headbox



This facilitates the energy (calculated using Bernoulli's Equation) to remain constant across the width of the header or machine width. This design allows operation over a wide range of flow volumes and is virtually unlimited in machine width.

The compact design, combined with tube banks (organ pipes), allows flexible mountings in various locations relative to the headbox proper. The high stock flows of nonwovens/high-dilution formers result in large pipe sizes and large size and weight of the header. This makes the flexible location feature of this design very desirable.

An additional feature of the design is the bypass flow that is regulated to balance the flow velocity pressure for varying conditions. This design is used today on most paper machines and all new nonwovens forming elements.

Other headbox design considerations

An important part of the tapered flow distribution manifold system is the flow restriction provided by the perforated plate or tube bank (organ pipes). These restricted passages produce the pressure drop which forces the flow to be spread uniformly to each passage, across the width of the throat of the headbox. This higher stock velocity projects into slower moving stock in the explosion chamber, creating microturbulence and macroturbulence.

The explosion chamber design and other considerations then combine to reduce and control the macroturbulence in the headbox flow passage. Provision is made for proper decay of the high velocity jets from the tubes or passages of the perforated plate.

One major development and feature of the headbox systems of the Rotoformer, Deltaformer, Adaptaslice, and adjustable dry vat was the pond regulator or flow synchronizer. This concept, originally patented by Sandy Hill, provides a means of controlling the stock velocity not only into the forming zone but all the way through the sheet formation process. This feature and function of controlling the stock velocity is important in sheet formation as well as control of directionality of the sheet properties.

Inclined wire formers

Figure 13 shows an open headbox fourdrinier with a dispersing roll. The large slice opening required by large water volumes results in an uncontrollable formation. In order to accommodate higher volumes of water to the flat wire fourdrinier, the inclined wire former was developed.

Figure 14 illustrates the basic Deltaformer open headbox for inclined wire formers, which adapted the pond regulator's control of stock velocities in the forming zone. The open headbox has been used for most nonwovens formers until recently and will continue to be used for many lower speed machines where flexibility is required. The pond height of these was sufficient to accelerate the stock into the forming zone for most applications. With the demand for increased production rates and increased line speeds, control of directionality of the sheet deteriorated.

The use of an extended pond height to develop the desired velocity pressure or head creates a large "dead pond" area. This results in flocculation or forming of cakes in the pond area. Creation of an artificial (effective) pond height by increasing the suction under the forming zone usually results in excessive macroturbulence in the pond area. This is caused by excessive throat velocities and lack of adequate explosion chamber dampening. These often are the result of running higher stock flows than the headbox system was designed to handle.

The "air-pad" headbox, illustrated in **Fig. 15** and used in the paper industry for many years, was adapted to provide the "head" required for higher speeds on the inclined wire machines without the excessively high pond of the "open" style headbox. The volume of stock and resulting dwell time required to reduce macroturbulence to an acceptable level is often excessive.

The early hydraulic headbox design shown in **Fig. 16** used a standard open headbox configuration capped with a hydraulic elbow. This design considers two of the deficiencies of the open headbox: the pressure "head" for higher speeds and reduction of macroturbulence. The confined chamber and tapered approach passage combine to control the macroturbulence. However, the large volume of stock and resulting dwell time between the tube bank and the forming zone remained a problem.

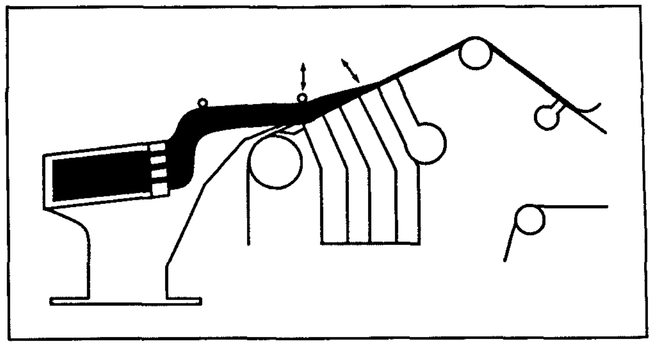
A second generation hydraulic pressurized headbox was developed to reduce the dwell time of the stock from the exit of the tube bank to the forming zone. The design shown in **Fig. 17** is the current hydraulic headbox, based on many of the principles of paper machine hydraulic headboxes.

If the current hydraulic headbox on the Deltaformer, Fig. 17, and the Sigmaformer, Fig. 7, are closely examined, it can be seen that they are virtually identical. The only difference is that the tapered forming zone of the Sigmaformer is curved, whereas the forming zone of the Deltaformer is straight.

Hydraulic pressurized headbox

The current hydraulic pressurized headbox designs of these specialty high-dilution wet-lay formers, the Deltaformer and Sigmaformer, incorporate several design principles and concepts. Each is integrated into the overall design of the former for a specific application to meet the process requirements. These principles include:

17. Second generation hydraulic headbox



1. A tapered flow distribution manifold or header with by-pass recirculation flow control to balance the header for excellent cross-machine direction basis weight uniformity.
2. A perforated plate or tube bank (organ pipes) to aid cross-machine uniformity and create microturbulence for improved dispersion and small area uniformity.
3. Stock flow passage and explosion chamber designed to preserve microturbulence by reducing dwell time between perforated plate and the forming zone; contain and reduce macroturbulence by allowing adequate decay length; control acceleration of the stock into the forming zone; and maintain random orientation of fibers in stock flow entering the forming zone.
4. Control of stock velocities into and through the forming zone by adjustable flow passages and articulated forming roof or flow synchronizer.

Summary

This article has traced the development of headbox systems from the direct-flow vat "cylinder" machine through the current hydraulic pressurized headbox systems of the Sandy Hill Deltaformer and Sigmaformer. Each of these design changes addressed new process demands and the resulting improvements in product properties. This was truly an evolutionary process, with developments structured to meet the specific demands of the processes and products. This current design, the second generation hydraulic headbox, will undoubtedly be replaced by an improved version developed to meet the future demand for improved product properties.□

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