Trends and developments in size press technology

Charles P. Klass

New modifications in size press design can reduce operational problems and improve sheet quality.

Traditionally, the purposes of surface sizing have been to provide resistance to penetration of liquids, to give better surface properties, and to improve certain physical properties of the paper sheet, such as surface strength and internal bond. Surface sizing operations have typically utilized starch films to fill in the surface voids in the sheet, reducing the pore radius and therefore the rate of penetration of fluids, including printing inks (*1*). Over the past decade, however, the varieties and complexity of surface sizing operations have grown. This growth has been brought about by several factors:

1. Coated papers have become more important. Surface sizing is a key element in making an improved basestock.
2. Specialty papers demand new and unusual sheet properties. For years, if a property was needed, furnish changes and wet-end additives were employed. Now, the papermaker routinely considers surface treatments when he is considering performance requirements and grade development. Many new surface sizing additives and much data have been presented to the industry by suppliers.
3. Everyone has become aware of the need for a more efficient operation, both in cost and in the conservation of raw materials. Surface sizing provides close to 100% retention of added chemicals. This improved retention also reduces the problems of wet-end deposits and increases the life of machine clothing.
4. Environmental laws have placed new restraints on paper mills. Compared to wet-end addition, surface sizing allows reduction or removal of chemicals from the white water to assist in environmental improvement.

These are only a few of the varied reasons for surface sizing application growth (*2*).

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Conventional size press configurations

In a conventional size press, the objective is to flood the entering nip with sizing solution. The paper absorbs some of the solution, and the balance is removed in the nip. The overflow solution is collected in end funnels or a pan below the press and is recirculated back to the nip.

Conventional size press configurations are generally categorized as vertical, horizontal, or inclined, as shown in **Fig. 1**. The vertical configuration provides the easiest sheet run, but the pond depth of solution in each nip is unequal. The horizontal size press arrangement solves the problem of unequal absorption by providing identical pond forms on either side of the sheet. The inclined size press is a compromise, developed to avoid the awkward vertical sheet run of the horizontal size press.

Size press pickup

Size press operations must be carefully controlled to assure that the sheet absorbs the desired amount of chemical uniformly across the machine. At the same time, the amount of water absorption should be minimized to maintain after dryer requirement at the lowest practical level. The primary factors determining solids pickup at the size press are listed in **Table I.**

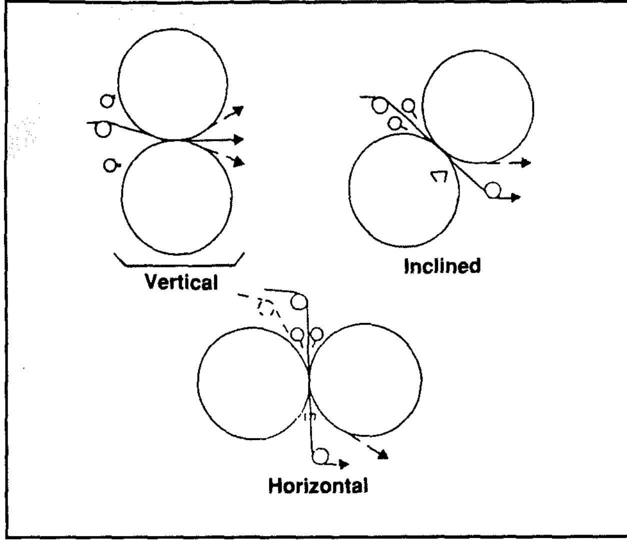
There are two basic mechanisms for incorporating starch solutions at the size press (*3*). The first is the ability of the sheet to absorb the size solution. The second is the amount of solution film passing through the nip and the manner in which the paper and the roll surfaces separate. Factors that favor greater absorption include low solution viscosity (higher solution temperature), low machine speed, and low level of internal sizing. The factors favoring greater film thickness include sheet roughness and low nip pressure.

Of the factors affecting pickup, solution viscosity and solids content are the easiest to manipulate. The solids concentration, however, is usually maintained at the highest manageable level consistent with the desired viscosity in order to minimize the amount of water that must be subsequently evaporated.

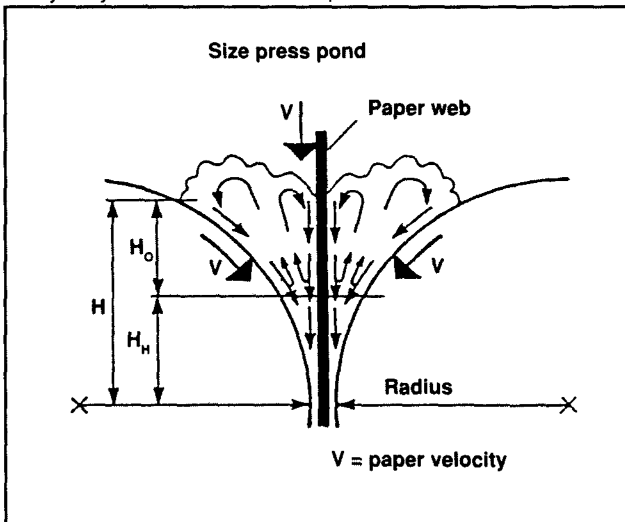
I. Factors influencing size press pickup

- I. Sheet characteristics
  - A. Paper substrate (basis weight, density, smoothness, capillary structure, void size, etc.)
  - B. Level of internal sizing
  - C. Moisture content
- II. Sizing solution
  - A. Solids content
  - B. Temperature
  - C. Viscosity (fluidity)
  - D. Composition (type of starch, use of additives)
- III. Design and operational
  - A. Machine speed
  - B. Pond depth
  - C. Nip pressure
  - D. Nip width (affected by roll hardness and diameter)

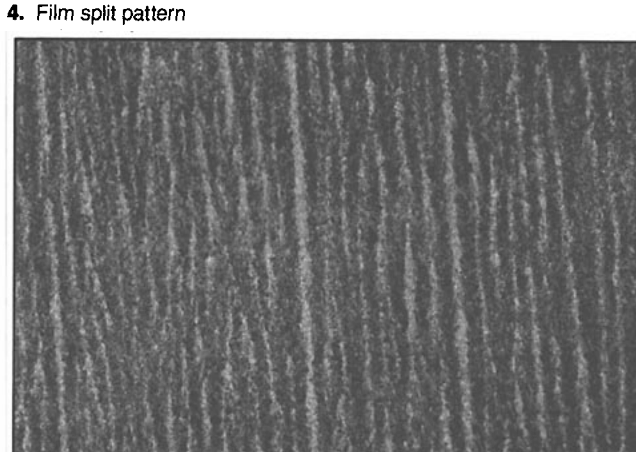
1. Conventional size press configurations



2. Hydrodynamic forces in the size press



4. Film split pattern



Starch properties

Starch is a carbohydrate synthesized in corn, tapioca, potato, and other plants by polymerization of dextrose units. The polymer exists in two forms: a linear structure of about 500 units and a branched structure of several thousand units. The linear chain polymer, called amylose, constitutes 27% of natural corn starch, while the branched polymer, called amylopectin, makes up the remaining 73%. Fractionated starches are available for special uses.

Starch is supplied as a white, granular powder which is insoluble in cold water because of the polymerized structure and hydrogen bonding between adjacent chains. However, when an aqueous suspension is heated, the water is able to penetrate the granules and cause them to swell, producing a gelatinized solution or paste, depending on concentration. Cooling this hot solution causes thickening, which is called setback. Starch for surface sizing application is cooked using either batch or continuous systems (*4*).

Unfractionated and unmodified starch, called pearl starch, is "thick boiling" (i.e., viscous) and has a tendency toward gelling or setback even without cooling. Setback is avoided by using 100% amylopectin, a waxy starch which forms a clearer paste and is nongelling. However, a loss of sizing efficiency results because the linear fraction contributes more toward film formation.

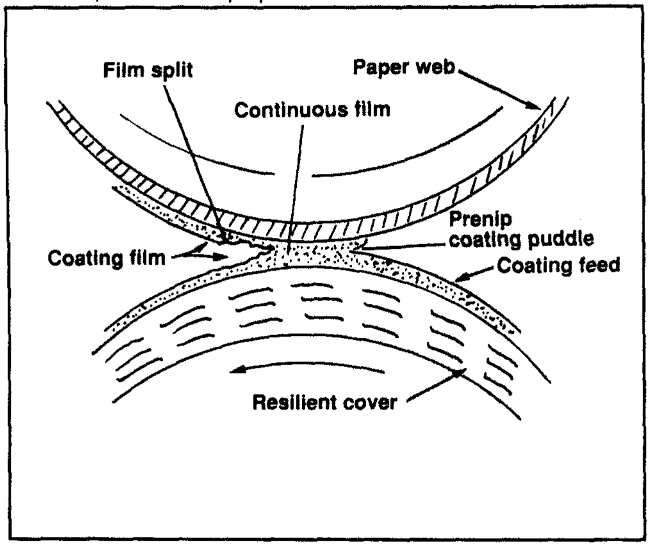
Lower viscosity and setback resistance are achieved by using chemically or thermally modified starch (e.g., oxidized starch). A "thin boiling," low viscosity starch can be produced by enzyme conversion, with film formation properties and setback resistance unaffected.

In common paper mill practice, a relatively low viscosity, concentrated starch solution of 3-9% solids is used at the size press to achieve pickup in the range of 60-100 lb of dry starch per ton of paper produced.

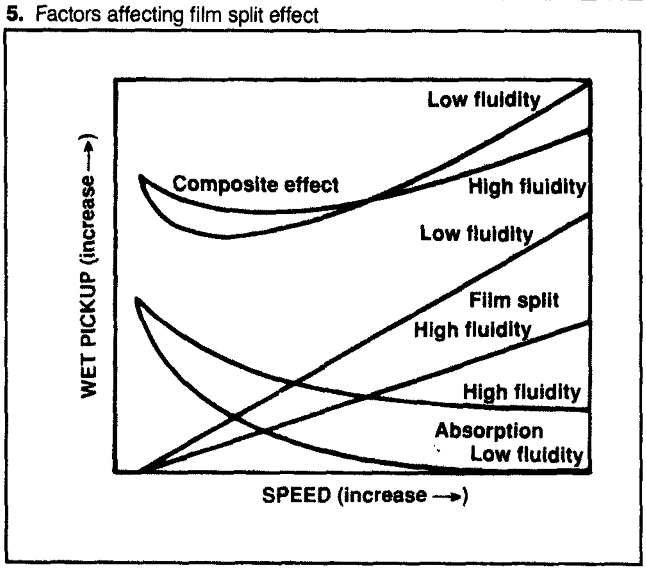
Conventional size press limitations

In the conventional size press, the size solution is delivered to the nip between a pair of oppositely rotating rolls to form a pond of material above the nip. With high speed roll rotation and high speed movement of the web, the pond

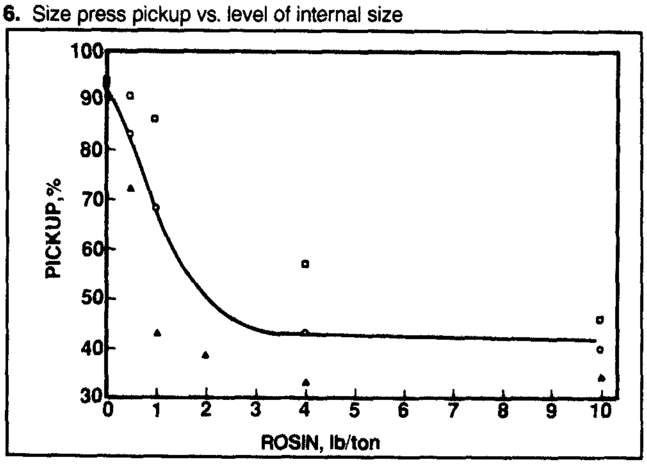
3. Development of film split pattern



5. Factors affecting film split effect



6. Size press pickup vs. level of internal size



tends to absorb kinetic energy from the moving web and rolls (*5*). As shown in **Fig. 2**, an excess of liquid is flowing toward the nip, but the nip pressure of the rolls limits the amount of sizing solution passing through the nip, causing the remaining solution to flow back upwards. If hydrodynamic forces are too great, this upward velocity becomes high enough to cause the solution to break the surface of the pond and splash out of the nip. This pond turbulence and "nip rejection" results in uneven pickup of solids across the machine.

Size solution viscosity contributes to the hydrodynamic force in the roll nip. This may make it impractical to use the size press to apply dilatant materials. As machine speeds increase, it may be necessary to dilute the starch solution or go to a more degraded starch to avoid nip rejection. These approaches, in turn, may increase after dryer requirements and also affect sheet properties adversely.

Another problem associated with the size press is film splitting. Although most of the size solution is absorbed into the sheet at the nip, excess solution remains on the surface of the sheet between the paper and the roll. At the exit of the nip, this film is split into two layers with one part following the web of the paper and the rest remaining on the roll surface, as shown in **Fig. 3** (*6*).

This pattern will appear as heavy rings of fluid across the roll face, as shown in **Fig. 4** (*7*). The severity of the pattern depends on the rheology of the size, absorption properties of the sheet, speed of the rolls, and volume of material being split. As shown in **Fig. 5**, the problem becomes worse with higher speeds, higher viscosity, and higher film thickness (*3*).

Moisture content of the sheet entering the size press has a significant effect on pickup. Higher moisture content promotes absorption; thus a variable moisture content across the machine causes variations in pickup and sheet properties affected by surface sizing. Thus the ingoing sheet is usually dried down to 1-2% or less to ensure an even moisture profile and to keep the sizing agent nearer to the surface. This "overdrying" of the sheet is inefficient from an energy standpoint and may place a limit on machine speed.

As illustrated in **Fig. 6**, studies have shown that the level of internal sizing is the greatest factor in size press pickup control (*8*). In fact, it is essential to have at least a minimal level of internal sizing even to run the sheet through a size press and into the after dryer section without breaking.

The level of internal sizing required to provide runnability is inversely related to basis weight and wet tensile strength. Thus it may be necessary to use high internal sizing levels and expensive wet strength agents in order to get lightweight papers to run through the size press. Even with these additives, the size press is usually a major source of lost time on machines making lightweight or weak papers.

Since the commonly used reactive neutral/alkaline internal sizes are slow curing, problems are often encountered with size press breaks in alkaline papermaking (*9*).

Another difficulty with the conventional size press is matching the speeds of the two rolls. If the roll speeds are not matched precisely, "sheet scuffing" or "scrubbing" can lead to paper surface marking and increased web breaks. The difficulty of precision roll speed matching increases as machine speed goes up.

Size press design improvements

As machine speeds have increased, paper machine designers have increased size press roll diameters to help compensate for greater hydrodynamic forces. As shown in **Fig.** 7, increased roll diameters reduce the proportionate accelerative forces on the sizing solution. Some of the newer uncoated free sheet machines, equipped with 60-in. diameter size press rolls, operate successfully at speeds approaching 3000 ft/min; however, it has been found necessary to use short chain length (degraded) starch and solution concentrations in the 2–3% solids range to keep pond turbulence manageable.

Figure 8 shows the apron size press, patented as the "high speed size press" (*10*). It is designed to prevent pond splashing by isolating the sizing pond from the high speed surfaces of the rolls and paper. Since less kinetic energy is absorbed by the size solution, circulation velocities are reduced, and the size solution does not have a tendency to jump out of the pond. The baffles are usually made of sheet plastic material. This size press modification is effective in reducing pond turbulence, but users have reported problems in keeping the baffles clean as well as excessive wear on the dry sides of the baffles. "Icicles" building up on the baffles can create not only streaks but also scratches severe enough to break the sheet. Very few mills have been able to use the apron size press in day-to-day operations.

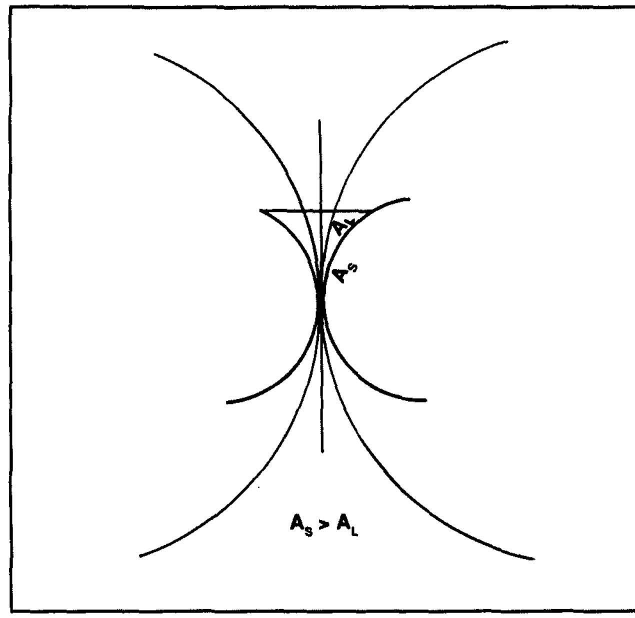
An improvement on the apron size press concept is to combine its use with restricted flow of sizing solution to the pond. The simplest and most reliable device for this use is a weir and spreader pan. Restricting the flow over the baffle aprons decreases the loads on them and minimizes the dry side wear problem. It also aids in reducing the amount of splashing in the size press nip. Several fine paper mills are reporting good results in routine application of the weir/apron size press modification; nevertheless, these users have emphasized the need for good housekeeping and preventive maintenance to make this application successful.

Modified size press designs

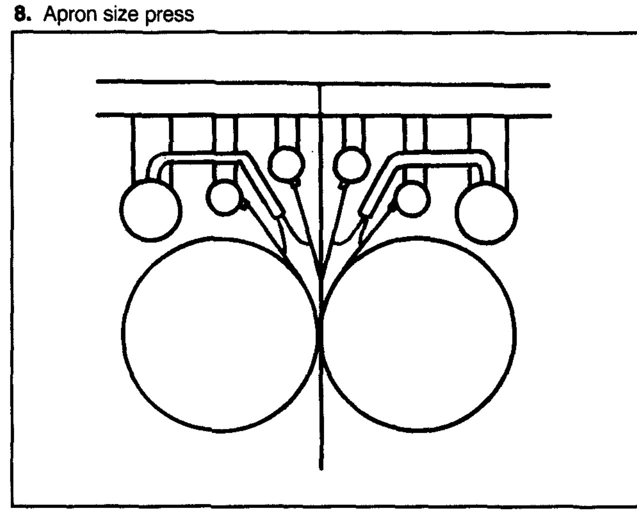
The problems with pond turbulence motivated development of modified size press designs which eliminated the pond. The gate roll size press, illustrated in **Fig. 9**, has an offset pond which is not in contact with the sheet. This offset pond feeds a metering nip which controls the amount of size going to a second nip. The second nip controls the film uniformity. It is essential that the rolls in the gate roll train be run at different speeds to minimize film split patterning (*11*).

With the gate roll size press, sizing solution solids and pickup rate are independent variables. It is possible to increase starch solution concentration to reduce load on the after dryers, and the "print on" application method keeps the starch on the sheet surface. Nevertheless, the problems associated with film split and fiber picking on the outgoing side are still present and may be increased due to higher starch solution concentration. The high *z*-direction shearing forces created as the sheet leaves the

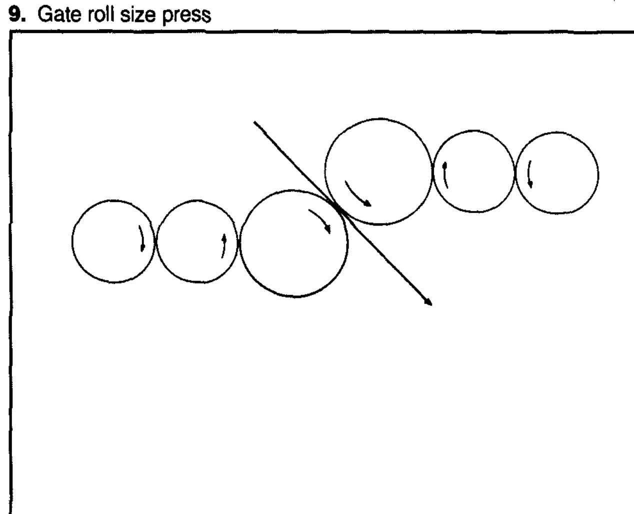
7. Larger size press roll diameters reduce relative acceleration lengths



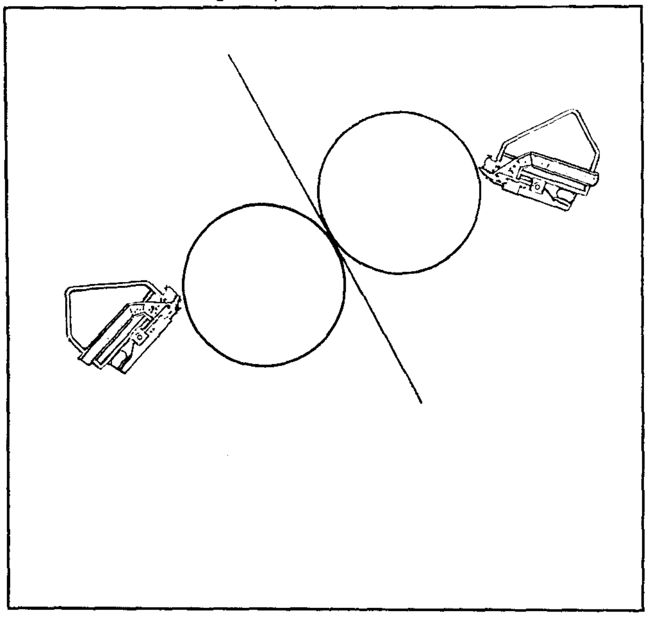
8. Apron size press



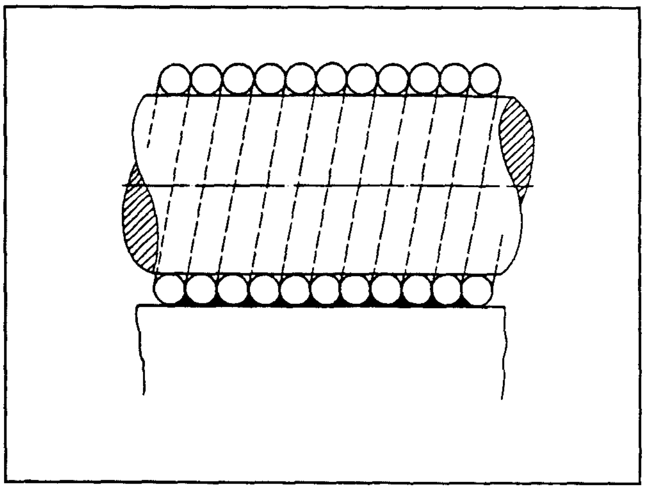
9. Gate roll size press



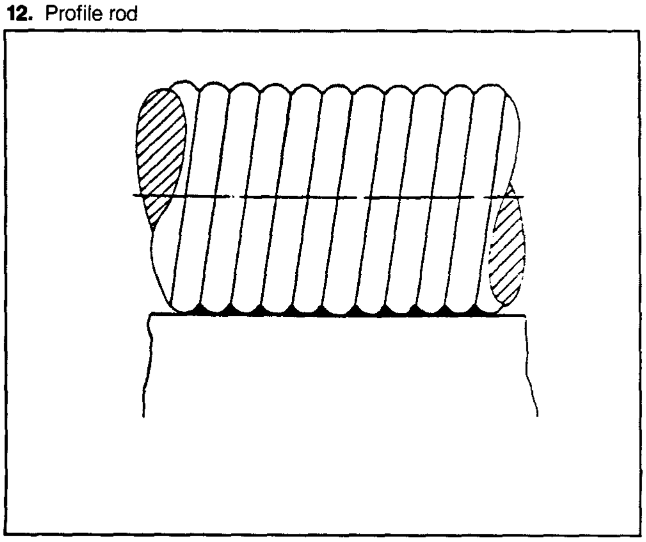
10. Blade/rod metering size press



11. Wire wound rod



12. Profile rod



nip cause sheet roughening and linting. These factors contribute to the "orange peel" sheet surface defects normally associated with the gate roll size press.

Substitution of a gate roll size press for a conventional size press involves replacing two rolls with six, contributing to increased initial investment, and the potential of significantly higher maintenance costs and downtime for roll changes. It also involves installation and maintenance of six drive units compared to two. It is necessary to crown all six rolls and run them with relatively high nip loads; this causes heat buildup and short roll cover life with a corresponding requirement for a large investment in spare rolls. When the gate roll size press was introduced about 25 years ago, it was heralded as a breakthrough in surface sizing technology. However, maintenance and sheet quality problems have caused most North American and European gate roll size press installations to be either converted back to conventional size presses or replaced with other types of surface sizing equipment. The gate roll size press continues to be well accepted in Japan, and a large new uncoated free sheet machine in Canada includes a gate roll size press.

The roll maintenance and film split pattern problems of the gate roll size press led to development of the blade/rod metering size press shown in **Fig. 10** (*12*). Short dwell blade coater heads are used to apply and meter the size to the size press rolls. Blade or rod metering permits operation without a pond or with a very limited one.

The choice of metering element can have a major impact on runnability and quality. Problems encountered in some of the earliest applications of the blade metering size press included scratches and streaks and inability to control the amount being applied; these problems were related to running a beveled blade against a smooth applicator roll. Even a minimal amount of contamination or gelled starch particles caused streaking. Another major problem was severe picking on the outgoing side of the nip; buildups on the roll faces further aggravated the streaking problem. Attempts to solve this problem by installation of water sprays and/or water lubricated cleaning doctors proved unsuccessful. Change of the metering element to a bent blade reduced the problems of scratches and streaks.

With blade metering, the amount of surface size being applied may be controlled and easily changed by varying the blade pressure. This feature makes it practical to control pickup and solids content as independent variables. The ability to control wet film thickness provides the capability to control the degree of penetration of surface size into the sheet, i.e., to locate the size near the surface or to drive it into the sheet with pressure induced migration.

Use of a bent blade for metering provides the capability to control cross machine profile of the wet film thickness and thus the amount of starch applied. Although this may provide the papermaker with a valuable tool, this profiling capability should be used with discretion. It has the potential to mask profile problems that should be corrected at the wet end or in the main dryer section. In addition, application of varying amounts of starch across the machine can lead to differences in printability and other sheet properties.

Rods are also used as metering elements in modified size presses (*13*). Initially, wire wound rods were used. As shown in **Fig. 11**, the application of size is not done with hydraulic pressure as in a conventional coater, but is achieved solely by volumetric application. The wet application of size suspension to the size press roll is a function of the wire diameter. The relationship is linear and independent of speed. Pressure differences across the width do not cause variation in the amount of sizing material. Volumetric metering does not subject the material being applied to the same amount of shear as blade metering, and thus the rheology constraints on the sizing material may not be as critical. Since control of wet film thickness is a function of wire diameter, it is necessary to change to a different rod in order to vary pickup.

There has been concern about the use of wire wound rods on high speed machines, i.e., the potential for damage or injury if the wire unwraps or wears through. These concerns have been addressed by the introduction of a new profile rod construction which has machined grooves similar to those of the wire wound rod, as shown in **Fig. 12.** It has higher resistance to mechanical loads, compared to rods with thin wires.

In most designs of the blade/rod metering size press, short dwell coater heads are used to supply the sizing material. Standard short dwell coater heads require relatively high pumping rates in the range of 2.0-2.5 gal/min per inch of width. This flow rate results in recirculation rates which are considerably higher than those required for a conventional size press. High recirculation rates necessitate larger filtration equipment, pumps, heat exchangers, and tanks in the surface size supply system. One of the machine builders has introduced a novel applicator design which incorporates a sealing blade in the application chamber ahead of the metering blade (*14*). The sealing blade is perforated, which allows the sizing liquid to pass through the blade, with the excess amount recirculated. The puddle before the sealing blade forms an airtight seal at the tip of the sealing blade and also lubricates the sealing blade. This feature minimizes the potential for skips from air entering the metering zone. Recirculation rates can be kept in the same range as a conventional size press. **Figure 13** shows the dynamics of this arrangement.

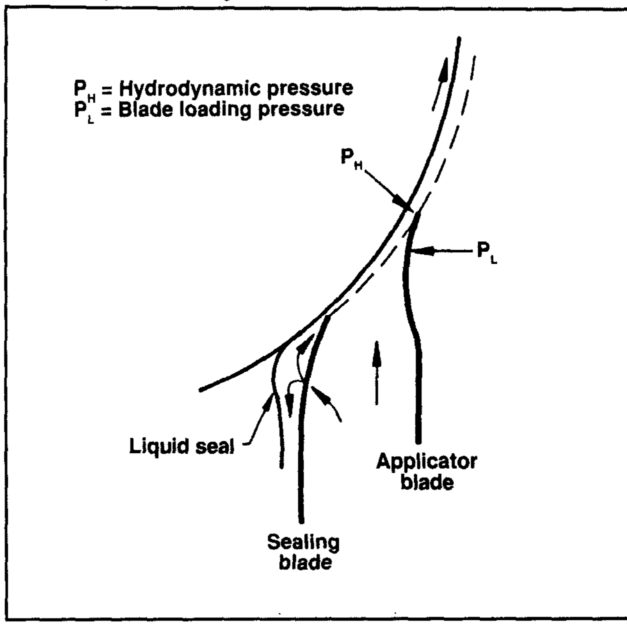
Another development which combines some of the advantages of volumetric metering and low recirculation rate is the high solids metering roll size press, illustrated in **Fig. 14** (*15*). Large diameter wire covered metering rolls are used to apply wet film to the size press rolls. Metering is volumetric, analogous to a wire wound rod metering size press. The shear rate with the high solids metering roll is not as great as with a blade or rod metering applicator. Thus the rheology requirements for the surface size are not as critical.

Effects of sheet properties

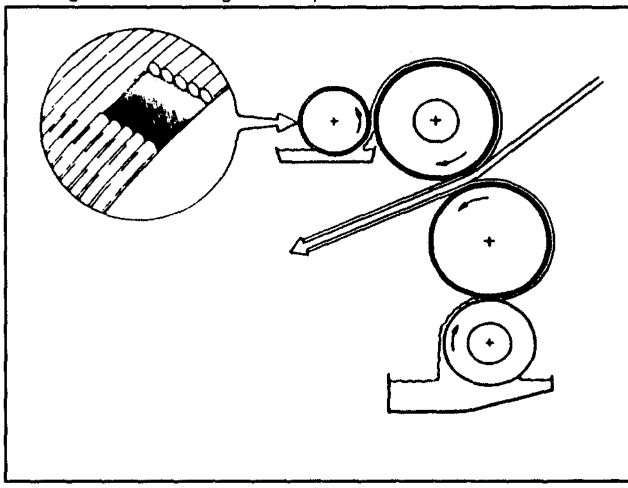
The key factors which differentiate the effects of various surface size application methods on sheet properties are:

1. Pressure induced migration
2. Dwell time at pressure
3. Lifting forces on the sheet surface as it exits the nip.

13. Sealing blade arrangement



14. High solids metering roll size press



II. Comparison of key factors for various applicators

	Conventional size press	*Gate roll size press*	*Blade/rod metering size press*
Pressure induced migration	High	Low	Moderate and controllable
Dwell time at pressure	Long	Long	Medium
z-direction lifting forces	High	Highest	Moderate and controllable

A combination of the first two factors determines the location and uniformity of distribution of starch in and on the sheet. The second factor is the primary determinant of the amount of fiber swelling. The third factor controls integrity of the starch film and disturbance of the sheet surface. As shown in **Table II**, the conventional size press and each of the major alternatives discussed above represent various combinations of the above factors, resulting in differing effects on sized sheet properties.

The size press and modified size presses all have rolls which run at the same speed as the sheet. The sized sheet exits via a diverging nip, which creates film split and lifting forces on the sheet surfaces. These forces are higher in a gate roll coater or blade metering size press than in a conventional size press. In either of the modified size presses, the wet starch film is premetered onto the applicator rolls. Dwell time at pressure is the same as for a conventional size press, but the nip is not full of starch solution. This causes dewatering of the starch solution in the nip and location near the sheet surface. The dewatering causes an increase in viscosity, which adds to the *z*-direction pull on the sheet as it exits the nip.

Since the severity of film split pattern is dependent on viscosity, it imposes a limitation on the amount of pigmented coating that can be applied via conventional or modified size presses to produce a sheet without objectionable sheet surface marks. In general, the upper limit is about 3-5 g/m^2 per side.

A starch layer located closer to the surface does not reduce opacity to the same extent as deeply penetrating starch. In cases where titanium dioxide is used to obtain opacity, a significant savings can be realized. It should be practical to control this parameter with the premetering size presses by controlling the degree of starch penetration.

A switch from a conventional to a premetering size press can also help to increase stiffness. This effect is related to location of the starch near the surface, which creates a modulus effect similar to an I-beam.

A higher concentration of starch solution can influence porosity. Premetered starch application provides better film forming and thus reduces porosity. Less refining horsepower may be needed to reach a given porosity. The volumetric premetering size presses may make it practical to apply dilatant materials to produce sheets with high Gurley density.

Orientation of the starch closer to the surface results in better ink holdout, improved solvent holdout, and higher ink gloss.

The conventional size press forces starch into the interior of the sheet, resulting in an increase in internal bond. With a premetering size press, penetration depth can be controlled, making it practical to obtain internal bond improvement if other quality control parameters favor deep penetration of the starch solution.

Deep penetration of starch into the sheet tends to decrease tear strength. The penetration control capability of the premetering size press makes the tear strength/surface sizing relationship controllable.

Location of the starch nearer the surface increases its effectiveness in providing sheet surface strength. The penetration control of the premetering size press can be used to improve sheet surface strength at equal starch pickup.

Effects on drying and machine speed

The decrease in water added to the sheet during surface sizing also reduces the sheet draw to the after dryer section.

With a conventional size press, pickup is directly dependent on starch solution concentration. Thus the primary method of controlling pickup is to vary the solids. With a premetering size press, solids concentration and pickup rate can be varied independently.

Experiences to date with the various premetering size presses show that it is practical to apply surface size at concentrations 1.5-2 times higher than with a conventional size press. Application of surface size at higher concentrations decreases after dryer load proportionately. On a machine which is after dryer limited, a switch to high solids surface sizing with a premetering size press can result in significant machine speedup and added value of incremental tonnage.

Conclusion

The new generation of premetering size presses may provide solutions to some of the problems associated with the conventional size press, especially in high speed operation. It may be practical to overcome after dryer speed limitations, decrease drying energy cost per ton, improve paper quality parameters, and extend the benefits of surface sizing to grades where size press use is not practical.□

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