Tissue Machine Shower Applications

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ABSTRACT

Production of tissue and toweling requires some of the highest performing paper machines in the world. As these machines go faster with lower quality fiber and more contaminants in their furnishes, fabric condition optimization becomes crucial. Fabrics are designed to perform at precise permeability, void volume, and surface smoothness. Maintenance of fabrics within design limits is necessary for steady state operation, allowing machine control and optimization. Proper application of showers enhances runnability and allows optimum performance of fabrics for maximum life. Contaminants can be removed as they are deposited, and fabric degradation can be minimized. The application and efficient operation of showers is discussed from both a theoretical and practical viewpoint.

INTRODUCTION

Tissue machines compared to other types of paper machines are delicate things. They typically run fast and make light sheets. Modern machines are often required to use increased recycled content, further complicating operation with inferior fiber and increased levels of insidious contaminants. It is imperative to reduce break-in times for press fabrics, and run the entire machine in a condition as close to steady state as possible at all times. If the machine is in steady-state, its performance is predictable and it can be optimized. Along with proper clothing design, an intelligent application of cleaning systems can help achieve this operation. Good clothing condition has a positive effect on dewatering efficiency and thus energy use, profile, surface finish, bulk, and many other factors influencing operating expenses such as fabric life.

Cleaning most often means removal of contaminants. Contaminants can be affected by heat, chemicals, and kinetic energy. Usually, fabric temperatures are kept as close to sheet or system temperature as possible to avoid negative impacts on dewatering or other adverse sheet interactions. Application of chemicals is an extremely powerful way to remove contaminants. This paper will concentrate on the third and most economical means of contaminant removal: the application of cleaning energy with showers.

SHOWERS

Showers are by definition systems that apply fluids. On a paper machine, there are most basically two types of showers: fan showers and needle, or jet, showers. Fan showers are used to apply liquid, usually water, evenly across the whole cross machine width of a fabric. Sometimes fan showers are used for the application of chemicals too. Needle jets are used to directly apply energy via a high velocity stream of liquid, almost always water, to the surface of a fabric. Even though these showers are both designed to apply liquid, they are very different in design and application.

Fan Showers

Fan showers are designed to apply liquid evenly across the width of a fabric. Most often this liquid is simply water. It can also be water with chemical to effect contaminants, sheet release, or some other aspect of operation. Water itself can be needed for cleaning or lubrication. Fan showers do not clean by direct application of energy with the water stream. Rather, water is applied in relatively large volumes and flushes, or floods, contaminants away. A lubrication shower is used to apply a surface film of water between a fabric and stationary element such as a suction box. Optimally, the lube water is applied such that it does its friction-reducing duty and is then removed before it has a chance to be wicked into the fabric. For flooding, chemical, or lube showers, the most important factor to judge efficiency of operation is profile of water volume applied. Ideally, there is exactly the same volume per width applied for every unit width of the showered fabric.

Showers are designed with nozzles, because it is inexpensive to manufacture nozzles precisely such that consistent performance is obtained. For a fan shower, each orifice is ground such that the water is dispersed, or “fanned” out, evenly in the cross machine direction (CD). The quality of CD water distribution is therefore mostly determined by the evenness and efficiency of the CD dispersal through each nozzle.

There are two types of variation between nozzles of the same type. The first is total flow volume through each nozzle. The second is the distribution of that volume in the CD length showered by each nozzle. As it happens, total volume variation is very small. Good nozzles will vary within 1% total flow in a population of the same type. Even the cheapest nozzles are within 4%. The most important determiner of flow volume is pressure. Of course, for a properly designed shower pipe each nozzle is pressurized to the same level, so no volume variation occurs due to pressure. The second most important determiner is orifice area. It is not difficult to precisely make the same size hole repeatedly, so flow variation is usually quite small.

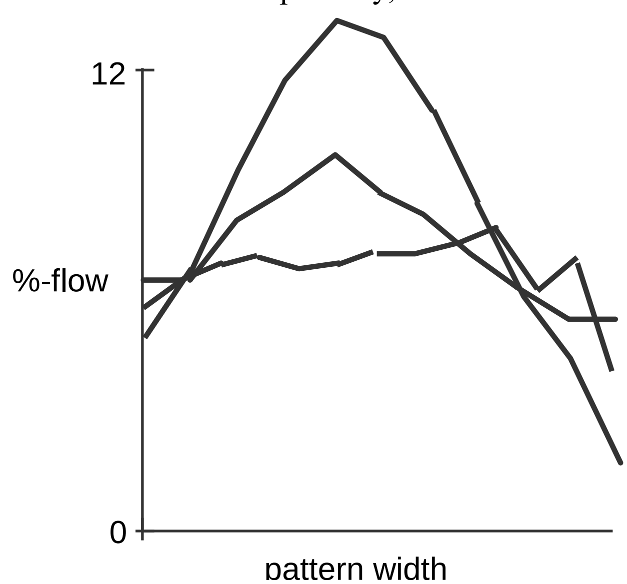

Figure 1: Flow Distributions for a Typical Nozzle Type

The modification of orifices to make fan patterns is inherently less precise than hole drilling, so it follows that there is more error in distribution of flow. Indeed, the largest variation in nozzle flow is in the pattern of application. Figure 1 is a graph of gpm/inch for one nozzle that generates about a 45^0 fan and has an orifice of about .050 inches. Note that side-to-side variation in the pattern is relatively great, as much as about 2/3 of peak flow. Certainly, this variation will have a much greater effect on the overall profile than volume differences. To compensate for this variation, nozzle patterns are overlapped. Every nozzle has a nominal pattern width, usually defined as an angle. This angle assumes the orifice is a point, and flow coverage spreads evenly from that point outward toward the fabric. Figure 2 is an illustration of this concept. The coverage width is calculated as:

Coverage width = (distance between nozzle and fabric) x tan (angle/2)

Consider the profile variations within each nozzle. What is the effective nominal width, if the flow tapers so dramatically at the edges? Compound the uncertainty with the dependence of the fan width on pressure: the pattern tends to "neck in," or get narrower at very high or very low pressure. Clearly, assumptions must be made to design the best showers possible.

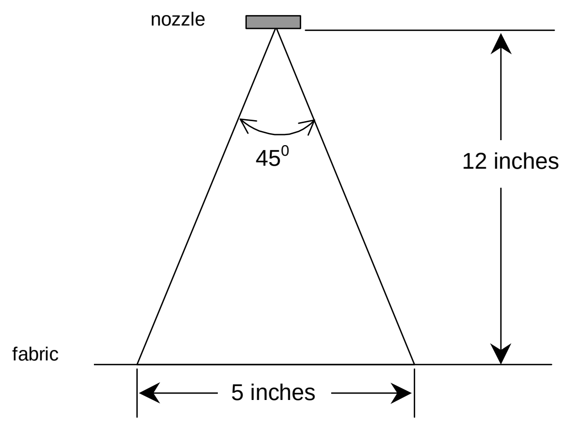

Figure 2: 45^0 Fan Nozzle

Figure 3 illustrates a condensation of the considerations of effective pattern width. Often, when there is variation in a system of components, the system is designed to the average. Here, that might make sense. However, if nozzles are spaced on a pipe to the average pattern width and two narrow nozzles end up side by side, a dry streak will occur. While wet streaks are undesirable, dry streaks are absolutely unacceptable. Therefore, nozzles are spaced to the narrowest width. In other words, the patterns are overlapped most of the time. This is a conservative and very conventional method of shower design: to preclude dry streaks, wet streaks are designed in.

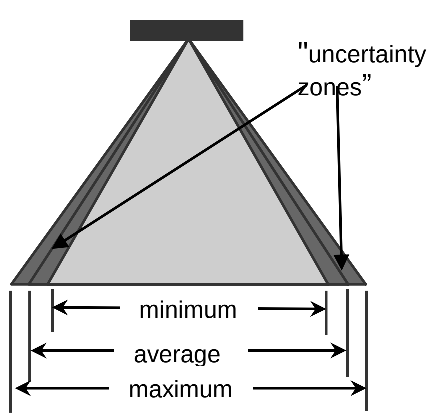

Figure 3: Fan Patterns for Shower Design

Figure 4 illustrates a full-width profile of water volume application for a typical shower. Note that this is a nominal profile, with no plugged nozzles, that is, the profile results from a well designed shower. Note that maximum to minimum peak variation is over 2:1.

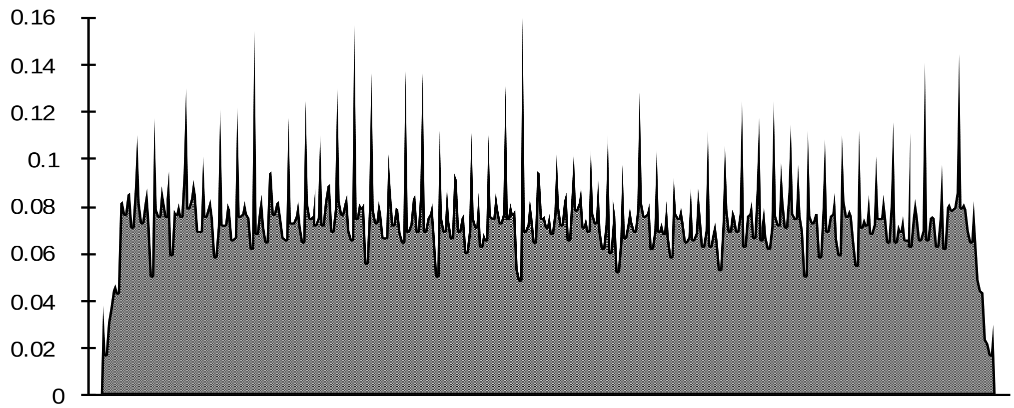

Figure 4: Shower profile for a 300 inch wide shower with 45^0 nozzles spaced at 6 inches, ½ inch pattern overlap.

An easy way to eliminate these peak-to-peak variations is to oscillate the shower. Figure 5 illustrates the same shower as that illustrated in Figure 4, except the shower is oscillated. Note that the local variations remain the same. The difference is that the peaks are "smeared" to adjacent areas, so that the net variations are essentially eliminated.

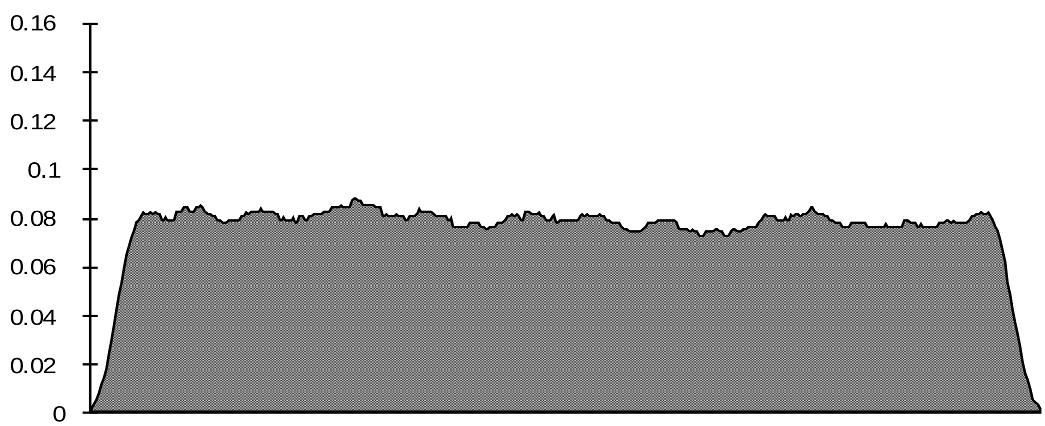

Figure 5: Same shower as shown in Figure 4, oscillated 12 inches.

Needle Jet Showers

While both fan and needle showers are designed to spray water, the mechanisms of their functions are very different. Fan showers deliver water for its own sake. Needle showers use water as a vehicle to apply power to the fabric to dislodge contaminants, usually at or near the surface. It has been proven that the mechanism of high pressure needle jet function is power application. The energy of a stream of water can be determined from the simple relationship

$$E = \frac{1}{2} m v^2$$

where **E** is energy, **m** is mass, and **v** is particle velocity. Local cleaning is determined by instantaneous energy. Energy over time is power **P**, which can be calculated as

$$P = \frac{1}{2} \dot{m} v^2$$

For a given orifice, that is, an orifice of fixed diameter, the operational parameter that determines both mass flow and velocity is pressure. (This assumes other factors such as viscosity are constant, a fair assumption for this system.)

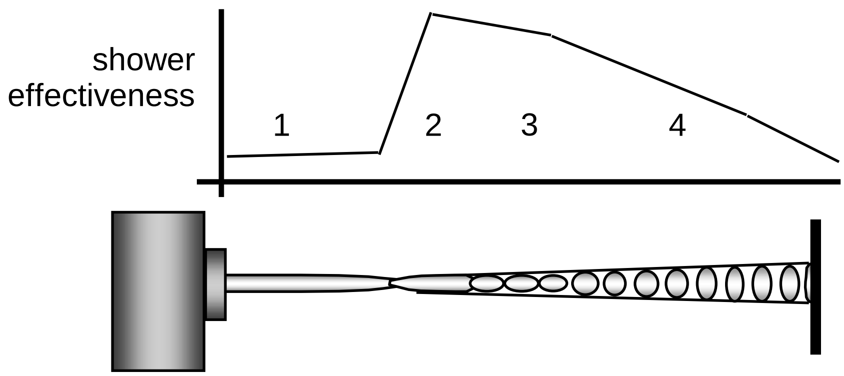

Figure 5: Shower Effectiveness vs. Distance from the Fabric

Figure 5 illustrates the four zones of a needle jet. Just as the stream leaves the nozzle, the stream is clear and the flow is laminar. As edge effects begin to become significant, turbulance is introduced into the stream, and the velocity profile becomes more uneven. The stream begins to contract in the second zone. In the third zone, air begins to mix with the water and the flow becomes two phase, but still remains reasonably concentrated. Eventually, in the last zone the flow begins to disperse and the jet becomes ineffective. Experiments have shown that the most effective point of cleaning is between zones 2 and 3, after the jet has contracted but before it is dispersed, and while the flow is two phase. It is very interesting that laminar high pressure showering is relatively inefficient, as shown in Figure 5. Particle collisions as droplets of water strike the fabric apparently play a large role in cleaning effectiveness.

For application, the above translates to an optimum placement of a high pressure shower from 6 to 14 inches from the outside surface of the fabric. Note that nozzle quality has a large effect on the jet character. A poor or worn nozzle will have a very short laminar zone and the flow will disperse immediately. It's easy to tell the condition of a nozzle by looking at the stream. If the flow disperses immediately, the nozzle should be replaced.

The application of power with a high pressure water stream is an effective way to clean a fabric. The "down side" of high pressure showers is that the mechanism that cleans is the same as that which destroys. If a needle jet is directed at a fabric for long enough duration and at high enough pressure, it will destroy the fabric. While it is optimum to oscillate fan showers, it is absolutely imperative that needle jet showers *must* be oscillated.

Sometimes to reduce fabric damage especially for more delicate fabrics, needle jets are placed very close to the fabric. This greatly reduces the effectiveness of power application. It eliminates fabric damage, but it also probably greatly reduces cleaning while maintaining the expense of pressurizing the water. It is far more efficient to leave the shower at its optimum stand-off and reduce pressure to acceptable levels.

Oscillation

Since needle jets work their magic in very localized areas of the fabric equal to or slightly greater than the stream diameter, they only cover small portions of the total fabric area at a given time. Typically nozzles are spaced every 6 inches on a pipe, and are rarely closer than 3 inches for a forming fabric and 6 inches for a felt. The effective width of a .028 inch diameter jet is most simply .028 inches. The shower must therefore be moved back and forth across the fabric so that the cleaning is performed over the whole area.

To optimize profile, cleaning must be done evenly over the whole fabric face. This is accomplished by moving the shower at a speed such that it moves one nozzle diameter for every fabric revolution. Also, at the end of the oscillator stroke, turn around must be instantaneous to avoid over-showered streaks in the fabric resulting from turn-around dwell. Proper oscillator speed is easily calculated as

Oscillator speed = (machine speed x nozzle diameter)/(fabric length)

(Don't forget to correct for proper units: oscillator speed is usually expressed in inches/minute. This formula works without correction for feet/minute machine speed, inches nozzle diameter, and feet fabric length.)

For example, a shower with .040 nozzles on a 100 ft. fabric running at 2500 feet/minute should run at 1 inches/minute.

Nozzle Plugging

The best way to avoid nozzle plugging is to use fresh water. Unfortunately, fresh water is seldom available, so precautions must be taken to be sure nozzles remain clean and shower water application remains even. Considering nozzle contamination: there are three basic shower designs: plain nozzles, brush nozzles, and self-purging nozzles. Water contamination is usually expressed as contaminant loading in the water, as parts per million, ppm. Smaller nozzles are more susceptible to plugging. Therefore, for a given high pressure shower application for example, even though a .028 inch nozzle might be adequate to deliver sufficient energy at available pressure, a larger nozzle may be required because of water contaminant loading. This could be wasteful of water and pumping energy.

Typically, loading of 50 to 75 ppm is acceptable for .040 inch nozzles, and loading as high as 200 ppm is allowed for .125 inch nozzles. (Note that .125 is quite large for a paper machine nozzle.) For loading greater than 200 ppm, a brush shower is required, and above 500 ppm, self-purging nozzles are required.

A brush shower contains a long shaft down its center, to which polymer or stainless steel brushes are attached. The shaft is rotated or axially energized, and the brushes scrape contaminants off the nozzle and into the stream. Usually, a dump valve is opened on the end of the shower, allowing the dislodged contaminants to flow out during the brushing cycle.

Brush showers are simple mechanisms, but some rules must be observed for their proper use. First, the brush should be activated at regular intervals, depending on contamination level. Second, brushes should clean the whole pipe, freeing the flow path of all contaminants. Brushes should be of sufficient strength and density to dislodge all contaminants. They should be ductile enough so the bristles do not break and themselves become contaminants.

Self-cleaning, or purging nozzles are wonderful devices but have certain shortcomings. Since each nozzle is a mechanism, higher maintenance is required compared to a conventional shower. Usually the contaminants are dumped onto the fabric when the nozzle purges. For some applications, this can be detrimental to operation. Also, during the purge cycle high volumes of water are required. Even though the purge water can be at low pressure, pump limitations and water availability could be a problem.

There are other shower water considerations to optimize cleaning efficiency. For press fabrics there is a certain critical particle size that causes filling. Particles larger than about 50 microns will stay on and not penetrate press felts. Particles less than 10 microns will pass through. Therefore, shower water should be filtered so that it is free of contaminants above 10 microns.

PRESS FABRIC DEWATERING

So far, we’ve discussed means of adding water via showering. Indeed, a primary function of a fabric is to accept water from the sheet and carry it away. More water is added by showers to clean. There is only one practical way to remove water from a fabric and maintain a steady state moisture content. The water must be sucked out, in the case of a press fabric, with a uhle pipe or suction box (the terms are interchangeable).

Reference 5 summarizes a standard means for determining suction box performance. The amount of water removed from a felt is greatly dependent on the length of time the fabric is exposed to the vacuum, the dwell time. This time is calculated as (5 x number of slots x slot width)/machine speed, where slot width is in inches and machine speed is in feet/minute. Airflow can be more accurately determined as

$$V = \frac{(.069 \times dP^{.476} \times t^{.11} \times perm^{.916})}{m_{p1}^{\ .628}}$$

Where V is airflow in acfm/in^{2}of slot area, dP is vacuum in inches-Hg, t is dwell time in milliseconds, perm is felt permeability in cfm/ft^2 at ½ inch WC, and m_{p1} is felt water content before the suction box in lb.water/lb.felt. Note that performance is greatly dependent on vacuum level too, and it is assumed that the system can deliver at least about 7 inches-Hg to a new, open felt.

Adequate dwell time is usually 4 ms, except for very fast machines where excessive slot width would be required, or for very open felts where airflow would be excessive. Then, 3 ms is allowable. Some arbitrary limits for the transition points are 4000 fpm and 75 acfm/in^2. These are rules of thumb. Good results have been seen on machines with dwell times as low as 2 ms.

SHOWER APPLICATIONS

To achieve steady state operation, cleaning and conditioning of press fabrics should be done on a continuous basis. The process must be started when the fabric is new, using full-width oscillating showers. Pressures for fan showers should be the minimum possible to maintain nominal fan angles and adequate volume. Pressures for needle showers should be high enough to clean and low enough to avoid fabric damage. All showers should be designed and placed using the design considerations described in the sections above. Generally, showers should be applied as soon after the nip as possible, and suction boxes should be applied last before re-entry into the nip. Suction boxes should be supported with sufficient volume capacity for new felts, and sufficient high vacuum capacity for older, more closed felts. Several general rules should be followed:

Start when the fabric is new
Use full width showers and suction boxes
Use acceptable minimum water pressure
Deliver water uniformly

The use of fresh or processed water determines the type of showers to be used. Using the contaminant loading guide presented above, fresh or lightly loaded processed water will permit the use of fixed orifice nozzles. More contaminated processed water dictates the use of filtration and equipment that provides for cleaning the nozzles on the run.

To develop a cleaning and conditioning strategy consider three items. First, identify contamination and determine its source. Contaminants could be fines and fillers, pitch, stickies, or plastics brought in from secondary fiber. Contaminants could also be rust and scale from the water or other chemicals used in the process. Location of the contaminants is also important. Contamination could be on the surface of the fabric or embedded in the fabric void volume. As discussed above, high pressure showers are best at removing surface contaminants, and void volume must be cleared with flooding. Surface contamination greatly affects sheet quality and void volume contamination impairs the ability of the fabric to accept water from the sheet.

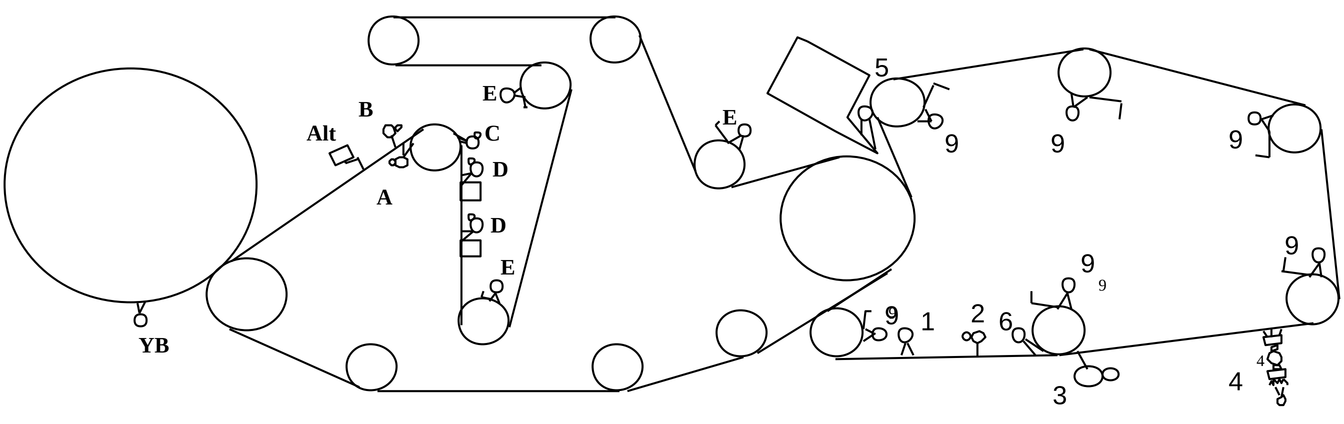

Figure 6: Single Felted Tissue Machine Schematic.

The chart below lists the various showers used on a typical machine, as shown in Figure 6.

No.	Application	Function	Type	Space	psi	gpm/in.	Nozzle*	Dist.*
1	Fiber/Sheet knockoff	Flood, Chemical Appl.	Osc/fan	3"	200-400	1.0-2.0	.125"	4"
2	Inside HP	Fabric Cleaning	Osc/jet	3"	250-400	.18-.23	.040"	6"
3	Outside HPS	Fabric Cleaning	Osc/jet	3"	250-400	.18-.23	.040"	6"
4	Brush Cleaning	Brush Cleaning	Stationary 45^o Fan	3"	60-80	.87-1.0	0.125"	4"
5	Breast Roll Apron	Headbox & Apron Clean	Stationary 45^o Fan	6"	30-40	.06-.07	0.055"	8"
6	Flooded Nip	Knock-off Cleaning	Stationary 30^o Fan	3"	80-150	Calculate	0.188"	12"
7	Suction Roll	Cleaning	Oscillating Needle Jet	3"	350-600	.21-.25	0.040"	4"
8	Headbox	Foam Killing Stock Buildup	Rotating 90^o Fan	10"	20-40	.04-.05	0.055"	X
9	Doctor Lube	Doctor Lube	Stationary 45^o fan	6"-8"	25-30	.07-.09	0.055"	8"
10	Chemical Treatment	Chemical Application	Stationary 45^o fan	6"	40-60	.07-.09	0.055"	8"
11	Sheet Side High Pressure	Fabric Cleaning	Oscillating Needle Jet	6"	150-300	.06-.07	0.040"	6"-8"
A	Flooding	Flood & Chemical Application	Oscillating 45^o Jet	3"	40-60	Calculate	0.094"	4"
B	Sheet Side Chisel	Fabric Cleaning	Oscillating 15o Jet	3"	200-300	.18-.23	.040"-15^o	4"
C	Suction Pipe Lube	Wear Surface seal & Lube	Oscillating 45^o Jet	6"-8"	25-30	.07-.09	.055"	8"
D	Doctor Lube	Doctor Lube	Stationary 45^o fan	6"-8"	25-30	.07-.09	.055"	8"
E	Suction PU Lube	SPU Lube & Seal	Stationary 45^o fan	6"-8"	25-30	.07-.09	.055"	8"
YB ALT	Yankee Boom Traversing Shower	Additive Application Spot Cleaning	Double Tube Single Jet	**MILL** x	**SPEC** 150-300	.36-.50	.040"	6"-8"

***Shaded data is for reference only. Dimensions may vary as machine requirements dictate.**

Shower #1 is knock-off shower. It is used on all design formers and is run continuously or intermittently. It is used to clean the fibers from the fabric if run continuously, and to knock the sheet from the fabric during start-up or sheet break. It is a stationary fan shower having nozzles on 3-inch centers and operates between 200 to 400 psi. It is located inside the fabric.

Shower #2 is the inside high-pressure shower. This shower is rarely used today because of heavier fabric designs. It is usually run intermittently to move the contaminants out of the void volume of the fabric from the back side, where the batt is lightest. It is an oscillating shower having needle jet nozzles on 3–inch centers and operates at 250 to 400 psi. It is located at least 6 inches from the fabric 90^{o} to the run.

Shower #3 is the sheet side high-pressure shower. This is the most effective shower in the cleaning system. It is run continuously. Its purpose is to remove contaminants from the surface, their most likely location. This shower is oscillated and has needle jet nozzles on 3-inch centers operating at 250 to 400 psi. It is located 6 to 8 inches from the fabric 0^{o} to 15^{o} into the run close to an inside return roll.

Shower #4 is the fabric brush-cleaning shower. This shower operates only when the fabric brush is rotated to clean the contamination picked up by the bristles. It is a stationary shower having fan nozzles on 3-inch centers and operates at 60 to 80 psi.

Shower #5 is the breast roll apron shower. It can be used on all formers and runs continuously. Its keeps the apron free from fiber buildup. It is a stationary shower having fan nozzles on 6-inch centers and operates at 30 to 40 psi.

Shower #6 is the flooded nip knock-off shower. It is used on all formers and runs only at start-up or during sheet break conditions. This shower is an excellent cleaning devise; however, its very expensive to run because of the large volume of water it uses. It is a stationary shower having fan nozzles on 3-inch centers and operates at 80 to 150 psi. The amount of water used is calculated by using fabric caliper, fabric width, machine speed and void volume.

The amount of water required to knock off the sheet in a flooded nip position can be calculated by determining the “Running Void Volume” (RVV). The RVV must be filled with water to knock off the sheet. RVV is found by multiplying the fabric caliper (inches) times the fabric width (inches) times the machine speed (fpm) times the void volume (usually about 60%), all divided by 19.25 (for units conversion). This yields RVV in gpm. RVV is adjusted for machine speed: faster machines need less water because of the increased centrifugal forces. At 2000 fpm the correction factor is about 1, and is about .7 at 4000 fpm and above. It is about 1.75 at 1000 fpm. A flooded nip is also a very effective cleaning tool. The same RVV considerations use for knock off apply for cleaning.

Shower #7 is the suction roll-cleaning shower. This shower is used only on formers having suction breast rolls. Its purpose is to keep the holes of the shell free from contamination, thus ensuring CD uniformity of vacuum airflow. It is an oscillating shower having needle jet nozzles on 3-inch centers. It operates at 350 to 600 psi about 4-inches from the shell toward the center of the roll.

Shower #8 is the headbox-cleaning shower. It is used to break down foam and to prevent stock build-up on the sides of the headbox. A rotating shower is used in closed, pressurized headboxes and a swing shower is used in the open design units. The fan nozzles are on 10-inch centers and they are positioned along a helix on the shower, and in line on the swing shower. Operating pressure is 20 to 40 psi.

Shower #9 is the doctor lubricating shower and is the most used shower on the tissue machine. Every roll in the forming section should be doctored. These lube showers are run continuously to reduce friction between the blade and roll surface. The shower also provides the water to carry away contaminants removed by the blade. It is a stationary shower having fan nozzles on 6 to 8-inch centers operating at 25 to 30 psi.

Shower #10 is a chemical application and pH control shower. It is a stationary shower having fan nozzles on 6-inch centers operating at 40 to 60 psi.

Press Section

Shower A is the sheet side needle jet high-pressure shower and is probably the most important shower on the press fabric. It is operated continuously to remove contaminants from the fabric surface. It is an oscillating shower having jet nozzles on 6-inch centers angled into the run up to 15^o. It operates at 150 to 300 psi about 6 to 8-inches from the fabric. It is used on single and multiple felted press sections.

A single-jet traversing shower augments the high pressure shower. This shower is valuable because it can spot-clean streaks, and so improve profile problems in the fabric on the fly. The application of single jet showers can be very good for treating streaks, but usually these showers are very maintenance intensive and their use should be carefully considered.

Shower B is the flooding and chemical application shower. It is run continuously and adjusts the amount of water in fabric. It can also be used to apply chemical-cleaning solutions either intermittently or continuously. It is an oscillating fan shower having nozzles on 3” centers operating at 40 to 60 psi. It is located to apply water into the nip of the first inside return roll if possible.

Shower C is the high-pressure chisel shower. This is a shower unique to the tissue industry. It is used continuously along with the needle jet high pressure shower to remove stubborn contaminants. It is an oscillating shower having 15^o fan nozzles on 3-inch centers. Most mills operate this shower on the sheet side opposite an inside return roll at pressures of 200 to 300 psi.

Showers D are suction pipe lubricating showers. These are used on every suction pipe assembly in all positions. They are used to reduce friction between the suction pipe wear surfaces and the fabric. They are also used to make certain a proper seal is maintained to prevent vacuum leakage across the width of the machine. They are run continuously and are oscillated. The nozzles are on 6 to 8-inch centers operating at 25 to 30 psi.

Showers E are the doctor lubricating showers. All sheet side rolls should be doctored. The showers reduce friction between the doctor blade and the roll surface and the water provides a vehicle to carry contamination from the roll and blade. All press roll doctors should be lubricated. These showers are stationary and have fan nozzles on 6 to 8-inch centers operating at 25 to 30 psi continuously.

Shower F is the suction pick-up-lubricating shower. This shower is not found on the Crescent Former. Its description and purpose is the same as the doctor lubricating showers (shower D).

Shower YB is the yankee boom shower. It applies additives to the surface of the yankee drum. It is usually a double tube shower that can be removed from the machine on the run for quick maintenance. The fan nozzle spacing and operating pressure is to mill specification, depending on the coating. Each company seems to have their own specifications for this application, and everyone tends to be very secretive about their coatings.

Total Water Volume for Press Fabrics

The total amount of water applied to the press fabric should be about 0.1 lb.-water/lb.-fabric. The total flow rate is calculated by multiplying the fabric width (in.) times the fabric weight (oz/ft^2) times the machine speed (fpm) times the factor C (.000063, for unit conversion) to yield gpm. The flooding shower volume is calculated last. It is the highest volume shower, so the volume of the other showers is subtracted from the required volume to determine the flooding volume.

Example: consider a fabric 222" wide, weighing 4.5 oz/ft^2, and running at 5000 fpm. Then:

222 x 4.5 x 5000 x .000063 = 315 gpm total flow

high pressure showers, 36 nozzles each: 18 gpm/shower x 2 showers = 36 gpm
lube showers, 36 nozzles each: 14 gpm/shower x 2 showers = 28 gpm
Therefore 315 – (36 + 28) = 251 gpm for flooding shower.

Water quality is also an important consideration. In the forming section filtered fresh water should be used in all high-pressure needle showers. Clarified white water can be used in all other showers. In the press section, filtered fresh water is recommended for all showers. The water should be heated and pH balanced. Water having little solids loading can be used with fixed orifice nozzles. However, water containing a higher level of contamination will require some type of nozzle that can be cleaned on the run.

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