SPUNLACE PRINCIPLES AND SYSTEMS AS IT RELATES TO COTTON AND CELLULOSIC FIBERS

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The process of using jets of water under high pressure to entangle fibers is called Hydroentanglement, often referred to as Spunlacing. The development of Spunlace technology is relatively new, with the first commercial lines from Perfojet installed in 1984, with the world market today having approximately 120 lines over a range of width up to 5.0 meters wide. The use of hydroentanglement with cotton and cellulosic fibers differs little from standard synthetic fibers in the general context of the use of water needles entangling the fibers. The differences can be seen in the pressures required, and the applications in which the finished fabrics are marketed.

It may be of interest to review the concepts of hydroentanglement (to be termed "Spunlace" hereafter), and highlite where special consideration to cellulosic fibers alters the standard format used with synthetic fibers.

The Spunlace system uses high-pressure pumps with each pump dedicated to an injector, where the water is forced through holes in the injector "strips" onto the fiber matrix. The strips are special hardened strips of steel which have been treated to create holes of diameters ranging from 120 to 140 microns, which in effect create the water needles which entangle the fibers. The strips can have multiple rows, and it is the hole diameter, number of holes per row and per strip, and the pressure of the injector, which dictate the water flow for the each injector. There are no special considerations for cotton fabrics, as the same considerations for finished fabric appearance applies to cotton as with other fibers. In general, the finishing of non-apertured fabrics will have single row, close hole spacing with smaller hole diameters. The fabrication of apertured fabrics means that high water flow is required, in order to move the fibers, and therefore multiple rows with larger hole diameters will be the norm.

The injectors are placed either above transport aprons or above driven cylinders. In fact the standard format today is to use a combination of aprons and cylinders together, to create a Spunlace machine. There are normally 2 aprons employed, the first helping to transport the fabric through the pre-wetting zone, and possibly the first injector to the first cylinder. The second apron is used for finishing, aperturing, patterning and /or de-watering of the nonwoven fabric.

The feeding apron transports the fiber matrix to the pre-wetting zone where there is a low energy injector, normally a spray injector, which is used to provide the energy needed to transfer the batt to the first cylinder. The feeding apron may possibly be fitted with a feeding compression apron when the weights produced exceed 120-150 g/m^2, as the loft of the batt requires a controlled compression and stabilization in the initial bonding zone. The feed compression apron will house the pre-wetting, thus the pre-wetting occurs when the fibers are at their compression point, and are under control, which helps to maintain batt uniformity. If the fabric weights are expected to be heavy, then an injector may be employed after the pre-wetting, prior to the transfer of the fabric to the first bonding cylinder.

The first cylinder will have one or two injectors, depending upon both the range of weight and the line speeds foreseen. A second cylinder will always be used, once again having one or two injectors. The minimum format in a Spunlace machine is two cylinders, thus allowing bonding energy to be applied to both sides of the fabric. The potential for additional cylinders and injectors is dependent upon the weights used, normally when the finished weight is foreseen to be greater than 8*0-100 g/m^2*, a third cylinder will be installed.

It may seem contradictory to state that in order to bond both sides of the fabric, that two cylinders are needed, as it has just been stated that it is possible to have an injector on the feed apron thus both top and bottom sides of the fabric would be bonded. The reason for two cylinders is the injector on the feed apron is used only when fabric weights are high, and would therefore follow the batt compression apron. If a line were to produce lightweight fabrics, then two cylinders would be used, as there would not be an injector on the feed apron, and if heavy weight fabrics were to be fabricated, two cylinders (at the minimum) would be used in order to obtain sufficient bonding. There is one exception to this rule, which is the machine for de-makeup pad production which will be reviewed later in this paper.

The use of additional cylinders or injectors does not mean that all of the injectors must be used. A machine which, for example has 6 injectors, can operate with some of the injectors dormant, thus all the injectors could be employed for heavier fabrics and fewer injectors used when the fabrics are lighter.

The injectors are designed for a maximum operational energy, referred to as its bar rating, although this does not mean that the injector must operate at that specification. An injector head which is designed for a maximum of 250 bar may operate with a pump which has a maximum pressure of 120 bar with a given flow rate.

The pump and motor define the flow rate in meters per hour, and this flow requirement is determined by the hole diameter, and the number of holes per meter in the injector strip, and the maximum bar rates foreseen for that injector. In essence, the complete Spunlace plant is based on the number of injectors and the flow rates for each injector based on the maximum flow rates for each strip at the maximum pressure for each injector.

Thus, if a machine is based on lightweight fabrics with a range of fabrics up to 120 g/m^2, the machine may be fitted with 6 injectors, which may have a maximum pressure of 150 bar. It is important to remember that too much pressure can destroy the web or batt uniformity, or cause too much fiber loss. The choice of the injector strip specification will then give the required flow rate for the injector, and added with the other injectors on the line at full throttle, will determine the pump and motor specifications as well as the flow requirements for the filtration plant. This simple scenario is further complicated should the customer desire to aperture the fabrics (normally done on fabrics less than 60 g/m^2), as the flow rates for aperturing are much higher, as the elevated flow rates help to move the fibers from the knuckled points on the conveying apron. In essence, when aperturing, the high flow rates move the fibers from the intersection of the warp and weft intersections, which is where the "knuckle" of the apron is located. The concept of aperturing is not necessarily to bond the fibers by high energy, but rather to wash (flood) the fibers with high flow rates off the knuckle on the aperturing wire (apron). Thus the energy is low, 120-130 bar, but the flow rates are high.

In fact, a machine which manufacturers both standard Spunlaced fabrics and aperatured fabrics may have 5-6 injectors, and when processing standard fabrics will employ all of the injectors, whilst one of the injectors may be idle in the production of aperatured fabrics. The purpose to idle an injector for aperatured fabrics is two fold, one reason is the production of aperatured fabrics requires that the fabric be stable prior to the aperture injectors, but the fibers must also have the ability to move away from the knuckle of the wire under the water flow and pressure in the aperture zone. This means that all of the injectors available may not be needed, in that sufficient strength and cohesiveness of the fabric are obtained with fewer injectors. When aperatured fabrics are made, it is important not to create a

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fabric which is too strong, and therefore prevents the migration of fibers during the aperturing phase.

The second reason to idle an injector is the increased flow rates for the aperaturing injector may be higher than the flow rates for the same injector pump in normal fabric production mode when the strip would have lower flow rates due to the hole size and population of holes in the strip. Thus, using the flow rate from the pump of the idled injector to supplement the flow rate of the aperaturing injector pump enables the aperture injector to operate at flow rates necessary to produce the desired aperatured look.

Aprons and Sleeves

There is a range of different web transport apron designs which are used, although the introduction apron is normally different in specification from the finishing apron, especially if aperatured fabrics are to be made.

The introduction apron is the apron which links the web transport or batt conveying apron to the Spunlace machine. This apron has a generic weave, as its primary function is to transport the fiber matrix through the pre-wetting, and primary injector (if required due to the weight range foreseen). What we mean by "generic weave" is the function of this apron is web or batt transfer, not patterning, which may-or-may not be the function of the finishing apron.

The finishing apron, which is placed after the cylinders, and includes the de-watering suction zones, will have multiple options in respect to the different weaves based upon the desired fabric appearance. Normally the aperturing is done on the finishing apron, and thus, the openness of the weave will be based on the open area size desired in the finished fabric. This does not mean that aperaturing cannot be done on the cylinders, but rather there is a wider selection of apron designs than normally seen with cylinder screens.

An important criteria for apron selection is the CFM airflow capability, this relationship is derived from the openness of the weave structure. The impact the weave structure has on the flow of water through the fabric should also be taken into account. The apron should also be selected taking into consideration the effect water pressure has on leaving an imprint (a mirror image of the weave) on the face of the fabric. The higher the CFM, the more open the weave construction and/or the larger the warp and weft fibers, which will contribute to leaving an impression on the fabric. If the fabric is to be aperatured, the concept of leaving an impression is magnified to the point that we leave holes at the intersection of the warp and weft. If we want to create normal flat fabrics, or fabrics which have a non-aperatured pattern, then the supporting apron design and its CFM become very important.

The apron selection for the feeding apron is therefore chosen for its ability to allow water to freely pass while holding the unbonded fibers during the pre-wetting stage. The heavier fabric weights (> 150 g/m^2) will have a more open weave due to the fact that there will be a compression apron with an injector enclosed and possibly an injector on the apron positioned prior to the first cylinder. The open weave will enable better efficiency of the suction coming from the de-watering slot positioned directly below the injector, and hence enhanced water flow through the fabric.

It is important to realize that the fibers used are normally 1.5-3.0 denier, and that as weight increases, the density of the fabric can impede water flow through the fabric to the de-watering slot. The need to have good water flow is to maximize the efficiency of the injector energy into the fabric. If the water accumulates, or remains on the surface of the fabric, then the energy of the water needle is lost as it comes into contact with the water on the surface of the fabric, remember, we want to entangle the fibers not blend the water!

The screens are metallic covers for the cylinders, and come in many different surface textures based on its position in the line, and the resulting textile appearance desired.

The screens used on the first cylinders are normally a micro-perforated screen (MPA) with a patented random open surface design, which is <10% open surface area and >90% closed surface area. The closed aspect of this design allows for the use of secondary energy of the water as it passes through the fabric and reflects off of the surface of the screen. This reflected energy helps to further bond the fibers, which in effect reduces the energy necessary to achieve fabrics with the appropriate strengths for their respective application.

The use of these MPA screens with a low percentage of open surface area, would lead one to imagine that very little water would pass through the screen to the de-watering slot which is fitted below the screen, placed opposite of the injector inside the Honeycomb cylinder. In fact, the majority of the water does pass through the screen to the vacuum slot. This is possible due to the energy of the water penetrating the fabric, thus the water is already on the back of the fabric next to the surface of the screen, and the amount of suction generated by the air-water separators pulls the water through the perforations on the screen. The common suction at these de-watering slots is 700-800 Water Column.

The suction points which are located under every injector and at the end of the line are very important to the operational effectiveness of the injectors, as the efficient removal of the water promotes better bonding. Another important aspect of the suction is this is the start of the re-circulation of the water, as the suction used to remove water from the injector sites is also used in the air/water separators.

De-Makeup Line Requirements

The production of all Spunlaced fabrics use the same basic principles of alternate bonding using an arrangement of cylinders and injectors to enable the production of a range in fabric weight and appearance. The general form being to use a feed apron (where there may be a compressing apron for the heavier weight fabrics) which transports the web or batt to the first bonding cylinder. There may be an injector prior to the first cylinder should the range of fabric weights exceed 120 g/m^2 (again, this value is not written in stone). After the cylinders (at least 2 of them) there will be the finishing apron with the potential for further bonding, aperturing and de-watering. The global machine being modular in concept, based on the limits of fabric production intended.

The exception to this generic rule is the spunlace machine for de-makeup pads. The production of de-makeup pads requires bonding of the surface of the pad (front and back sides uniformly) while the loft and softness of the pad remain intact. Therefore, few injectors are required, and the energy from the injectors will be quite low, in the order of 25-30 bar. As the requirement is not the bonding of the internal fibers within the pad, the hole diameter and spacing within a single row will be small. Bonding uniformity and light surface abrasion resistance along with an aestethic aspect of the pad are the key elements in the fabrication of these pads.

This machine is a very simple machine, where only one cylinder is employed. The de-makeup pads are made of 100% bleached cotton, although other fibers or blends can be used. The machine has a feed apron where one injector is located for bonding the top surface, and the single cylinder has an injector to bond the reverse surface of the pad. The feed apron will have a compressing cylinder with a pre-wetting injector (very low pressure) prior to the first injector, to stabilize and reduce the bulk of the cotton batt before the first injector.

The traditional format off batt development is to use an airlaid machine, normally two in line, to allow for higher linear speeds, creating batts of 240-250 g/m^2. The line speeds are typically 20-25 meters per minute.

Filtration Plant

The efficiency of the Spunlace plant can be directly attributed to the efficiency of the filtration plant. The removal of solids from the water supply increases the effectiveness of the injectors, and more specifically, the injector strips. As previously stated, the injector strips have hole diameters of 120-140 micron, thus the contamination of these holes can destroy the uniformity of the water needles, and in turn the fabric.

The filtration plant for all production lines will have a minimum of filtration, which could include flotation, sand filters, and possibly band filters or automatic and/or bag filters. The exact filtration plant will depend upon a variety of factors, which are evaluated on a case by case basis.

There are two factors which determine the filtration plant, fiber and flow rates. As stated above, the fiber selection will determine the complexity of the filtration plant in regards to the number of filtration stages. The flow rates will determine the size of each stage.

A review of the different filtration processes will help to establish the technologies which are available.

The Flotation filters use an injection of air into the water, which capture the larger particles in the water and rise to the top of the holding pool to be subsequently removed. This refuse is then skimmed, with the waste being removed from the processed water, but this also means that the fresh water must be added in order to maintain the same water level within the system. The floatation filter typically has an efficiency of 80%, which means that 80% of the solids at the inlet are captured as the dissolved air which is injected lifts the solids to the surface for skimming. As the surface is skimmed, there is more water loss than with most other filtration systems, in principle, between 5-8 m^3/hr of water and sludge is removed by the flotation filter.

The Sand filters system of filtration operates in two formats, depending on the fiber types used, i.e. if cotton (depends upon whether the cotton is bleached or unbleached) or pulp is used, then the Sand filtration will require continuous filtration where air is introduced to help the process. In the event of synthetic fibers (including viscose), the Sand filter will operate much like the sand filters used in swimming pools, where a backwashing must occur on a periodic frequency.

The question of whether to use continuous sand filters versus periodic filters is dependent upon the amount of particulate matter released by the cotton fibers into the water system. Unbleached cotton fibers, which are used in some Asian plants for the fabrication of agriculture applications, is very dusty, and contaminates the water supply rather quickly. Thus even with a flotation filter prior to the sand filter, it would quickly cake the periodic sand filter due to the smaller diameter sand particles which are used in periodic sand filters. Thus the continuous sand filter would be used, as it uses larger sand particles, and operates in a continuous mode, thus accumulation which causes caking in the periodic filters cannot occur.

The use of bleached cotton dramatically reduces the dust and other natural pollutants, but it is not totally free of dust, as the bleaching process can damage some of the fibers, although in general, bleached cotton much cleaner compared to unbleached cotton.

The band filter is essentially a two-stage filter, which works much like a coffee filter. There are two holding chambers with a nonwoven fabric that covers the bottom of each chamber. The water is pumped to the top chamber, where it is filtered by gravity through the nonwoven filter media, normally a 300-g/m^2 needlepunched fabric, to the bottom chamber. Sensors regulate the water levels within the two chambers, and as the filter media becomes saturated, the flow rates diminish and water levels rise. The rise of water triggers the sensor, and initiates the forward advancement of the filter media through the chamber. The filter media is in roll form, and provides an inexpensive method to remove particulate matter from the water. There is little to no water loss with this format of filtration.

The bag filter system is similar to the concept of Band filters, where the affluent passes through a filter media (once again a nonwoven fabric), but here the media is a cut-and-sewn bag contained within a pressurized vessel. The water is forced through the contained bag, with the micron rating dependent on the specifications for the filter media.

An alternative to bag filtration is the use of Automatic–disc filter systems, where grooved plastic discs are pressurized in a vertical stack, with the water passing through the grooves in the disk(s). The groove dimensions in the disks give the micron rating of the filtration system. The system is called automatic as there is a backwashing cycle every hour (or multiple times per hour based upon either the pressure differentials or a pre-programmed time sequence, and this is where the water consumption occurs. The consumption of water is approximately 2 m^2 per hour.

It is important to have an influx of fresh water into the system, which helps to reduce the buildup of spin finish and bacteria in the water. There is a consumption of water in the system due to the differing filtration steps taken, but most hydroentanglement manufacturers inject higher fresh water quantities than required to supplement the water lost by the filtration process. The reason for this is the low cost of water and the added benefits of keeping the particle population, spin finish accumulation, and bacteria at acceptable levels. The injection of fresh water at levels of 10-15 m^3 every 3-4 hours greatly benefits the plant efficiency and reduces the consumption of the filter media.

A benefit with the high turnover rate of the water supply is the impact cleaner water has on the clean life expectancy of the injector strips. It should not be forgotten that the purpose of the Hydroentanglement line is to produce a textile fabric, and thus clean injector strips equate to fabrics without defect, which can happen if the injector holes become blocked by contaminants. This defect is very similar to the needle marks made by broken needles in needlepunched fabrics. The volume of water for an average Spunlace plant, within the closed water system is between 25-35 m^3, thus an injection of 15 m^3 every 3-4 hours means that there will not be any accumulation of contaminants which could affect the outcome of the fabric production, as the water system will be completely replenished multiple times each day. For manufacturing of fabrics where the cotton and/or pulp is introduced into the matrix, higher consumption levels, and hence, a higher fresh water replenishment rate would be foreseen.

The infusion of fresh water for man-made fiber lines is not due to the inefficiency of the filtration process, but is stimulated by the need to maintain low levels of spin finish and bacteria. The difficulty with spin finish is that its an oil based particulate, which has a very small micron rating, but tends to accumulate into clusters which are difficult to capture due to its oil based chemistry. The constant infusion of fresh water keeps the buildup of spin finish at a minimum.

De-Watering and Fabric Drying

The use of water as the medium for transmission of bonding energy means that we must dry the fabric. As we have stated previously, there is a de-watering slot for every injector. The purpose of these slots is to pull the water from the bonding zone, which helps improve the efficiency of the water needles. Another purpose is to minimize the thermal energy required to dry the fabric.

In addition to the de-watering slots at each injector, there is also a de-watering slot (or multiple slots) which is located at the end of the finishing apron, just prior to the transfer of the fabric to the next machine, normally the drier.

The vacuum at this position is very high, in the order of 4 meters water column. Although this is a high level of suction, the fabric is not affected due to the support of the conveying apron, and the fabric at this point in the line has considerable strength. Once again, the CFM of the conveying fabric comes into play, as a more open apron will allow a greater efficiency of water removal from the fabric.

The decision of what type of apron to use on the finishing table is dependent on the types of product being made. There is a trade off between the efficiency of de-watering and the need to support the fabric during final bonding by the injectors located on the finishing apron. An example of this is when short fibers or pulp are used, as an apron with a tighter weave and lower CFM rating would be required in order to reduce the loss of fiber or pulp during bonding. This lower CFM apron would not be optimal for de-watering, and thus a balance between efficiency for de-watering and support for bonding must be met. A possible solution to this is to have separate aprons for the finishing table with its injectors and an apron for de-watering. In this way, we can choose aprons whose characteristics are optimal for either requirement.

The amount of water lost by the absorption (or retainment) of water into the nonwoven is less than one cubic meter per hour per card. This value is determined by the general rule of thumb, which states that for every kilo of fabric produced, one kilo of water will need to be dried. This is not an exact rule of thumb, as viscose will absorb water whilst polyester is hydrophobic, and thus the amount of water to be evaporated will depend upon the actual fiber blends used. If we use the rule as an example where we had a polyester/viscose blend of 50/50, and produced at 200 kg/hr/m on a 3.5-meter line, we would need to evaporate 700 kg/hr. The volumetric weight of water is one kilo per liter; thus the consumption of water by the production line is less than one cubic meter.

Airlace Fabrics

The infusion of pulp (cellulosic fibers) into the fabric enables fabrics to be made, which have absorbency characteristics at a cost of production which is less than when using staple fibers such as viscose. A good example of an application where pulp or paper fused with Spunlaced technology is baby wipes or cleaning cloths.

There are two methods of injecting pulp into the spunlace fabric, either by adding a paper to the pre bonded spunlace fabric, or by adding pulp using airlaid technology. As stated above, the advantage of using pulp is in the reduction of raw material costs, as the use of fluff pulp is considerably less expensive than viscose, and the average blend ratio for pulp and fiber is 50/50. As the cost of fibers can easily approach 70-80% of the manufacturing costs in a Spunlace line, the reduction of raw materials cost for a component which is 50% of the fabric blend has an advantage. The additional cost of capital equipment is therefore offset by the reduction of operating costs, and the payback for the Airlaid technology is quickly returned.

A manufacturing line that has Airlaid machinery does not have to operate specifically in Airlaid mode, as the plant can produce non-Airlaid fabrics as well.

Line Speeds, Fabric Weights and Scrim

The operating speeds of Spunlaced plants are dependent upon the ability of the web or batt forming system feeding the Spunlace machine. The weight range of fabrics desired would dictate whether the line is made of multiple cards on a common axis, or whether crosslapping and batt drafting are incorporated into the line. The batt forming system can also be arranged where there is both in-line carding and crosslapped carding.

The production of Spunlaced fabrics is not relegated to staple fiber use, as it is possible to spunlace a spunbond fabric. The spunbond could be employed as a scrim for use with staple fibers or can be used either in pre-bonded or non pre-bonded form. The selection of injector energy will depend on the objective and form in which the spunbond is used. An example where high injector strength might be desired is when the fusion points of the spunbond need to be weakened (providing a better hand), whereas lower (relative) injector energies may be used to entangle staple fiber to the Spunbond fabric, creating a composite type of fabric.

The weight range, and the MD/CD tensile and elongation requirements will help to determine the arrangement of web and batt forming machinery. This arrangement will also help determine the line speeds, although it does not necessarily dictate the production rates (kg/hour), as this determined by the doffing speeds and web weights of the carding machine(s). For example, a line operating with a card/crosslapper/ batt drafting machine arrangement may have line speeds of 50 meters per minute as compared to in-line carding which may have speeds of 200+ meters per minute, but the kg/hour production may be similar.

The range of fabric weight produced on Spunlace lines is normally between 30 to 400 g/m^2 (~1 - 12 opsy). The fabrics will have strength proprieties which will enable usage in a wide range of finished good s applications, with the largest growth potential in areas like home furnishings and textile replacement fabrics. If there are additional requirements which are not characteristically inherent in the Spunlaced fabric, then they can be added either before or after the Through Air Dryer.

The application of resin or other chemical finishes can provide additional strength or other characteristic, such as barrier protection, which would bring added value and performance to the fabric. It is also possible to alter the fabric characteristics through the use of scrim, which can be applied prior to the entanglement zone of the Spunlace machine.

The use of cotton and other cellulosic fibers adds value to the fabrics produced, not only in marketing them as natural fibers (which can be very powerful in marketing them in infant and hygiene applications). The use of bleached cotton, which is essentially a byproduct of the spinning process (normally combed noils), is well suited for Spunlaced applications, which include the above referenced markets as well as medical uses. The use of bleached cotton does not require additional steps in the filtration process compared to synthetic fibers, and plants who use bleached cotton may also operate with other fibers either in blends or as separate production runs without difficulty.

In conclusion, the Spunlace production line has a wide range of possibilities, and has the potential to operate throughout a wide range of speeds and weights, with an effective and continuous source of bonding energy applied to the fiber matrix as the fabric passes through each injector. The bonding efficiencies are based on the pressure applied at each injector site, the injector strip types used, the efficiency of water filtration, and the apron and/or cylinder sleeve specifications. It is the knowledge of these four key points, and the application of this knowledge, which will help foster the growth of Spunlaced fabrics into the future.