MINIFIBERS, INC.

Dispersion of Synthetic Fibers in Wet-Lay Nonwovens

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ABSTRACT

Successful development and production of wet-lay nonwovens is linked closely to the knowledge, understanding, and proper use of synthetic fibers. Some factors related to the characteristic dispersion properties of synthetic fibers are presented. These include effects of the generic fiber type, fiber size, aspect ratio, fiber end-out condition, surface characteristics, and fiber yarn. Some methods of dispersion evaluation are also noted.

There is increasing demand for suppliers to provide higher quality with more technical definition to wet-lay nonwoven manufacturers and end users. The ability to produce these more demanding paper and nonwoven products with higher quality and free of defects is directly related to the degree of dispersion and uniform incorporation of the various ingredients into the furnish. When synthetic fibers are used, they must be given some additional consideration.

This paper discusses factors affecting fiber dispersion and methods for evaluating that dispersion. While nonwovens may be made by several methods, this paper looks primarily at fiber supplied to wet-lay processes. Some of these principles may apply to other processes as well.

DEFINITION OF FIBER DISPERSION

What is fiber dispersion? How do we know when we have it? Each person may have a different answer to these questions. However, when we examine a nonwoven product and find that there is a uniform distribution of the various elements and that the sheet formation is excellent, we know that we have achieved fiber dispersion.

Complete fiber dispersion is the goal. Only if you are making a decorative or artistic product would you possibly desire a lumpy or poorly formed sheet. Complete dispersion occurs when each fiber filament is separated completely from its closest neighbor filament. Each fiber must have sufficient space and volume of water or fluid medium around it to keep it suspended apart from other fibers. There will be random contact between fibers and other particles in the medium; they may touch each other or bump randomly against other particles, but that should not result in their sticking together.

While complete fiber dispersion is our goal, this is rarely achieved. Variations occur from mediums with little dispersion to those with almost complete separation.

THE DISPERSION PROCESS

The dispersion process begins with fiber or wood pulp materials that are packed tightly together. Fiber products may be baled and compressed up to more than 15 lb/ft^3. Wood pulp is pressed into sheets, which are quite dense also. These fibers must be dispersed into water by pulping and mixing processes that separate the fibers and introduce water between the fibers and the other mix components.

The resulting fiber solids density, when dispersed, could be as little as 0.5% consistency. Thus, the fiber has expanded 1000 or more times over its original volume, and this must be done in such a way that there is a uniform, free flowing, non-clumpy dispersion of the fibers with the water and other ingredients ready to be formed into the sheet.

FACTORS IMPORTANT FOR DISPERSION OF FIBER

Filament Size: Length/Denier Ratio

When dispersing a fiber filament into the dispersant medium, consider the two extremes of length and diameter: (1) a long, thin string, and (2) a short, thick string, both of which consist of a multitude of fibers.

If we attempt to disperse several of the long, thin strings, we would most likely get a clump of knots. However, the short, thick strings would tend to disperse easily and have no tendency to tangle with each other. Some mid-point between the two extremes would give us a more desirable dispersion and maintain the advantage of the fiber length in the mix.

There is a range of length/diameter ratios (aspect ratios) that work well. The optimum ratio is about 500:1. Fibers with higher ratios are more difficult to disperse, while we do not get the most benefit of the fiber with lower ratios.

Fiber stiffness (modulus) also is a factor. The higher modulus of fibers enhances the dispersibility as compared to the lower modulus.

In Table 1, the aspect ratios for polyester over a range of fiber lengths and deniers are shown. Other fibers would show a similar pattern. The ideal combinations near the 500:1 ratio indicate good starting points for getting good dispersion as well as good benefit from the fiber. The areas below 300:1 and above 700:1 are not as likely to optimize the dispersion and strength of the web. Fibers with higher modulus will work with higher aspect ratios than those with lower modulus.

1. Polyester length/diameter (aspect ratio). Length (1/8 inch to 1.0 inch), diameter (1-25 denier per filament)									
Diameter, denier	**Length, m**	**0.125 3,175**	**0.250 6,350**	**0.375 9,525**	**0.500 12,700**	**0.625 15,875**	**0.750 19,050**	**0.875 22,225**	**1.000 25,400**
1.0	10.1	314	627	941	1255	1568	1882	2196	2510
1.5	12.4	256	512	768	1025	1281	1537	1793	2049
2.0	14.3	222	444	665	887	1109	1331	1553	1775
3.0	17.5	181	362	543	724	906	1087	1268	1449
4.0	20.2	157	314	471	627	784	941	1098	1255
6.0	24.8	128	256	384	512	640	768	896	1025
9.0	30.4	105	209	314	418	523	627	732	837
12.0	35.1	91	181	272	362	453	543	634	724
25.0	50.6	63	125	188	251	314	376	439	502

Fiber Cut Quality

Fiber end-cut condition is most important to dispersion. The ideal cut is a clean, square cut. With rayon and other hot-melt type fibers, there is little or no tendency for the ends to fuse together as they are cut. However, with polyester, polypropylene, and nylon, which are hot-melt spun, friction during cutting begins to melt and fuse fiber together. This produces poor end cuts and fused ends on the fiber. Bundles of filaments may be bound together and fail to disperse. In addition, the poorly cut ends may hang on other filaments and reduce the completeness of dispersion.

Fiber Stock Effects

Synthetic fibers are spun and packaged in many yarn sizes and configurations which have a definite effect on the ultimate use and performance of the nonwoven being produced. Often, fiber produced originally for textiles or other industrial purposes is used as stock for wet-lay nonwovens. Textile fiber typically is spun into a yarn for further processing into a cloth product by weaving or knitting. These yarns may be small, with only a few filaments in each yarn. These smaller yarns, with their textile finish and often with some twist, are difficult to disperse.

Yarns spun for industrial purposes (such as tire cord) may be 1000 or 2000 total denier and have 200 or 300 filaments in each yarn. These yarns, with moderate total denier and no twist, also cut and disperse easily. Still others may be spun and formed into a large tow bundle, which may have a million total denier and thousands of filaments in the tow bundle. When cut properly, these disperse very well.

The larger yarn bundles with all filaments aligned and with no twist will cut and disperse more easily than the smaller, twisted yarns. Yarns that have been texturized or crimped are the most difficult to disperse and generally are unsatisfactory for wet-lay purposes.

Fiber Surface Characteristics

Each type of fiber has its own surface characteristics that affect dispersion. When synthetic fiber is spun, a small amount of “finish” is applied to control static charge buildup and give it lubrication to assist in winding and packaging. This is usually a combination of oils and compounds that are not necessarily compatible with water systems. To counteract this, some surfactants and dispersants are added to help the dispersion.

The fiber surface texture is different among the different fibers. Fibers such as rayon and acetate are rough and striated. This rough surface seems to allow the water to surround the fiber more easily and, along with its higher water absorption, gives excellent dispersion. The hot-melt fibers such as polyester, nylon, and the olefins disperse less easily because they are smooth and may tend to adhere to each other if they are packed tightly together.

Most synthetic fibers are spun in round cross-section. However, some are spun in shapes such as trilobal or modified cross-section fibers. Fibers having other than round cross-sections may pack together as they are being cut, becoming more difficult to disperse. The round cross-section fibers generally disperse better.

Generic Fiber Type

Generic fiber characteristics affect dispersion. The chemical and physical nature of the polymer is important in how the fibers interact with other fibers and the fluid medium. The fiber strength and stiffness determine how easily the fiber will deform, distort, and tangle with other elements in the mix. Melt point and cutting characteristics also play a significant part in fiber dispersion.

Rayon: Rayon and other cellulose based fibers are regenerated from cellulose and are much like natural wood and plant fibers. They absorb water easily, with a regain of 11 to 13%, and thus will wet out and mix into the furnish easily. The medium tenacity rayons have a tenacity of about 3 grams per denier (gpd), with an average stiffness of about 10 gpd. High tenacity rayon may be as high as 7 gpd and have a stiffness of 13 to 50 gpd. The cellulose based fibers have temperature resistance up to about 180^{o}C. Rayon does not melt and therefore is not prone to end fusing during cutting. However, intense pressure and packing may cause bundles to form, which are slow to disperse. When rayon is cut to the proper length/diameter ratio, it is one of the easiest synthetic fibers to disperse. It works well in combination with both wood pulp and other synthetic fibers.

Nylon: Nylon is a hot-melt synthetic fiber spun from a long-chain polyamide. The surface of the fiber is usually smooth and absorbs water sparingly, with a moisture regain of 3 to 6%. It usually does not need surfactants or dispersant to aid in dispersion. The regular tenacity fibers have a tenacity of 3.5 to 7 grams per denier (gpd). The high tenacity nylon may have tenacity of up to 10 gpd. The stiffness ranges from 13 to 50 gpd. The melt point of nylon is near 260^{o}C, making it sensitive to fusing during cutting. Nylon is used extensively in wet-lay products because of its strength and toughness.

Polyester: Polyester is hot-melt spun from polyethylene terephthalate polymer. The fiber is smooth and does not absorb a significant amount of water; it is therefore somewhat hydrophobic. It usually needs some surfactant or dispersant to assist in its dispersion. The regular tenacity fibers have a tenacity of 3 to 5 grams per denier (gpd) and a stiffness of 12 to 16 gpd. The high tenacity fibers have a tenacity of 7 to 9 gpd and a stiffness of up to 75 gpd. While polyester needs some help in wetting out, the higher stiffness values in the high tenacity types allow them to disperse very well. The melt point is similar to that of nylon 265^{o}C, and it also is sensitive to fusing during cutting.

Due to its availability and combination of strength and ease of dispersion, high tenacity polyester is probably the most popular synthetic fiber used in wet-lay webs.

Olefin Fiber – Polypropylene and Polyethylene: Olefin fibers are spun from long-chain polymers of propylene, ethylene, or other olefin units. These fibers are lightweight, with a density less than water, and tend to float. They are very smooth, do not absorb water, and the surface is hydrophobic. Surfactant wetting agents often are used to aid in wetting out the fiber. The tenacity of polypropylene ranges from 4 to 7 grams per denier (gpd). It has a stiffness similar to polyester of up to 60 gpd. The melt points of the olefins are considerably lower than the other synthetic fibers mentioned (130-150^{o}C). This makes them useful for binding, but it also makes them the most sensitive to fusing during cutting. Care must be taken to prevent fused ends and clumps, which adversely affect dispersion. The olefins have found a place in nonwovens for their binding properties and other properties that make them resistant to abrasion and to most chemicals.

EVALUATION OF DISPERSION

It is really not possible to evaluate in advance how a single ingredient of furnish mix will work in the overall mix. That must be done when all ingredients are put together and evaluated. However, the fiber supplier, as well as the fiber user, needs a method for evaluating and judging how the product would be expected to perform in relation to other fibers. We have developed tests that give a quick evaluation of our cutting process. The following tests are used to make these evaluations.

Dispersion in Water or Alcohol Solution

A small sample of cut fiber (about 0.25g) is mixed in water or 70% isopropyl alcohol with mild agitation. The mixing is done either by shaking in an Erlenmeyer flask or with a stirring rod in a beaker. The resulting dispersion then is evaluated based on a subjective basis. A score of 1 to 5 is assigned, with “1” being a poor dispersion, and “5” an excellent dispersion. Specific dispersion problems also are identified as they occur. Fused ends, yarn clumps, crimps, curls, or other problems can be identified. This quick test method allows immediate feedback to the operator who is monitoring the cutting operation.

Handsheet Preparation

The handsheet test has been the standard test in papermaking. While this test simulates more closely the end user condition, the preparation of the handsheet takes more time than other methods. A sample is dispersed in water and collected on the handsheet screen, producing a low basis weight, 100% fiber sheet. This is transferred to blotter paper and dried. The handsheet formation is evaluated on a subjective scale of 1 to 10. Dispersion defects such as fused ends or stock clumps also are identified.

Dispersion in Viscous Medium

This method uses a viscous medium (glycerin) to disperse the fiber. A 0.25g sample of fiber is mixed for a period of 5 minutes in 40mL of glycerin with a mechanical stirrer, and then placed into a plastic bag and spread out for evaluation. The dispersion is evaluated on a subjective scale of 1 to 10, and defects are identified. This method can be run almost as quickly as the water and alcohol methods.

SUMMARY

The evaluation of fiber for its characteristic dispersion properties is an important aspect of nonwoven production, and the production of fiber for wet-lay nonwovens. The factors to be discussed are:

- Filament size
- Fiber cut
- Fiber stock effects
- Generic fiber type

The ways to evaluation dispersion are:

- Dispersion in water or alcohol
- Handsheets
- Viscous medium

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