NUMERICAL APPROACH TO INTER-FIBER FLOW IN NON-WOVENS WITH SUPER ABSORBENT FIBERS

by

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This paper establishes a 3-D numerical model for inter-fiber flows in non-woven materials composed of super absorbent fibers. The velocity distribution of the inter-fiber flow is obtained. The effects of absorbent fibers and geometrical structure of non-woven fabrics on flow properties are analyzed.

Keywords: *super absorbent fiber, non-woven material, random distribution, inter-fiber flow, velocity field*

Introduction

Non-woven materials made of super-absorbent fibers (SAF) [1-3] with diameter of 60-80 μm blended with other normal fibers which are about 20-25 μm in diameter. It can be widely used in health caring, medical protection, dewatering and filtration, and also oil-water separation. Non-wovens have very complex porous structure. To clarify the inter-fiber flow in this complicated structural materials plays an important role in many aspects, such as optimizing the structure design of non-woven materials which includes the selection of fiber blending ratio, fiber fineness and the design of aperture, porosity rate and shapes of fiber cross-section, improving water absorption capacity of non-wovens as well as understanding the failure mechanism of structure in application.

Experimental testing and numerical simulation can be used to study internal structure of porous materials and inter-fiber flow properties. Jaganathan *et al.* [4] studied the pore size distributions of a fibrous material and the pore space connectivity by simulating the intrusion of non-wetting fluid. Nilsson and Stenstrom [5] studied the theoretical relationship of gas diffusivity and the volume fraction of the fibers in fibrous porous medium using a cell model for numerical computing. Zobela *et al.* [6] simulated the hot calendaring process and used CFD tools to compute the dimensionless permeability of the calendared fibrous media. The CFD method was also used by Wang *et al.* [7] in their study to simulate the collection efficiency and pressure drop which generally characterized the quality of fibrous filters. Nishimura and Matsuo [8] studied the moisture transmission through a fiber assembly by means of numerical simulation. Li and Luo [9] developed a mathematical model to analyze the coupled heat and moisture transport in wool fabrics.

Previous researches have demonstrated that numerical analysis is helpful to explore the characteristics of fluid flow inside porous fiber assemblies. In this paper, we take the

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non-woven materials which composed of SAF (that are thicker) and other fine fibers as the research object and set up mesh generation for a 3-D numerical model of non-woven materials. By means of the CFD software based on finite volume method and fluid control equations, flow velocity distribution in the model is numerically analyzed and the whole information of the internal flow field is obtained.

Model construction

A model of the non-woven material is established. Both the forepart and back of the model is free space. The non-woven material layer inside the model is 0.9 mm in thickness and the porosity is about 74.5%. The fiber layer contains 30% of SAF which are about 80 μm in fineness and 70% of other kind of fibers which are about 25 μm in fineness. Fiber orientation is randomly distributed, similar to real non-woven material structure.

Considering the large computer space required for mesh generation, a section of size 4.62 × 3.52 × 1.45 mm (length × width × thickness) is cut out from the model. The section is then divided into a number of tetrahedral element meshes and z direction is defined as the direction from inlet to outlet.

Numerical simulation

Suppose that the fluid flowing through the non-woven material is pure water and the flow velocity at the entrance is 2 m/s. When water flows into the model, due to the random and disorderly arrangement of fibers inside the non-woven material, the internal pore channels are tortuous and small, so the flow pattern is complex and changeable and it is difficult to establish an ideal model to simulate the internal flow. By trial calculation and comparison, we find that the application of renormalization group (RNG) k-ε model using double-precision separation algorithm results in better convergence. Therefore, we choose RNG k-ε model for numerical simulation analysis. Based on values recommended by previous studies [10, 11], parameter values are set in this experiment: $C_u = 0.0845$, $\alpha_k = \alpha_\varepsilon = 1.39$, $C_{1\varepsilon} = 1.42$, and $C_{2\varepsilon} = 1.68$. Iteration calculation is performed until velocities of three directions and values of k and ε have reached the predetermined convergence criteria ($<10^{-4}$), so as to obtain velocity.

Results and discussions

Velocity

Cut the model into eight slices on x-y planes along the z-axis (equal interval) and divide them three times along the x-axis and y-axis, respectively. Flow velocities on different planes, shown in figs. 1 and 2, can be obtained by calculating.

On the mentioned condition (fluid flow through the model is pure water and its velocity at the inlet is 2 m/s), the following results have been observed. Flow velocity inside the non-woven material varies in the range of 0 m/s ~ 3.28 m/s. On planes near the inlet, for there is no disturbance by fibers, the velocity has less change. While on planes approaching the outlet, especially when there are more fibers on them, the change of velocity intensifies. Velocities at the location close to the pore center are higher than around fiber walls. Difference of velocity between the pore center and the edge of pore (close to fiber walls) is greater where there are dense fibers and it is more obvious in sharp corners.

Figure 2 shows velocity fields at three different x-intercepts on y-z plane and different y-intercepts on x-z plane. Flow slows down rapidly in small places in front of the

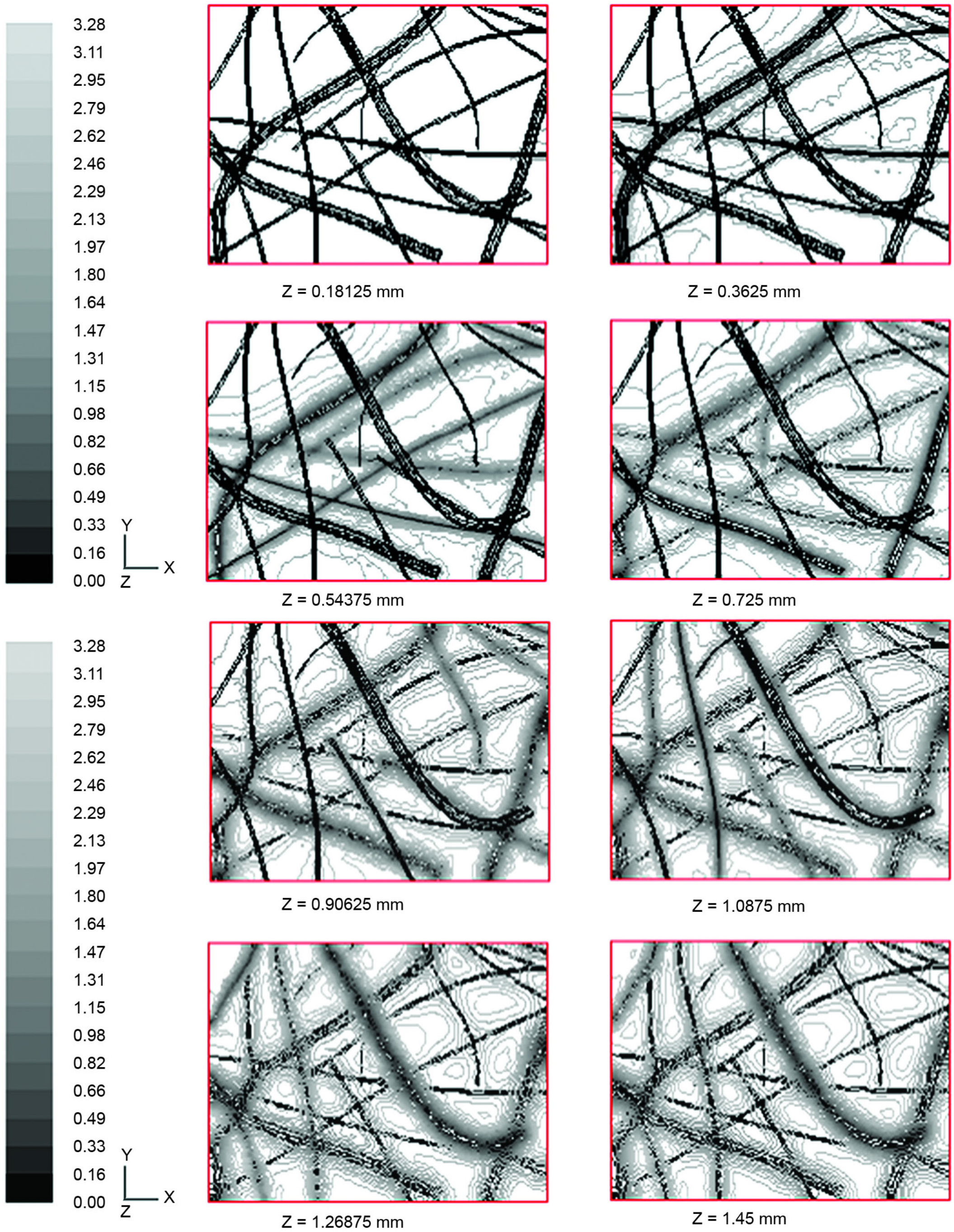

Figure 1. Distribution of flow velocity at different z-intercepts on x-y plane

upstream face of fibers. After bypassing fibers, owing to the disturbance, flow velocity becomes significantly lower than before. Thicker fibers, such as SAF, can lead to more distur-

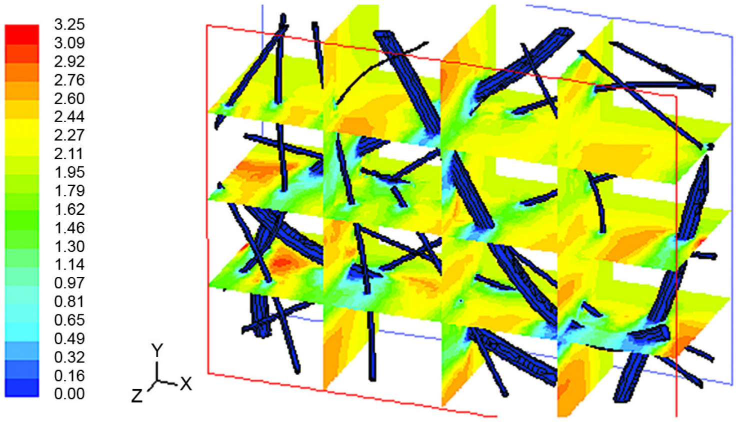

Figure 2. Slice nephogram of flow velocity at x-intercepts and y-intercepts

bing influence on water flow. Fibers close to each other may have mutual effects on flow around them. The smaller the curvature radius of fiber projection on the plane is, the greater the disturbance around its boundary becomes.

Moreover, it can be seen that there are some areas near the downstream face of super absorbent fibers where velocities are close to zero, which indicates that water flows extremely slowly here, nearly being still, or there is no water in these areas. This phenomenon will be more significant if fluid flows faster through the non-woven material. The formation of these areas may make it difficult for SAF to absorb water constantly. But there is not the same kind of areas forming around fine fibers. To our knowledge, finer fibers have higher specific surface area and larger contact areas with fluid. Therefore, improving SAF fineness may be helpful to absorb water more effectively used in non-woven materials.

Velocity direction

In this experiment, after entering the non-woven material, the pure water flow will be disturbed by fibers and the direction of flow will change. Figure 3 gives statistical distribution of the projection velocity of flow in x-, y-, and z-directions.

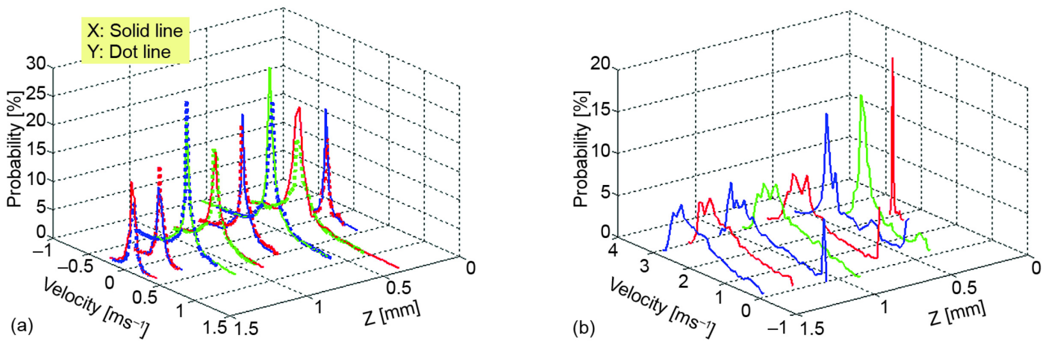

Figure 3. Distribution of flow velocity in different directions: (a) projection velocity in x- and y-direction at different z-intercepts (z = 0.18125 ~ 1.45 mm) on x-y plane, and (b) projection velocity in z-direction at different z-intercepts (z = 0.18125 ~ 1.45 mm) on x-y plane

It can be found that flow velocity projected in x- and y-direction are mainly distributed in the range of –0.75 ~ 0.75 m/s and the probability of 0 m/s is the highest. Projection velocity in z-direction mainly ranges between –0.12 and 3.28 m/s, and most of them are higher than 2 m/s. The data indicate that flow direction must has a tendency of diffusion on x-y plane after getting through pores in the material or even turning back after bypassing fibers considering the complicated structure of non-wovens. But projection velocities in other directions (not z-direction) are relatively low, suggest that water flows mainly from inlet to outlet along z-direction. Projection velocity of little reflux is lower than 0.12 m/s.

Due to the differences of the number of fibers, fiber fineness, and fiber arrangement on the different eight planes, distributions of projection velocity in the three directions are also not the same. For instance, in the plane which is at the edge of the non-woven fiber layer ($z = 0.3625$ mm), fibers lean to x-direction and there are more intersections on the left, since it's the first plane water flow contacts and fibers have effects on flowing, projection velocity on x-direction in this plane reach the maximum, about 1.5 m/s.

Conclusions

Based on numerical simulation technology, the paper investigated changes of flow velocity in non-woven materials made by super absorbent fibers with large diameter and other fine fibers under specified condition. Effects of the changes on hydroscopic property and structure of non-woven materials were also analyzed. From simulation analysis, the following conclusions were drawn.

- After entering non-woven materials, high velocity of fluid flow is likely to cause the formation of areas in which the velocity becomes close to zero on downstream faces of SAF. The formation of these areas may be unfavorable to absorbing water constantly by SAF. So, hydroscopic property of non-woven materials can be improved by using finer SAF.
- Thick fiber has greater effects on the flow disturbance than fine fibers. Fibers close to each other may have mutual effects on flow around them. The smaller the curvature radius of fiber projection on the plane is, the greater the disturbance around its boundary becomes.

Effects of the change of SAF diameter after absorbing water on fluid flow performance will be simulated in the following study. Besides, the effectiveness of the present simulation results has to be analyzed in the future work because there are difficulties in measuring the internal flow field of non-woven materials at present.

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