Role of Baffles on Flow Fields Inside Wet-Lay Mixing Tanks and Their Potential Influence on Fiber Dispersion

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ABSTRACT

Dispersion and separation of fiber bundles requires exposing them to a shear stress field to overcome interfiber frictional forces. To this end, fiber-mixing tanks are equipped with baffles to enhance shear and agitation in the water to help disperse the fiber bundles. The time and agitation required to separate and disperse the fibers depends on the fibers being used. It is well known, however, that excessive agitation will give rise to the formation of rope defects in the output because of the high-energy vortices that form behind these baffles. Optimizing the baffle geometry and position is therefore critically important in the wet-lay process. This paper presents some possible ways of eliminating the regions in the water velocity field where strong vortices may be present; in particular, the motivation for this paper is that minimizing vortex formation will lower the probability of rope formation. In this regard, we present a series of numerical simulations to model fluid-flow behavior inside wet-lay mixing tanks. A turbulent flow field is obtained by solving the Navier-Stokes equations in a two-dimensional geometry. The turbulent features of the flow are captured using the RNG k-e model. Fibers, modeled as spherical rigid particles with the same volume as the fibers, are introduced into the solution domain and their trajectories are tracked inside the mixing tank. The effects of the baffles and their orientation with respect to flow streamlines are simulated. We report the simulation results for different baffle configurations and show that aligning the baffles with the streamlines and increasing their surface area can eliminate the formation of vortices while still keeping the shear field at a satisfactory level. We hypothesize that eliminating the vortices in the mixing tank reduces the probability of rope formation, but this hypothesis needs to be verified experimentally.

The wet-lay process involves the suspension of fibers in water. A wet-laid nonwoven is formed by depositing this solution onto a forming surface and subsequently bonding the fibers to form a fabric. Most fibers are in the form of separable clumps and need to be separated into individual fibers in the mixing tank through the shear exerted on them by the flow field. To yield a uniform web and a satisfactory fabric, the fibers must be well dispersed in water. If they are not separated sufficiently, they may stay attached and appear as thick spots, referred to as log defects. Logs (or sticks) are bundles of fibers that have failed to disperse in the mixing tank; in most cases, the cut ends remain aligned. Logs usually appear in the fabric because of under-agitation during the initial dispersion. An analytical study accompanied by experimental observation by Shiffler [9] showed that the break-up rate of logs increases with increasing shear rate (speed of the stirrer). On the other hand, the interaction of vortices with individualized (dispersed) fibers may wrap them around one another and form a new twisted bundle, referred to as a rope. Ropes are fiber assemblies twisted over and around one another with unaligned ends. They form when fibers encounter a vortex that is about the size of the fiber [9]. Under such conditions, fibers are twisted into a string. Rope formation is a major concern, especially when fibers with varying degrees of stiffness are mixed. In this case, the more flexible fibers will twist and wrap around the stiffer fibers. Shiffler observed rope formation in a pilot mixing tank with a central vortex about ten times stronger than that in a nonvortex regime [10]. His study suggests that eliminating vortices from the flow field can be a key factor in minimizing roping.

In this study, we consider different baffle shapes and simulate the regions in the water velocity field where vortex formation is anticipated. Considering Shiffler's observation [9, 10], we then conjecture that one may reduce rope formation probability in a wet-lay mixing tank by minimizing vortex formation with a proper baffle