Effect of Nozzle Geometry on Hydroentangling Water Jets: Experimental Observations

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ABSTRACT

This paper reports on the role of nozzle geometry on the characteristics of hydroentangling water jets, specifically the behavior of three different conventional nozzle geometries under pressures below 3500 psi. Profiles of the water jets are digitized with a Nikon D1x digital camera from which we extract the water-jet breakup lengths and spray angles under different operating conditions. Our preliminary data indicate that the cone-up nozzle produces water jets with considerably shorter intact lengths and slightly larger spray angles and a higher coefficient of discharge compared to the two other geometries considered. We attribute this distinct behavior to friction-induced and cavitation-induced turbulence inside the cone-up nozzles; a constricted water jet is formed by cone-down or cylindrical nozzles. Our results are in excellent agreement with previous experimental and computational data.

Water jets with long breakup lengths are collimated beams of momentum. This peculiar characteristic has motivated the nonwoven industry, inspired by needle punching, to exploit high-speed water jets to develop a technique for entangling fibers in a loose web. Replacing steel needles with energetic water jets that maintain their kinetic energy downstream of the nozzle has led to the production of nonwoven fabrics at rates significantly higher than with needling. It is well known, however, that water jets break up into spray somewhere downstream of the nozzle. Once a water jet breaks up, its kinetic energy is lost and the jet disperses immediately.

The breakup mechanism of nozzle water jets has been studied extensively, both theoretically and experimentally, over the years in many fields utilizing such jets. These studies have suggested that the breakup behavior of the nozzle jet is determined by many factors. These may be summarized mainly as hydrodynamic forces (surface tension, internal, and viscous forces and initial disturbances) in the water jet, aerodynamic interaction effects, liquid turbulence at the nozzle exit, jet velocity profile rearrangement effects, flow supply pressure vibrations and cavitation, and flow separation inside the nozzle.

The cavitation phenomenon, which is currently receiving more attention, can be defined as the formation of vapor bubbles in a fluid. In the inlet region of the sharp-edged nozzles, a low local pressure region may form in the separated region between the boundary layer of the jet and the nozzle interior walls. If the local pressure is below the vapor pressure of the water, vapor bubbles will form, causing cavitation. Nozzle cavitation has been simulated and reported by Vahedi Tafreshi [16] among others [4, 13, 18]. While no single mechanism alone can be held responsible for water-jet breakup at high velocities, we believe that nozzle geometry is the most significant [1, 8, 9, 12].

In order to improve the quality and uniformity of the surface texture of hydroentangled nonwoven fabrics, it may be desirable to reduce the distance between the water jets. However, if the water jets are too close to each other, they may interfere with each other, especially at high pressures. Water jets issuing from different geometries behave differently, particularly at high pressures. The objective of this work is to visualize the water-jet profile and determine the breakup length for various nozzle geometries—a goal we did not achieve in our previous computational study [14, 15]. In this paper, we report our results for the water-jet spray angle and breakup length for three different nozzle configurations under various conditions. To accomplish this, it is necessary to develop an experimental hydroentangling test stand. Below, we discuss the components of our water-jet test stand and photographic equipment. We also present our results for the nozzle geometries and discuss them with respect to our previous computational and

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