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A study on flow through hydroentangling nozzles and their degradation

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Abstract

Hydroentangling is a technique for mechanically bonding loose filaments or fibers arranged in a web. The efficiency with which the web is entangled depends on the peculiar properties of laminar high-speed waterjets used. The characteristics of such waterjets strongly depend on the operating pressure and the nozzle inlet sharpness which influence the dynamics of fluid flow. In this study, we report on experiments and CFD simulations aimed at improving our knowledge of such two-phase flows. In particular, we simulate the formation and growth of the cavitation cloud inside a sharp-edge hydroentangling nozzle at pressures ranging from 10 to 200 bars ($5700 < Re < 25\,600$). Our experimental results run at the same pressures, confirm that nozzle cavitation will cause "hydraulic flip". Once hydraulic flip occurs, atomizing waterjets will turn into constricted laminar waterjets with long intact lengths—a necessary condition for hydroentangling. It has been observed that the nozzle inlet deteriorates under high pressures. Our CFD simulations show a striking similarity between the contours of shear stress at the nozzle inlet and the nozzle wear pattern. These findings together with the SEM elemental analysis at the nozzle inlet reveal the potential for metal oxidation around the inlet, implicating stress-induced corrosion as a major contributor to the nozzle wear. Cavitation might also be one of the mechanisms responsible for the above-mentioned wear at the inlet edge. Additionally, our water-borne solid particle tracking, confirms SEM experimental results that particle deposition can potentially play a considerable role in the deterioration of the nozzle inlet shape.

Keywords: Waterjet; Hydroentangling; Corrosion; Fluid mechanics; Hydrodynamics; Multiphase flow

1. Introduction

Nonwoven fabrics are becoming increasingly more sophisticated and continue to find new applications in many sectors including wipes, filters, automotive components, interlinings, acoustics media, geotextiles, diapers, cosmetics, and hygiene products. The nonwovens industry is the fastest growing segment of the fiber/textile complex. Nonwoven products are high-speed, low cost value added products. By definition, nonwovens are engineered assemblies of natural or man-made fibers bonded together in the form of sheets, webs, or bats (Butler, 1999).

One of the most popular methods used for bonding the fibers in a nonwoven web is hydroentangling (White, 1990; Connoly and Parent, 1993). Hydroentangling is a mechanical bonding process that uses high-speed waterjets originating from a series of cone-capillary nozzles with a typical capillary diameter of 100–130 μm (see Fig. 1). These nozzles are usually placed on a long strip of about 2.5 cm width and 1 mm thickness. Nozzles are arranged in single or double rows with a hole-to-hole spacing of about 500 μm. The jet strips run the width of the machine and can measure several meters. Loose fibers or filaments, in the form of a web supported by a moving permeable belt, are passed under a curtain of high-speed waterjets issued from nozzles of the type described above. These jets act as fine "needles" and cause the fibers or filaments to entangle and intertwine with one another thereby forming a condensed tangled web.

It has been observed that nozzle inlets deteriorate relatively quickly when operating at high pressures. Damaged nozzles are incapable of producing high-quality waterjets (collimated jets with long breakup lengths) essential for efficient entangling. The quality of nonwoven products being formed by hydroentangling strongly depends on the quality of the nozzle inlets.

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