IChemE
www.icheme.org/cherd
doi: 10.1205/cherd.05077

0263–8762/06/$30.00+0.00

Trans IChemE, Part A, March 2006
Chemical Engineering Research and Design, 84(A3): 231–238

NUMERICAL SIMULATION OF THE FORMATION OF CONSTRICTED WATERJETS IN HYDROENTANGLING NOZZLES
Effects of Nozzle Geometry

N. ANANTHARAMAIAH, H. VAHEDI TAFRESHI* and B. POURDEYHIMI

Nonwovens Cooperative Research Center, North Carolina State University, Raleigh, NC, USA
Fiber and Polymer Science Program, North Carolina State University, Raleigh, NC, USA

The role of nozzle geometry on the formation of constricted waterjets, waterjets that are detached from the wall throughout the nozzle, is considered in this paper. Such waterjets have found applications in various industries, including nonwoven processing. Due to the very small time and length scales involved in high-speed flow through micro-nozzles, experimental observation of the jet formation is cumbersome if not impossible. Computer simulation, on the other hand, can improve our understanding of the waterjet formation process under such conditions. In this paper, we report on flow simulations of water through sharp-edge cone-capillary nozzles having a diameter of 128 μm at different Reynolds numbers. Unsteady-state laminar two-phase flow is considered in axisymmetric nozzles with different capillary lengths. Our simulations show the separation of the flow from the nozzle wall as it enters the orifice. Simulations have also revealed that flow reattachment occurs in cases where the nozzle capillary length is longer than a critical length. For sharp-edge nozzles operating at high Reynolds numbers, the critical capillary length is found to be about 70% of the nozzle diameter. Nozzles with a capillary length less than the above critical length produce a constricted waterjet with no apparent cavitation during the jet formation.

Keywords: waterjet; flow simulation; reattachment length; hydroentangling; nonwovens.

INTRODUCTION

Hydroentangling

During the last decades, nonwoven products have shown tremendous growth. Nowadays, such fabrics can be found in a variety of industries. Examples of such applications are filtration media, wipes, hygiene products, acoustics, fire retardants and many others. The rapid growth of nonwoven products requires cost effective improvement of the involved technology. One of the most popular processes in nonwoven manufacturing is hydroentangling process. Hydroentanglement is a process used for bonding a web of loose fibres to form strong nonwoven fabrics. Hydroentangling is also known as waterjet-needling, spunlacing, hydraulic-entangling or fluid-jet needling (Rogers *et al.*, 1995). It is worth noting that fluid-jet needling includes the use of gaseous (e.g., air-jets) (USPTO classification, 2002; INNOTEX project, 2001a,b) or liquid stream for the entanglement process.

**Correspondence to*: Dr H. Vahedi Tafreshi, Nonwovens Cooperative Research Center, North Carolina State University, Raleigh, NC 27695-8301, USA.
E-mail: hvtafres@ncsu.edu

The underlying mechanism in hydroentanglement is subjecting the fibres to a non-uniform pressure field created by a successive bank of high-velocity waterjets. The impact of the waterjets with the fibres, while they are in contact with their neighbours, displaces and rotates them with respect to their neighbours. During these relative displacements, some of the fibres twist around the others and/or interlock with them to due to frictional forces. The final outcome of this process is a strong and uniform fabric composed of entangled fibres. These structures are highly flexible, yet are very strong and outperform their woven and knitted counterparts in performance. The process is a high-speed low-cost alternative to other methods of producing fabrics. The uniformity of the product and the repeatability of the hydroentangling process require a continuous and locally uniform jet-fabric impaction. It is important that the waterjets maintain their kinetic energy downstream of the orifice for an appreciable distance. However, waterjets are known to break up somewhere downstream of the nozzle. Once a waterjet breaks up, its kinetic energy is divided among thousands of very fine droplets. Broken waterjets have practically no utility and consequently, are not able to entangle fibres efficiently. There are a number of parameters that are known for waterjet breakup, many