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Research Paper

Experimental study of liquid nitrogen spray characteristics in atmospheric environment

Rong Xue, Yixiao Ruan, Xiufang Liu, Liang Chen, Xingqun Zhang, Yu Hou, Shuangtao Chen*

State Key Laboratory of Multiphase Flow in Power Engineering, Xi'an Jiaotong University, Xi'an 710049, PR China

HIGHLIGHTS

- Spray characteristics of the liquid nitrogen were experimentally investigated.
- Two fine fog nozzles with different outlet diameters were tested in the experiment.
- Spray characteristics obtained could benefit the nozzle selection in a cooling system.

ARTICLE INFO

Keywords:
Liquid nitrogen spray
Mass flow rate
Spray field
Spray cone angle
Droplet spatial distribution

ABSTRACT

A comprehensive understanding of the spray characteristics at the macroscopic and microscopic levels is crucial for taking advantage of a liquid nitrogen spray. In this study, an open cycle system is developed for investigating the liquid nitrogen spray characteristics of two fine fog nozzles with different outlet diameters in an atmospheric environment. The effect of the injection pressure and nozzle orifice diameter on the mass flow rate, discharge coefficient, spray field pattern, and spray cone angle are obtained, as well as the droplet spatial distribution. The correlation between these parameters could benefit the selection of spray nozzles in a cryogenic spray cooling system.

1. Introduction

Spray cooling is widely used in large spaces such as an ambient environment [1], greenhouses [2], and cooling towers [3]. The distinct physical properties of liquid nitrogen [4] make liquid nitrogen spray cooling a promising technique in aerospace engineering, the electronic industry, superconductor cooling, cryobiology, etc. One important application of liquid nitrogen spray cooling is the fast and effective cooling in a wind tunnel [5].

Understanding the characteristics of liquid nitrogen spray cooling is significant to several cryogen-based applications such as cryogenic wind tunnels and environment simulations of large spaces. The distinct thermophysical properties of liquid nitrogen could result in unique spray characteristics, particularly in comparison to water, the spray characteristics of which have been well studied. Therefore, this study is aimed at an exploration of liquid nitrogen spray characteristics, which can be used to guide relevant system designs.

In the case of the liquid nitrogen spray in a wind tunnel, the injection characteristics, including the injection pressure, ambient pressure/back pressures, and the geometry of the spray nozzle are very important parameters that affect the spray characteristics such as the mass flow rate, discharge coefficient [6], spray pattern, and spray cone angle at the macroscopic level, and the droplet distribution from a microscopic viewpoint. The effects of the injection pressure on the spray cone angle have been widely investigated in the literature [7,8]. The majority of the research has highlighted that a higher injection pressure can enhance the spray characteristics. Moreover, it has been reported that an increase in the back pressure has a negative effect on the spray characteristics [8,9]. In [10,11], the structures of various nozzles are detailed and their most important applications are summarized. It was found that the nozzle structure directly affects the spray pattern and spray characteristics.

Although extensive research has been conducted on the spray characteristics of room-temperature fluids, few studies have reported on the characteristics of a liquid nitrogen spray in large spaces. Liu et al. [11,12] performed an experimental investigation on the spray characteristics of liquid nitrogen mainly for the pressure swirl nozzle. The features of other types of nozzles in liquid nitrogen spray cooling still remain unclear. In order to gain a comprehensive understanding of the liquid nitrogen spray characteristics of nozzles having various

* Corresponding author.
E-mail address: stchen.xjtu@mail.xjtu.edu.cn (S. Chen).

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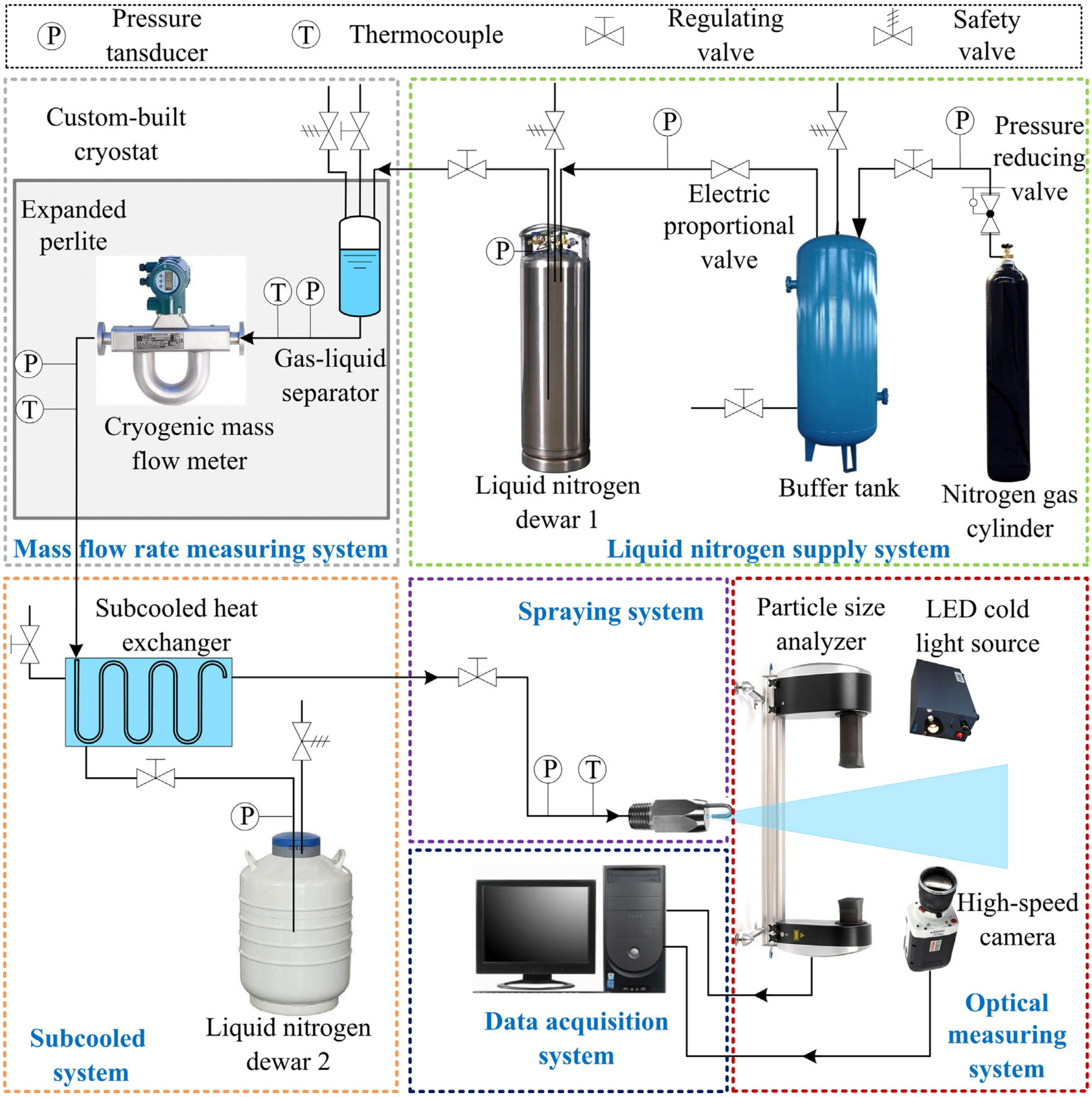

Fig. 1. Schematic of experimental system.

structures, in the present study, a spray cooling system with liquid nitrogen is built, and a series of visual measurements are performed on two fine fog nozzles over a wide range of injection pressures, and the mass flow rates, droplet spatial distributions, spray fields, and spray cone angles were obtained. The relation between the spray characteristics and pressure difference as well as the nozzle outlet diameter revealed in this study could provide theoretical and engineering guidelines for the design of a cryogenic spray cooling system.

2. Experimental setup

The schematic of a liquid nitrogen spray is shown in Fig. 1. The system is comprised of six parts according to their functions: the liquid nitrogen supply module, mass flow rate measuring module, subcooled module, spraying module, data acquisition module, and optical measuring module. The major components of the experimental system include a Coriolis mass flow meter for cryogenic applications, a high-speed camera for recording the spray field, and a Malvern Spraytec laser particle size analyzer for determining the particle diameter. The overall uncertainty of the temperature, pressure, and mass flow rate have been estimated to be ± 0.2 K, ± 0.42%, and ± 0.53%, respectively. The maximum uncertainty of the discharge coefficient is estimated to be 0.75% according to the error transfer function. The detailed introduction, procedure, and uncertainty analysis of the experimental system can be found in previous studies [11,12].

Two fine fog nozzles with a simple convergent structure obtained from BETE Fog Nozzle Inc. were tested in this study. The picture and flow channel of the nozzle are displayed in Fig. 2(a) and (b), and detailed information of the nozzle is shown in Table 1 [13]. The two nozzles have identical external dimensions while they have different outlet diameters. The needle was fixed at the outlet of each nozzle in order to enhance the spray atomization.

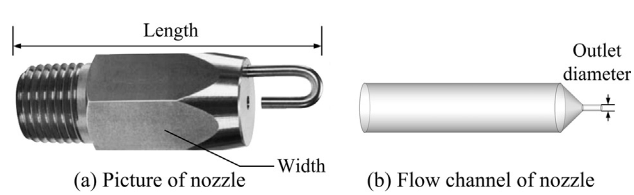

Fig. 2. Physical model of nozzle.