Particle Sizing and Flow Measurements in an Atomizing Mist Jet Nozzle: A Shadowgraphy Approach

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Abstract

Particle sizing and velocity measurements are undertaken in an atomizing water mist jet impinging onto a heated copper plate. This study forms part of an investigation into the heat transfer and flow field obtained from the mist jet. The droplet sizes obtained are compared to manufacturer's data. This analysis is performed for the near field and mid field. Ultimately, the effects of particle sizes and velocities will aid the understanding of the heat transfer mechanisms involved.

Introduction

Impinging air jets have long been known to achieve superior heat transfer coefficients, with the variation in their local heat transfer coefficients also lending itself to application in areas of large temperature gradients. Their ability to achieve effective cooling rates has led to the implementation of jet cooling in many situations including the replacement of lubricants in some machining operations. Previous work in the research group investigated their effect on grinding temperatures [1].

It is believed that the implementation of a fine water mist into the air stream has the potential to further increase the heat transfer rates. Indeed, Lee et al. [2] state that at droplet diameters of 30-80μm, a "superbly effective cooling scheme" is present. Convective heat transfer coefficients can increase by up to 10 times, through evaporation of an "ultra-thin" liquid film (50-100μm). The dispersal of water droplets into an air flow can be characterised as either spray cooling or mist jet cooling. A spray is obtained by pressurising the water in the nozzle in order to atomize it. Mist jets use the air pressure to atomize the water. Mist jets thus allow smaller droplet size [3]. The liquid flow can be controlled with less atomization constraints.

As part of this project, an investigation into the particle sizes and flow of the water droplets provides very interesting information. This paper will predominantly focus on the near field; that is the time averaged droplet distribution in comparison to nozzle manufacturer's data based on inlet air and water pressures, results will also be reported for the mid field, where the changes in droplet sizes and velocities change as the jet expands away from the nozzle and velocity profiles will be determined. At a later stage this investigation will expand to include data obtained in the far field; close to the impingement plate, which is potentially most interesting from both a flow field and heat transfer perspective.

Materials and Methods

This system contains a Quantronix Darwin-Duo Nd:YLF twin cavity laser (maximum pulse energy of 10 mJ at a repetition rate of 1000 Hz) and a Photron Fastcam SA1 (Lavision HighSpeedStar 6) CMOS camera, (1024 x 1024 pixels, 12 bit). For shadowgraphy, a technique similar to the one used by Berg et al. [4], will be utilised. Thus, pulsed laser light from the PIV system is sent through a diffuser which creates a uniform background illumination. The diffuser contains a diverging lens and a volume of water with dissolved fluorescent dye which is continuously circulating so as to prevent overheating. As the laser beam passes through the diffuser, the Rhodamine-B fluorescent particles in the water-dye solution absorb some of the 527 nm wavelength (green) laser light energy and emit light around 610 nm wavelength (red). This results in a quasi uniform yellowish background illumination. This set-up is shown in Figure 1. A 105mm lens and a series of extension tubes are fitted to the camera in order to increase the magnification factor, mimicking the performance of a long distance microscope, albeit with some loss of light intensity due to the use of a long extension tube. This results in a magnification of 6.67:1 or 2.93μm per pixel. Another method is that the lens is reverse mounted, again mimicking a long distance microscope; this tends to distort the image and has thus not been used so far. The mist jet is placed in line with the diffuser and camera. The diffused laser beam creates a uniform background illumination, whereas the water droplets cast a shadow onto the image. To resolve droplet velocity, the camera records images at each laser beam pulse, in a similar manner to 2D PIV.

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Using the LaVision Davis 7.2.2 software, the diameter of the water particles can be measured based on the shadow cast by the particle. Additionally the motion of the particles between frames can be detected, allowing particle velocities to be obtained. Both in-plane (x and y) components of the velocities as well as shape and droplet intensity (number of droplets per second) can be calculated. The shadowgraphy technique provides excellent particle imaging in the range 10μm-100μm, [4]. Visualization of particle shape and spray morphology, such as the observation of break-up regions close to the nozzle exit is possible with the shadowgraphy technique, unlike techniques such as Interferometric Mie Imaging and Phase Doppler Interferometry, [4].

Results and Discussion

The bulk of the research thus far has revolved around the near field, however both near field and mid field flow data will be presented in the paper.

Shadowgraphy tests were performed at a range of water and air flow rates and pressures. The root mean square of the diameter is chosen because the volume median and sauter diameters are affected more by the incorrect large particles detected. The trends show broadly similar trends to the manufacturer's guidelines, shown in the full paper. As the air pressure is increased, droplet diameters decrease; the bump at 21 psi is most likely an error due to the out of phase shadows being mis-interpreted by the particle sizing algorithm. Droplet diameters also increase with increasing water flow rate; water pressure was not used due to constraints in the water pressure sensor, but water pressures are believed to be within the manufacturer's range. This dependence on air and water pressures follow the general science of primary atomization [5].

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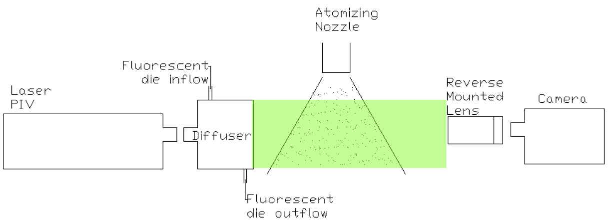

Figure 1. Shadowgraphy set up

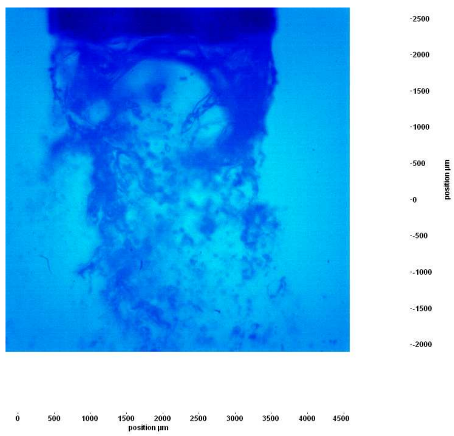

Figure 2. Typical shadowgraph at nozzle exit