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Heat and mass transfer processes between a water spray and ambient air – I. Experimental data

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Abstract

Evaporative cooling of air by water sprays is an energy efficient and environmentally benign technology that can be employed for producing a reasonably comfortable condition in arid climates. Experimental data on this process are limited and often have large uncertainties. This paper presents experimental data obtained for two ambient conditions, viz., hot-dry and hot-humid, covering dry bulb temperature (DBT) from 35 to 47 °C, and R.H. 10–60%. The studies were conducted for parallel and counter flow configurations, each with four nozzle sizes; water pressures were 1, 2 and 3 bar(g) and air velocities 1, 2 and 3 m s^{-1}. The controls on air and water conditions, and the accuracy of measurement were improved so that the uncertainties are considerably lower than in earlier studies. The data showed clear trends. For a specific water flow rate, a smaller nozzle at higher pressure produced more cooling than a larger nozzle at lower pressure.

Keywords: Water spray; Droplet; Evaporative cooling; Experiment; Parallel flow; Counter flow

1. Introduction

The use of water sprays for air cooling and humidification is an energy efficient and environment friendly technique for enhancing comfort in hot and dry climates. It is also used for fogging intake air of gas turbine power plants for enhancing performance. The underlying heat and mass transfer phenomena are not well understood and, therefore, data – experimental or simulation – are rather scarce. The antiquity of its origin, its seeming simplicity and the nature of location where it has traditionally been used seem to have discouraged scientific enquiry into evaporative cooling of air [1]. However, in the last decade, owing to the awareness of energy conservation and various environmental issues, there is renewed interest in this technology. Water sprays in air are employed in other applications as well, e.g. agriculture spray equipment design and cooling of water in water ponds.

The first efforts in producing experimental data under well-controlled conditions were by Kachhwaha et al. [2,3] where they introduced a hollow cone sheet water spray into a wind tunnel with air flowing in co- and counter flow configurations. Changes in air dry bulb temperature (DBT) and humidity between inlet and outlet planes were measured. The parametric study covered two commercial nozzles (3 and 5.5 mm diameter), three air velocities (1, 2 and 3 m s^{-1}) at three water pressures (1, 2 and 3 bar(g)). Due to several limitations of the experimental set-up, there was large variability in the data. Spray characterization, an important input to simulations was obtained by photographing the spray.

In this study, measurements of air DBT and wet bulb temperature (WBT) at the duct exit were made by manually traversing a pair of RTDs. Considering the instrument response time and the time to reach steady state, this

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Nomenclature

D	droplet diameter	$f(N)$	number distribution function
D_{30}	volume mean diameter		

technique had limitations in that it took at least 45 min to complete one set of temperature measurements by which time the inlet air condition could have changed [4]. This paper describes the experimental work by Sureshkumar [5] that overcame the shortcomings in the earlier experiments and resulted in accurate data that could serve as benchmark; these data are presented here.

2. Experimental studies

A new once-through wind tunnel facility was built for this study [6] and its important features are described below.

2.1. Wind tunnel

A schematic of the wind tunnel facility is shown in Fig. 1. It employs a centrifugal blower (capacity 1.9 $m^3 s^{-1}$ at 102 mm WC static pressure) driven by a 3.75 kW motor. Discharge air from the blower passes into a diffuser and then into the metering section that has a series of fine wire mesh to stabilize the airflow. Following the metering section, the air passes through a nozzle to the settling section and then into the test section. The former had to be incorporated because of water ingress into the tunnel in counter flow configuration. The result is a near-uniform velocity profile in the test section and this was confirmed by measurements. The design criteria and the parameters chosen are from ASHRAE handbook [7].

The test section is 585 × 585 mm in cross-section and is 1.9 m long. A drift eliminator with z-shaped plates is located at its exit after which a bank of thermocouples is placed. The transparent Perspex wind tunnel has features for inserting a water pipe with the nozzle and removable ports for access while photographing the spray.

As mentioned earlier, in previous studies the blower supplied air at ambient conditions as a result of which air temperature at inlet to the test section fluctuated due to diurnal and seasonal changes [4]. This limitation was overcome by employing electric heaters upstream of the blower inlet, Fig. 1. It consisted of three banks of heaters of different ratings that could be powered in any combination so that a pre-decided temperature rise could be obtained. At maximum blower capacity and with all heaters powered a

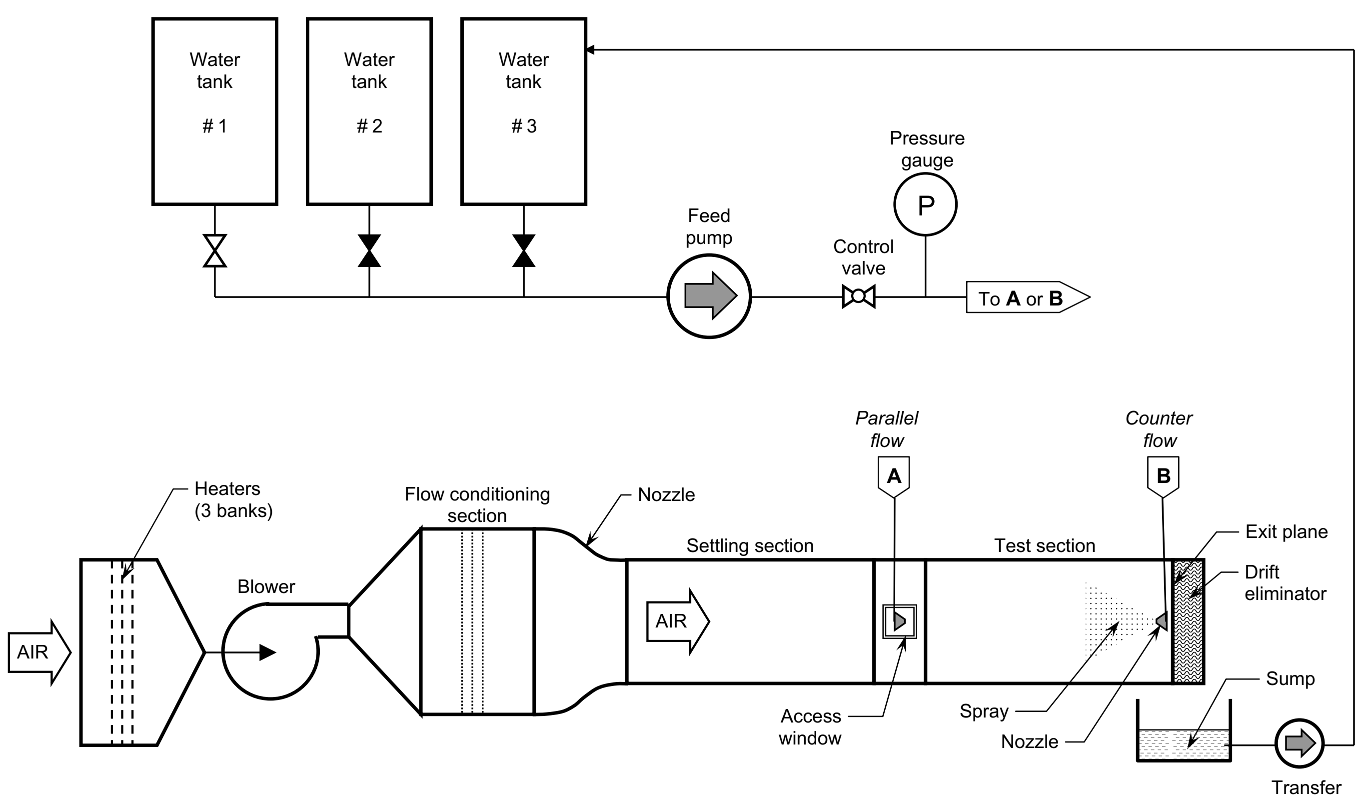

Fig. 1. Schematic of wind tunnel and water system. (Spray is shown for counter flow configuration).