Air-entrainment characteristics in a plunging water jet system using rectangular nozzles with rounded ends

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Abstract

When a water jet impinges a pool of water at rest, air bubbles may be entrained and carried some way below the pool's free surface. This process is called air-entrainment or aeration by a plunging water jet. In this study, air-entrainment characteristics such as volumetric airflow rate, air-entrainment rate, and bubble penetration depth in a plunging jet system using inclined rectangular nozzles with rounded ends were studied depending on effective jet width at impact point. An empirical correlation for an inclined rectangular nozzle with rounded ends is presented to predict the air-entrainment rate as a function of effective jet expansion ratio.

Nomenclature

a_n :   nozzle outlet height, m
b_n :   nozzle outlet width, m
b_j :   effective jet width at plunge point, m
d_n :   nozzle diameter, m
d_j :   effective jet diameter at plunge point, m
H_p :   bubble penetration depth, m
L_n :   nozzle length, m
L_j :   water jet length, m
Q_a :   volumetric airflow rate, $m^3 \cdot s^{-1}$
Q_w :   volumetric water flow rate, $m^3 \cdot s^{-1}$
Q_a/Q_w :   air-entrainment rate (-)
V_j :   water jet velocity, $m \cdot s^{-1}$
θ :   nozzle angle, degree

Introduction

A plunging water jet passing through the surrounding air entrains a large amount of air bubbles into a pool and forms a large submerged two-phase (gas-liquid) contacting area. Plunging water jets are encountered in a wide variety of industrial and environmental situations. Water jets are used to stir chemicals (e.g., jet mixer) and to increase gas-liquid transfer (e.g., oxygen transfer). Moreover, plunging water jets have applications such as aeration and flotation processes in sewage and water treatment plants (Bin, 1993).

For circular water jets, Henderson et al. (1970) defined the ratio of airflow to water flow by an empirical correlation for high velocity water jets:

$$Q_a / Q_w = (d_j / d_n)^2 - 1 \qquad (1)$$

where:

d_j and d_n are the effective or the mean local jet diameter at plunge point and circular nozzle diameter, respectively.

This equation implies that only the air within the diameter that contains the surface roughness is brought below the water surface.

Evans et al. (1996) measured the change in effective jet diameter (d_j) at plunge point as a function of free jet length for vertical circular water jets. The data were incorporated into a model to predict air-entrainment rate. McCarthy and Molloy (1972) studied the stability of liquid jets and the influence of nozzle design. In this study, effective jet width (b_j), volumetric airflow rate (Q_a), air-entrainment rate (Q_a/Q_w), and penetration depth (H_p) were studied in a plunging jet system using an inclined rectangular nozzles with rounded ends. An empirical correlation for the inclined rectangular nozzles with rounded ends are presented to predict air-entrainment rate (Q_a/Q_w) as a function of effective jet expansion ratio (b_j/b_n).

Experimental

Figures 1 and 2 show experimental apparatus and details of the nozzle used, respectively. The experimental apparatus consists of a recirculation pump and a water tank of 1.0 m long, 1.0 m deep, and 0.70 m wide, made of glass. The total water volume in these jet systems, which also includes the volume in circulation pipes, was held constant at $0.500 \ m^3$. A water rotameter was used to measure water discharge recirculated by the water pump. An inlet valve was settled to adjust water discharge. The bubbles were collected under a bubble trap. An air rotameter was installed on the bubble trap to measure the values of volumetric airflow rate.

Nozzles were made of copper. The preferred nozzle outlet geometry was a rectangular with rounded ends to prevent energy losses of rectangle corners. This nozzle outlet geometry was produced by contracting circular nozzle outlet. Nozzle contraction ratio (b_n/d_n) was selected to be 1.20. Nozzle length (L_n) used in this study was 50 mm. Cross section of nozzle inlet is circular. Nozzles with inlet diameter (d_n) of 4.7 mm and 7.5 mm were used in the experiments. The outlet height (a_n) of the nozzles was 3.5 and 5.0 mm and outlet width (b_n) of the nozzles was 5.5 mm and 9.8 mm. The free jet length (L_j) was varied as 150 mm and 200 mm. The angle between the water jet and the free water surface of the pool was selected as 45°. The maximum bubble penetration depth was determined with a scale attached to the tank wall. Moreover, effective jet width was simply measured with a millimetric scale.