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ORIGINAL ARTICLE

Study on the effect of alumina nano-fluid on sharp-edge orifice flow characteristics in both cavitations and non-cavitations turbulent flow regimes

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Abstract In the present study, the effects of alumina nano-fluid concentration on sharp-edge orifice flow characteristics in both cavitations and non-cavitations turbulent flow regimes are numerically investigated. At different concentration of AL_2O_3 nonmetallic particles (2%, 4%, 6%, 8%, and 10%) volume fractions in pure liquid water as a base fluid. A single-hole orifice pipe is with a small diameter ratio 0.297 and the orifice plate thickness 14 mm. The effects of alumina nano-fluid concentration on sharp-edge orifice flow characteristics have been investigated based on the turbulent kinetic energy, turbulent intensity, turbulent viscosity, and volume fraction of vapor. The results show that for increasing the nonmetallic particle volume fraction from 0.0 to 10%, the turbulent kinetic energy decreases by 20.87% in average downstream the orifice in the whole region, the turbulent intensity decreases by 11.11% in average downstream the orifice in the whole region, the turbulent intensity decreases by 11% in average in the whole region, and the volume fraction of vapor increases by 16.9%. Also, in the separation region downstream the orifice the turbulent kinetic energy increases by 160% in average and the turbulent intensity increases by 74% in average for increasing the nano-fluid concentration from 0.0% to 2%. These are mainly because for using the alumina nano-fluid the separation phenomena decrease due to the increase of the viscosity of the nano-fluid, the total losses in the sharp-edge orifice increase for the increase of the viscosity of the nano-fluid and this causes the increase of the rate of vaporization. In the orifice pipe the total-stress criterion predicts larger cavitating regions in the flow field. However using the nano-fluid with high concentration accelerates the cavitations at the orifice pipe.

1. Introduction

In industrial processes, cavitating flows are known to sometimes generate significant levels of noise and high vibrations

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Nomenclature

D	pipe diameter, mm
d	orifice diameter, mm
I	turbulence intensity
k	turbulence kinetic energy, m^2/s^2
ℓ	mixing length, mm
n	the number density of bubbles per volume of liquid, m^{-3}
P	pressure, Pa
P_v	vapor pressure inside the bubble, Pa
P_l	liquid pressure, Pa
r	radial distance from pipe centerline, mm
R	pipe radius = $D/2$, mm
R_{cb}	radius of cavitations bubble, mm
Re	Reynolds number
t	orifice plate thickness, mm
u	instantaneous velocity, m/s
u_{avg}	mean flow velocity, m/s
u'	root-mean-square of the velocity fluctuations, m/s
v_t	turbulent viscosity, m^2/s
x	axial distance downstream the orifice, mm

Greek symbols

β	diameter ratio
δ_{ij}	strain rate tensor
ε	rate of dissipation, m^2/s^2
μ	coefficient of dynamic viscosity, Pa s
α	volume fraction of the vapor phase
ρ	density, kg/m^3
φ_m	mass concentration of nano-particles in nano-fluids
φ_v	volume concentration of nano-particles in nano-fluids

Subscripts

avg	average
k	turbulence kinetic energy
l	liquid
l,nf	liquid nano-fluid
nf	nano-fluid
np	nano-particle
pf	pure fluid
v	vapor
v,nf	vapor nano-fluid
ε	dissipation rate

of structures. In the process a single-hole orifice is used to restrict the flow in the piping system. Fig. 1 shows a single-hole cavitating orifice in a water pipe with a small diameter ratio ($\beta = d/D = 0.297$, where d is the orifice diameter and D is the pipe diameter) is used to generate the high pressure drop and control the flow rate in water coolant for electrical power plants. The high pressure drop is also required in the bypass line of heat exchanger and pump. Cavitations bubbles form because of the high pressure drop in the orifice. The cavitations phenomenon, including bubble nucleation, growth, and collapse process, produces noise and vibration in the pipe line. Cavitations can cause damage and erosion. Addition of nano-particles to the pure fluid, the so called "nano-fluid", can improve the thermal conductivity of the mixture. The nano-fluids make larger thermal conductivity compared to the pure fluids.

In order to produce a high pressure drop and control the flow rate of the process line, lots of previous work emphasized on the design and study of throttling unit – the orifice disk. However, most of them focused on the one or more orifices in a single disk. Moraczewski and Shapley [1], Oliveeira and Pinho [2], and Borutzky et al. [3] studied the pressure drop enhancement through an axisymmetric sudden expansion after

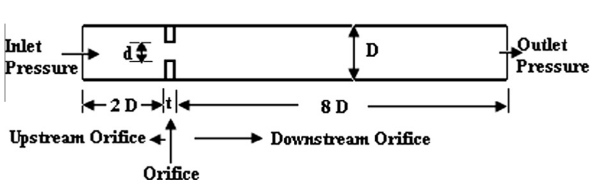

Figure 1 Description of orifice pipe.

a single orifice disk. Wu et al. [4] simulated the fluid field for different opening shape of orifice. Shah et al. [5], Kozubkova et al. [6], and Oliveira et al. [7] used CFD method to study the pressure drop characteristic. Aly et al. [8], Haimin et al. [9], and Seoud and Vassilicos [10] utilized experiment method to study the pressure drop characteristic. In addition, the vibration and noise is also a serious phenomenon that should be settled. Hassis [11], Franklin and McMillan [12], and Yan et al. [13] studied the flow induced the vibration and noise when fluid flows through the single orifice. As to the orifices, Jankowski et al. [14] developed a model to predict the pressure drop and discharge coefficient for incompressible flow through orifices with ratio of length-to-diameter greater than zero (orifice tubes) over wide ranges of Reynolds number. Kim et al. [15] Study the effect of orifice plate thickness on the discharge coefficient. Other references Payri et al. [16], Payri et al. [17], and Stanley et al. [18] studied the cavitation phenomena due to pressure drop through the orifice.

The cavitation models developed by Kubota et al. [19] and Giannadakis et al. [20] are based on the assumption of spherical cavitation bubbles and the effects of deformation of bubbles have not been considered. In this paper, effects of cavitation bubbles on the velocity field are investigated to find the mechanisms that are responsible for the increase in the disturbances in the flow. In addition, the deformation of the cavitation bubbles is re-solved which will be helpful in understanding the other contributions of the cavitation bubble to the velocity field in addition to the volume change, modeled by spherical bubbles.

Depending on the cavitation number, the flow could show no cavitation, cavitation with traveling bubbles, cavitation with a fixed vapor bubble behind the corner, or super-cavitation.