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Investigation of transient vaporous cavitation: experimental and numerical analyses

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Abstract

The current paper aims at the experimental and numerical analysis of the cavitating pipe flow during the occurrence of hydraulic transients in a quasi-horizontal straight copper pipe rig. Transient events were simulated by the quasi-instantaneous closure of a pneumatically actuated ball valve located at the downstream end of the pipe. A hydraulic transient model has been developed for describing cavitating pipe flow by means of two approaches – the discrete vapour cavity model (DVCM) and the discrete gas cavity model (DGCM). Firstly, the model has been calibrated by using transient data without cavitation. Numerical results have been compared with collected data and a good agreement has been observed as long as the unsteady friction losses are considered. Secondly, DVCM and DGCM have been used to describe cavitating flows. Results of both models have been compared, and the DGCM model has shown to better describe transient events with cavitation.

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Keywords: Cavitating flow; Fluid transients; Pipe-rig; Experimental data; Column separation.

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1. Introduction

The literature describes two main types of transient cavitation occurrence in fluid systems: *gaseous cavitation* (two-component two-phase flow) and *vaporous cavitation* (single-component two-phase flow). In the former the pressure drops below the saturation pressure but keeps above the liquid vapour pressure. The flow is characterized by the presence of micro-bubbles of free gas distributed along the pipeline and, thus, the wave speed is pressure-dependent. Gas cavities increase their volume due to the pressure drop and dissolved gas is released. The added compressibility of the gas reduces the mixture celerity and gives rise to significant pressure wave dispersion [1-8]. Experimental investigations have shown that the energy dissipation is higher in gas-liquid mixtures than in pure liquid flow. In the vaporous cavitation, the local fluid pressure falls to its vapour pressure and a sudden growth of air cavities containing vapour occurs. This is the basis of column separation regimes in which the liquid flow is completely separated by its vapour phase when the cavity is formed [9-18]. Bergant et al. [19] distinguishes two types of vaporous cavitation in pipelines: local column separation (large void fraction – the ratio of the volume of the vapour to the total volume of the liquid/vapour mixture) and distributed vaporous cavitation (small void fraction), which occurs over an extended length of the pipe. Actually, a combination of both phenomena is produced during low pressure transients in existing systems [5]. The response may involve column separation and subsequent re-joining, vaporization and condensation, air release, dispersion of wave fronts and shock waves. As shown by Adamkowski and Lewandowski [16] the phenomenon can have a distributed nature, which means that gas-vapour zones may be spread along the pipeline length.

The current paper focuses on the analysis of transient cavitating flow in pressurized pipes. A hydraulic transient solver that incorporates the description of dynamic effects related to unsteady friction losses and the cavitating pipe flow has been developed. The discrete vapour cavity model (DVCM) and the discrete gas cavity model (DGCM) have been used to describe transient cavitating flow. Such models assume that discrete air cavities are formed at fixed sections of the pipeline and consider a constant wave speed in pipe reaches between these cavities. An extensive experimental programme has been carried out in an experimental set-up composed of a straight copper pipeline. Numerical results obtained for the cavitating flow for both cavity models have been compared with collected data and a very agreement has been obtained, being the DGCM the one that describes more accurately physical measurements. The contribution of unsteady friction losses on pressure dampening has also been analysed.

2. Mathematical models

2.1. Elastic model

One-dimensional transient flows in elastic pipes are described by the following momentum and continuity equations [20-22]:

$$\frac{\partial H}{\partial x}+\frac{1}{gA}\frac{\partial Q}{\partial t}+h_f=0 \tag{1}$$

$$\frac{\partial H}{\partial t}+\frac{a^2}{gA}\frac{\partial Q}{\partial x}=0 \tag{2}$$

where x = coordinate along the pipe axis; t = time, H = piezometric-head; Q = discharge; A = pipe cross-sectional area; a = celerity (or elastic wave speed); g = gravity acceleration; and h_f = head loss per unit length.

In order to take into account unsteady friction effects, the friction losses, h_f, have been separated into two components:

$$h_f=h_{fs}+h_{fu}=\frac{fQ|Q|}{2gDA^2}+h_{fu} \tag{3}$$