Analytical and numerical modelling of trapped air pockets in hydraulic pipeline systems

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Abstract. During operation of water-filled pipelines, air can get trapped in the primary water flow in the form of air trapped pockets or moving bubbles. Consequently, entrained air may change the liquid-filled-pipeline system's transient response significantly. It could have either a beneficial or a detrimental effect on pressure oscillations. The effect is dependent on the spatial dimensions and other physical properties of the pipeline system, an amount, a location of the air pocket(s) and the nature of the transient excitation. This paper overviews two different approaches to modelling the filling of a hydraulic pipeline system with an entrapped air pocket. In the first instance, the water column is rigid and in the second instance elastic. One-dimensional analytical and numerical transient solutions of the two phase-flow are presented. An analytical solution is acquired by solving rigid water column differential equations, whereas a numerical is obtained for a rigid plug elastic column approach based on the method of characteristics (MOC). The trapped air pocket is treated as a boundary condition and is described by an ideal gas equation. Results of analytical and numerical models are compared and discussed.

1. Introduction

In this paper, behaviour of air pockets in hydraulic pipeline systems will be explored. When air pockets are trapped in pipelines, they can be subjected to compression or expansion by moving water slugs. The elastic nature of the air pockets enables them to act as pressure storage elements. Bulk modulus of air is significantly lower than that of water. Therefore, the pockets represent pressure build-up spots or pressure lowering spots in a pipeline. The relief of stored pressure in the pockets is achieved with their expansion, compression, or release from the system. Many incidents of this dangerous phenomenon have been documented. Especially in sewage pipeline systems, where a fast pocket release caused geysering through sewer ventilation shafts [1]. Apart from sewage systems, rapid pipe filling and emptying is also a feature in the systems of auto-ignition, steam condensation, fire-fighting pipelines, pipeline cleaning, crude oil pipelines, among others [2].

2. Hydraulic pipeline system

Our focus will lie on a closed hydraulic pipeline system consisting of a reservoir, horizontal pipeline, valve, and an air pocket. The system represents an expanding control volume of water in a pipeline, as in figure 1 (control volume marked as C.V.).