Closure to "Computational fluid dynamics for sub-atmospheric pressure analysis in pipe drainage" by Mohsen Besharat, Óscar E. Coronado-Hernández, Vicente S. Fuertes-Miquel, Maria Teresa Viseu, and Helena Margarida Ramos

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The authors would like to thank A. Rokhzadi and M. Fuamba for considering the publication on numerical simulation of pipe drainage. As it has been mentioned in the discussion, transient events can be modelled using various models. The original paper belongs to a set of researches conducted to examine the ability of different simulation methods where amongst available models, a rigid water column model (RWCM) as a one-dimensional (1D) model and CFD were examined. It has always been interesting discussions about the pros and cons of 1D models when compared to CFD models. There is no doubt that 1D models are able to provide results for some significant parameters with less computational cost than CFD models. However, as highlighted in the discussion as well, they fail to predict specific occurrences that are the sources for consecutive situations and help to understand the whole phenomenon much better. Particularly, the effect of backflow air intrusion was analyzed in the original paper that defines the pressure oscillation inside the air pocket

The PMSV model presented in the discussion predicted the pressure variation for two cases quite well. Nevertheless, since discussers did not have the exact discharge coefficient and the valve resistance coefficient for valve manoeuvre, few deviations exist. The deviations could be reduced considerably if discussers had the resistance coefficient of the valve for different percentages of valve opening from the manufacturer, so they could find the resistance coefficient more accurately. Previous studies (Besharat 2020; Fuertes-Miquel et al., 2019a) show that the correct simulation of the valve parameters has a profound effect on the accuracy of the results and also on the behaviour of air pocket pressure pulses during the occurrence of an emptying process.

Following the points mentioned in the above lines, this closure presents a summary of different mathematical models that can be used to predict the process of sub-atmospheric pressure pulses in pressurized pipe drainage.

The CFD model applied by the authors in the original paper solves the mass conservation and the momentum equations for no-slip conditions. The realizable k-ε model was used for turbulence simulation that has advantages over the standard k-ε model for the studied case in the original paper. The explicit volume of fluid (VOF) multiphase model was used for the discretization with the realizable k-ε turbulence model while using the enhanced wall treatment feature for near-wall calculations and supposing an ideal gas condition for the air phase. The CFD model could appropriately predict the behaviour of main hydraulic and thermodynamic variables in a single pipeline as presented in Fig. 1 along with other methods.

The discussers applied the modified Saint-Venant formulations to the water column and the polytropic equation to the air pocket located at the highest part of the water installation assuming a vertical air-water interface. The discussers solved the partial differential equations using the method of characteristics (MOC) with the mentioned boundary and initial conditions. The mathematical model presented by the discussers is classified as an elastic water column model (EWCM) since considers the elasticity of the air and water phase, and the volumetric changes of the pipe during hydraulic transient events.

The authors present in this closure the RWCM as another alternative mathematical technique for analysing the drainage process. In addition, the polytropic law of an air pocket and the vertical air-water interface are also considered by the authors. The RWCM model only considers the effect of air elasticity since is much greater compared to the water and pipe elasticity (Fuertes-Miquel et al. 2019b). The RWCM can be applied to compute the air pocket pressure pulses during a draining process as discussed by Fuertes-Miquel et al. (2019a). The RWCM was applied to the experiments presented in the original paper obtaining a friction factor of 0.018 (Fuertes-Miquel et al. 2019a; Coronado-Hernández et al. 2018).

$$\frac{dv}{dt} = \frac{p_1^* - p_{atm}^*}{\rho_w L} + g\frac{\Delta z}{L} - f\frac{v|v|}{2D} - \frac{R_v g A^2 v|v|}{L} \tag{1}$$

For the benefit of the reader, a comparison of the three discussed methods with the experimental data has been presented in Figure 1. The results from 1D models of PMSV and RWCM is quite satisfactory for the pressure data presented in Figure 1. However, this fact that 1D models are not able to predict significant aspects like the backflow air intrusion analysed in the original paper must not be ignored, particularly, for two-phase flow conditions.

The authors thank the discussers for presenting the PMSV model based on an EWCM that can be used to predict the behaviour of variables during a draining process in water pipelines.

Notation

v = water velocity (m/s)

t= time (s)

p_1^* = air pocket pressure (Pa)

p_{atm}^* = atmospheric pressure (Pa)

ρ_w = water density (kg/m^3)

Δz= difference elevation (m)

L = water column length (m)

f = factor friction (-)

D = internal pipe diameter (m)

g = gravity acceleration (m/s^2)

A= cross-sectional area (m^2)

R_v= Resistance coefficient of a drain valve (s^2/m^5)

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test 1 (τ = 12%, x_o = 0.205 m) test 6 (τ = 6%, x_o = 0.450 m)

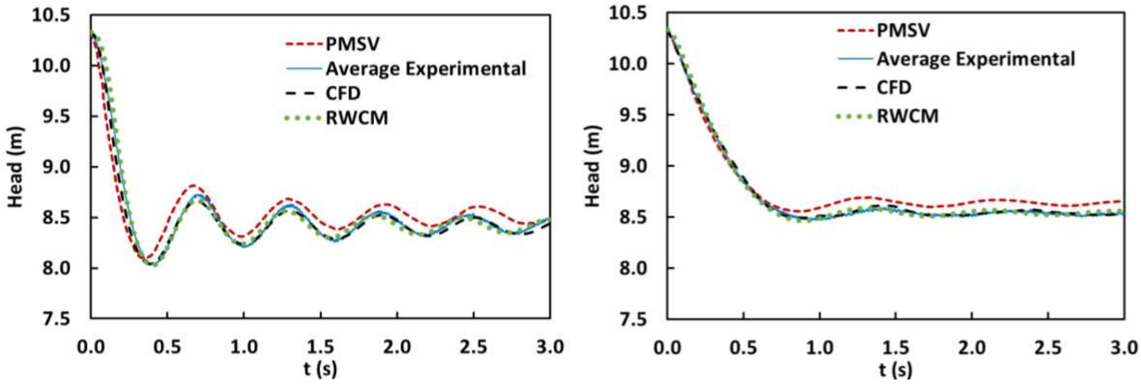

Figure 1 Summary of the pressure variation within the air pocket predicted by the CFD model from the original paper, PMSV method from the discussion and RWCM presented in the closure.