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Three-Dimensional Simulation of Transient Flows during the Emptying of Pipes with Entrapped Air
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Abstract
Two-and three-dimensional analyses of transient flows considering the air-water interaction have been a challenge for researchers due to the complexity in the numerical resolution of the multiphase during emptying in pressurized water pipelines. The air-water dynamic interaction of emptying processes can be analyzed using thermodynamic and hydraulic laws. There is a lack in the current literature regarding the analysis of those phenomena using 3D models. In this research, several simulations were performed to study the complex details of two-phase flows. A 3D model was proposed to represent the emptying process in a single pipeline, considering a PVoF model and two-equation turbulence model. The model was numerically validated through 12 experimental tests and mesh sensitivity analysis. The pressure pulses of the air pockets were evaluated and compared with the experimental results and existing mathematical models, showing how the 3D models are useful for capturing more detailed information, such as pressure and velocity patterns of discrete air pockets, distribution of air and water velocity contours, and the exploration of temperature changes for an air pocket expansion. © 2023 American Society of Civil Engineers.

Index Keywords
3D modeling, Air, Sensitivity analysis, Turbulence models, Two phase flow, Water distribution systems, Water pipelines; 3D models, 3d-modeling, Air pockets, Computational fluid dynamic, Emptying process, Entrapped airs, Pressure pulse, Three dimensional modelling, Three dimensional simulations, Transient flow; Computational fluid dynamics; air-water interaction, computational fluid dynamics, hydraulics, pipeline, sensitivity analysis, thermodynamics, three-dimensional modeling, transient flow, turbulence

References

- Aguirre-Mendoza, A.M., Oyuela, S., Espinoza-Román, H.G., Coronado-Hernández, O.E., Fuertes-Miquel, V.S., Paternina-Verona, D.A.
  2D CFD modeling of rapid water filling with air valves using OpenFOAM
  (2021) *Water*, 13 (21), p. 3104.
- Aguirre-Mendoza, A.M., Paternina-Verona, D.A., Oyuela, S., Coronado-Hernández, O.E., Besharat, M., Fuertes-Miquel, V.S., Iglesias-Rey, P.L., Ramos, H.M.
  Effects of orifice sizes for uncontrolled filling processes in water pipelines
  (2022) *Water*, 14 (6), p. 888.

- (2016) *Air Release, Air/Vacuum Valves and Combination Air Valves (M51)*, AWWA (American Water Works Association). Denver: AWWA.
- Baines, W.D.
  Air cavities as gravity currents on slope
  (1991) *J. Hydraul. Eng.*, 117 (12), pp. 1600-1615.
- (2021) *Bentley OpenFlows HAMMER CONNECT Edition Help*, Bentley. Exton, PA: Bentley.
- Besharat, M., Coronado-Hernández, O.E., Fuertes-Miquel, V.S., Viseu, M.T., Ramos, H.M.
  Backflow air and pressure analysis in emptying a pipeline containing an entrapped air pocket
  (2018) *Urban Water J.*, 15 (8), pp. 769-779.
- Besharat, M., Coronado-Hernández, O.E., Fuertes-Miquel, V.S., Viseu, M.T., Ramos, H.M.
  Computational fluid dynamics for sub-Atmospheric pressure analysis in pipe drainage
  (2019) *J. Hydraul. Res.*, 58 (4), pp. 553-565.
- Bombardelli, F.A., Hirt, C., García, M.H., Matthews, B., Fletcher, C., Partridge, A., Vasquez, S.
  Computations of curved free surface water flow on spiral concentrators
  (2001) *J. Hydraul. Eng.*, 127 (7), pp. 629-631.
- Chosie, C.D., Hatcher, T.M., Vasconcelos, J.G.
  Experimental and numerical investigation on the motion of discrete air pockets in pressurized water flows
  (2014) *J. Hydraul. Eng.*, 140 (8).
  04014038.
- Coronado-Hernández, O.E., Fuertes-Miquel, V.S., Besharat, M., Ramos, H.M.
  Experimental and numerical analysis of a water emptying pipeline using different air valves
  (2017) *Water*, 9 (2), pp. 92-98.
- Coronado-Hernández, O.E., Fuertes-Miquel, V.S., Besharat, M., Ramos, H.M.
  Subatmospheric pressure in a water draining pipeline with an air pocket
  (2018) *Urban Water J.*, 15 (4), pp. 346-352.
  a. " "
- Coronado-Hernández, O.E., Fuertes-Miquel, V.S., Iglesias Rey, P.L., Martínez-Solano, F.J.
  Rigid water column model for simulating the emptying process in a pipeline using pressurized air
  (2018) *J. Hydraul. Eng.*, 144 (4).
  b. " " 06018004.

- Coronado-Hernández, Ó.E.
  (2019) *Transient Phenomena during the Emptying Process of Water in Pressurized Pipelines*,
  Ph.D.Thesis, Departamento de Ingeniería Hidráulica y Medio Ambiente, Universitat Politècnica de València.

- Fang, H., Zhou, L., Cao, Y., Cai, F., Liu, D.
  3D CFD simulations of air-water interaction in T-junction pipes of urban stormwater drainage system
  (2022) *Urban Water J.*, 19 (1), pp. 74-86.

- Fuertes, V.
  (2001) *Hydraulic Transients with Entrapped Air Pockets*,
  Ph.D.Thesis, Dept. of Hydraulic Engineering, Polytechnic Univ. of Valencia.

- Fuertes-Miquel, V.S., Coronado-Hernández, O.E., Iglesias-Rey, P.L., Mora-Meliá, D.
  Transient phenomena during the emptying process of a single pipe with water-Air interaction
  (2019) *J. Hydraul. Res.*, 57 (3), pp. 318-326.
  a. " "

- Fuertes-Miquel, V.S., Coronado-Hernández, O.E., Mora-Meliá, D., Iglesias-Rey, P.L.
  Hydraulic modeling during filling and emptying processes in pressurized pipelines: A literature review
  (2019) *Urban Water J.*, 16 (4), pp. 299-311.
  b. " "

- Fuertes-Miquel, V.S., López-Jiménez, P.A., Martínez-Solano, F.J., López-Patiño, G.
  Numerical modelling of pipelines with air pockets and air valves
  (2016) *Can. J. Civ. Eng.*, 43 (12), pp. 1052-1061.

- Greenshields, C., Weller, H.
  (2022) *Notes on Computational Fluid Dynamics: General Principles*,
  Reading, UK: Computational Fluid Dynamics Direct.

- Hirt, C.W., Nichols, B.D.
  Volume of fluid (VOF) method for the dynamics of free boundaries
  (1981) *J. Comput. Phys.*, 39 (1), pp. 201-225.

- Hurtado-Misal, A.D., Hernández-Sanjuan, D., Coronado-Hernández, O.E., Espinoza-Román, H., Fuertes-Miquel, V.S.
  Analysis of sub-Atmospheric pressures during emptying of an irregular pipeline without an air valve using a 2D CFD model
  (2021) *Water*, 13 (18), p. 2526.

- Issa, R.I.
  Solution of the implicitly discretised fluid flow equations by operator-splitting
  (1986) *J. Comput. Phys.*, 62 (1), pp. 40-65.

- (2018) *Allievi Users Manual*,
  ITA (Instituto Tecnológico del Agua). Valencia, Spain: Polytechnic Univ. of Valencia.

- Jasak, H., Weller, H.
  (1995) *Interface Tracking Capabilities of the Inter-gamma Differencing Scheme*, London: Imperial College of Science, Technology and Medicine.

- Laanearu, J., Annus, I., Koppel, T., Bergant, A., Vučković, S., Hou, Q., Tijsseling, A.S., Van'T Westende, J.M.
  Emptying of large-scale pipeline by pressurized air
  (2012) *J. Hydraul. Eng.*, 138 (12), pp. 1090-1100.

- Laanearu, J., Hou, Q., Annus, I., Tijsseling, A.S.
  (2015) *Water-column Mass Losses during the Emptying of A Large-scale Pipeline by Pressurized Air*, p. 8.
  In Proc. Estonian Academy of Sciences, Tallinn, Estonia: Estonian Academy.

- Launder, B.E., Spalding, D.B.
  (1983) *Numerical Prediction of Flow, Heat Transfer, Turbulence and Combustion*, pp. 96-116.
  The numerical computation of turbulent flows." In, Amsterdam, Netherlands: Elsevier.

- Liou, C.P., Hunt, W.A.
  Filling of pipelines with undulating elevation profiles
  (1996) *J. Hydraul. Eng.*, 122 (10), pp. 534-539.

- Martin, C.S.
  (1976) *Entrapped Air in Pipelines*,
  In Proc. 2nd Int. Conf. on Pressure Surges. Bedford, UK: British Hydromechanics Research Association Fluid Engineering.

- Martins, N.M., Delgado, J.N., Ramos, H.M., Covas, D.I.
  Maximum transient pressures in a rapidly filling pipeline with entrapped air using a CFD model
  (2017) *J. Hydraul. Res.*, 55 (4), pp. 506-519.

- Menter, F.R.
  Two-equation eddy-viscosity turbulence models for engineering applications
  (1994) *AIAA J.*, 32 (8), pp. 1598-1605.

- Menter, F.R.
  Review of the shear-stress transport turbulence model experience from an industrial perspective
  (2009) *Int. J. Comput. Fluid Dyn.*, 23 (4), pp. 305-316.
- Menter, F.R., Esch, T.
  (2001) *Elements of Industrial Heat Transfer Predictions*,
  In Proc. 16th Brazilian Congress of Mechanical Engineering (COBEM). Rio de Janeiro, Brazil: Brazilian Society of Mechanical Sciences.
- Muralha, A., Melo, J.F., Ramos, H.M.
  Assessment of CFD solvers and turbulent models for water free jets in spillways
  (2020) *Fluids*, 5 (3), p. 104.
- Paternina-Verona, D.A., Coronado-Hernández, O.E., Fuertes-Miquel, V.S.
  Numerical modelling for analysing drainage in irregular profile pipes using OpenFOAM
  (2022) *Urban Water J.*, 19 (6), pp. 569-578.
- Pozos, O., Gonzalez, C.A., Giesecke, J., Marx, W., Rodal, E.A.
  Air entrapped in gravity pipeline systems
  (2010) *J. Hydraul. Res.*, 48 (3), pp. 338-347.
- Romero, G., Fuertes-Miquel, V.S., Coronado-Hernández, Ó.E., Ponz-Carcelén, R., Biel-Sanchis, F.
  Analysis of hydraulic transients during pipeline filling processes with air valves in large-scale installations
  (2020) *Urban Water J.*, 17 (6), pp. 568-575.
- Tijsseling, A.S., Hou, Q., Bozkuş, Z., Laanearu, J.
  Improved one-dimensional models for rapid emptying and filling of pipelines
  (2016) *J. Pressure Vessel Technol.*, 138 (3), p. 15.
- Vasconcelos, J.G., Chosie, C.D., Leite, G.M.
  (2012) *Investigation of Air Pockets Compression and Motion in Stormwater Storage Tunnels*, pp. 1458-1468.
  In Proc. World Environmental and Water Resources Congress 2012: Crossing Boundaries, Reston, VA: ASCE.
- Vasconcelos, J.G., Wright, S.J.
  Experimental investigation of surges in a stormwater storage tunnel
  (2005) *J. Hydraul. Eng.*, 131 (10), pp. 853-861.
- Vasconcelos, J.G., Wright, S.J.
  Investigation of rapid filling of poorly ventilated stormwater storage tunnels
  (2009) *J. Hydraul. Res.*, 47 (5), pp. 547-558.

- Wang, H., Zhai, Z.J.
  Analyzing grid independency and numerical viscosity of computational fluid dynamics for indoor environment applications
  (2012) *Build. Environ.*, 52 (6), pp. 107-118.

- Wilcox, D.C.
  Reassessment of the scale-determining equation for advanced turbulence models
  (1988) *AIAA J.*, 26 (11), pp. 1299-1310.

- Wu, G., Duan, X., Zhu, J., Li, X., Tang, X., Gao, H.
  Investigations of hydraulic transient flows in pressurized pipeline based on 1D traditional and 3D weakly compressible models
  (2021) *J. Hydroinf.*, 23 (2), pp. 231-248.

- Zhou, L., Liu, D.-Y., Ou, C.-Q.
  Simulation of flow transients in a water filling pipe containing entrapped air pocket with VOF model
  (2011) *Eng. Appl. Comput. Fluid Mech.*, 5 (1), pp. 127-140.

- Zhou, L., Wang, H., Karney, B., Liu, D., Wang, P., Guo, S.
  Dynamic behavior of entrapped air pocket in a water filling pipeline
  (2018) *J. Hydraul. Eng.*, 144 (8).
  04018045.

- Zukoski, E.
  Influence of viscosity, surface tension, and inclination angle on motion of long bubbles in closed tubes
  (1966) *J. Fluid Mech.*, 25 (4), pp. 821-837.

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