Closure to "Rigid Water Column Model for Simulating the Emptying Process in a Pipeline Using Pressurized Air" by Oscar E. Coronado-Hernández, Vicente S. Fuertes-Miquel, Pedro L. Iglesias-Rey, and Francisco J. Martínez-Solano

Oscar E. Coronado-Hernández

Associate Professor, Facultad de Ingeniería, Universidad Tecnológica de Bolívar, Cartagena 131001, Colombia (corresponding author). Email: ocoronado@utb.edu.co

Vicente S. Fuertes-Miquel

Associate Professor, Departamento de Ingeniería Hidráulica y Medio Ambiente, Universitat Politècnica de València, Camino de Vera S/N CP, Valencia 46022, Spain. Email: vfuertes@upv.es

Pedro L. Iglesias-Rey, Aff.M.ASCE

Associate Professor, Departamento de Ingeniería Hidráulica y Medio Ambiente, Universitat Politècnica de València, Camino de Vera S/N CP, Valencia 46022, Spain. Email: piglesia@upv.es

Francisco J. Martínez-Solano

Associate Professor, Departamento de Ingeniería Hidráulica y Medio Ambiente, Universitat Politècnica de València, Camino de Vera S/N CP, Valencia 46022, Spain. Email: jmsolano@upv.es

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This closure addresses how the mathematical model developed by the authors is appropriate to simulate emptying processes using pressurized air in pipelines of undulating profiles since it is based on physical equations. The writers thank the discussers for providing information regarding experimental data in the published paper of Laanearu et al. (2012) and for the comments in their discussion.

The mathematical model developed by the authors considers three assumptions. These assumptions are (1) a rigid water column model (RWCM) can be used to represent the water behavior, (2) the air–water interface is perpendicular to the pipe direction, and (3) there is a constant friction factor. The discussers agree with Assumptions 1 and 3; however, they disagree with Assumption 2 about the definition of the shape of the air–water interface.

The authors assume a piston-flow model to represent the air–water interface considering that the air tank is capable of pressurizing the pipe installation with initial gauge pressures ranging from 10 to 20 m_{H20}. Laanearu et al. (2012) reported initial values of the air–water front (x_i). The initial length of the water column (L_{e0}) was calculated by the authors from the air–water position (with a reference point at $x = 0$ m) to the location of the discharge valve ($x = 271.6$ m) [Fig. 2 and Table 3 of Laanearu et al. (2012)]. In this sense, the initial length of the water column corresponds to the region of pressurized flow of the pipe installation. The part of water corresponding to the free-surface flow was neglected during simulations. The total length of the pipeline (L_T) is 314.1 m (Tijsseling et al. 2016). Initial water columns vary from 91% to 93% regarding the total length of the pipeline installation for all runs. These percentages show that the piston-flow model can be used to represent the behavior of the air–water interface. The remaining percentage of the total length is occupied as either a free-surface flow or pressurized air.

The mathematical model presented in the original paper is based on physical equations; therefore, undulating profiles of pipelines can be modeled (Coronado-Hernández et al. 2017; Fuertes-Miquel et al. 2019). The discussers mentioned that the authors did not consider the pipe bridge and the upstream vertical leg to simulate the emptying process. Then, the gravity term ($\Delta z/L_e$) was modified in order to consider these pipe branches (Coronado-Hernández et al. 2018a, b). Fig. 1 shows six possible positions of the air–water interface. Positions 5 and 6 were considered in the original paper. Table 1 presents the corresponding values of the gravity term. Results of the mathematical model neglecting the pipe bridge were compared to the scenario considering it. Fig. 2 shows the comparison of the water flow oscillation pattern and gauge pressure pattern for Run 4. The pipe bridge does not affect the behavior of the water movement. A small discrepancy of the gauge pressure pattern was found between 4 and 6 s, which was generated by the pipe bridge. Results considering or neglecting the pipe bridge are similar since a small part of the initial value of the water column (L_{e0}) is inside of the pipe bridge. Also, the discussers determined a friction factor (f) of 0.0136 during measurements, and the authors considered a value of 0.0117 in the original paper. Mean square error (MSE) values of 5.18% and 6.22% were obtained when using friction factors of 0.0117 and 0.0136, respectively. Both values give similar results. This situation was reported in the discussion, where the discussers found that a fiction factor of 0.0117 was more adequate to simulate the emptying process than a value of 0.0136.

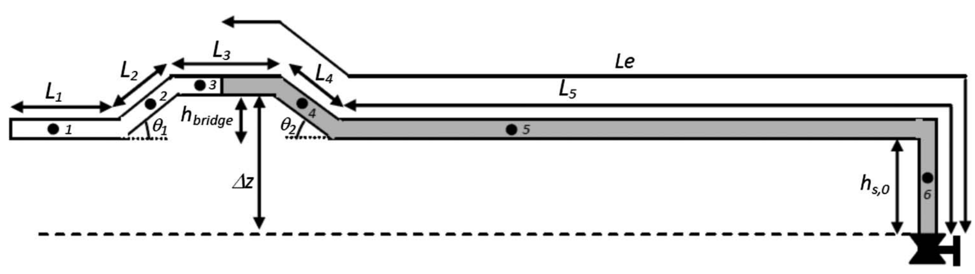

Fig. 1. Pipeline installation with a bridge pipe.

Table 1. Variation of the gravity term considering the pipe bridge

Position	From	To	$\Delta z/L_e$
1	$L_e \geq L_1 + L_2 + L_3 + L_4 + L_5$	$L_e < L_2 + L_3 + L_4 + L_5$	$h_{s,0}/L_e$
2	$L_e \geq L_2 + L_3 + L_4 + L_5$	$L_e < L_3 + L_4 + L_5$	$\frac{h_{s,0} + \sin\theta_1[(L_2 + L_3 + L_4 + L_5) - L_e]}{L_e}$
3	$L_e \geq L_3 + L_4 + L_5$	$L_e < L_4 + L_5$	$\frac{h_{\text{bridge}} + h_{s,0}}{L_e}$
4	$L_e \geq L_4 + L_5$	$L_e < L_5$	$\frac{(Le - L_5)\sin\theta_2 + h_{s,0}}{L_e}$
5	$L_e < L_5$	$L_e > h_{s,0}$	$h_{s,0}/L_e$
6	$L_e \leq h_{s,0}$	$L_e > 0$	1

Note: h_{bridge} represents the height of the pipe bridge with a value of 1.3 m (Laanearu et al. 2012); and L_i is the length of a pipe branch.

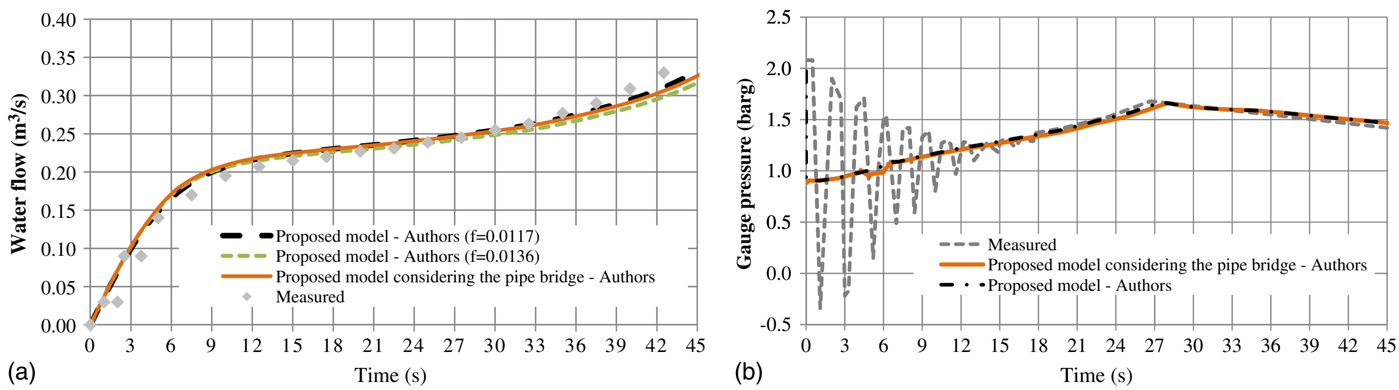

Fig. 2. Comparison of the mathematical model developed by the authors considering and neglecting the pipe bridge.

For all simulations, minor loss coefficients $k(\theta)$ were obtained by Laanearu et al. (2012). Then, the authors considered the reported values to simulate the emptying process.

In all runs, the mathematical model is capable of following the behavior of water flow (Fig. 4 of the original paper). The discussers commented that the mathematical model is not acceptable because differences of 0.5 m/s or more were found between computed and measured water velocities in some runs. Laanearu et al. (2012) contains only information regarding gauge pressure pattern for Run 4. In this sense, when the air–water front passed Section 1, the mathematical model predicted a water velocity of 4.17 m/s, which is similar to the experiment (a value of 4.20 m/s). An error about the estimation of a water velocity lower than 1% was found. Therefore, Figs. 5(a and b) (points closest to Section 1) of the original paper show a good agreement between measured and computed gauge pressure patterns. But, when the air–water front passed Section 9, a water velocity of 8.84 m/s was predicted by the mathematical model. The measured value was 8.14 m/s. Figs. 5(c and d) (points closest to Section 9) of the original paper show a greater discrepancy in the gauge pressure pattern compared to Figs. 5(a and b), which is expected considering a greater discrepancy in the estimation of water velocities. The remaining gauge pressure patterns could not be compared since Laanearu et al. (2012) does not contain the information.

Also, the mathematical model only considers a uniform velocity of the water column; therefore, it does not consider the free-surface flow, as mentioned by the discussers. This assumption was necessary in order to apply a piston-flow model. The mathematical model developed by the authors is robust; as a consequence, small variations of parameters produce small variations on hydraulic variables (water velocity oscillations and gauge pressure pattern). Physical equations to represent water profiles in the free-surface flow region need to be included in future works to simulate the emptying process.

The mathematical model developed by the authors is a good tool to simulate the emptying process with pressurized air because it is based on physical equations as presented in this closure.

Notation

The following symbols are used in this paper:

f = pipe wall friction coefficient;
h_{bridge} = height of the pipe bridge (m);
$h_{s,0}$ = height of the vertical pipe (m);
$k(\theta)$ = minor loss coefficient;
L_e = length of the emptying column (m);
L_{e0} = initial length of the emptying column (m);
L_i = length of a pipe branch (m);
L_T = pipe length (m);
x = axial coordinate (m); and
θ = pipe slope (rad).

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