Discussion of "Numerical Modeling of Mixed Flows in Storm Water Systems: Critical Review of Literature" by S. Bousso, M.Daynou, and M. Fuamba

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The discussed paper states that the rigid column model is applied for a single air pocket and the nature of the used equations makes it difficult to be employed in case of several air pockets. The discussers do not agree with this assertion.

In fact, other authors also use the rigid model approach. Liou and Hunt (1996) proposed a rigid column model of flow start-up in empty pipelines with undulating elevation profiles assuming a vertical interface between the air and water phases. They proposed a velocity-based criterion to justify the application of the rigid-column approach. Zhou et al. (2002) presented an experimental and numerical investigation on the description of the rapid filling of an empty horizontal pipe with limited ventilation. The numerical model was constructed using a lumped inertia approach and assumed a vertical interface separating the advancing waterfront and the air that initially filled the pipe.

The discussers have developed a general model for the simultaneous analysis of entrapped air pockets within a pipeline with irregular profile (Fig. 1). Previous papers have paid attention to this problem from both theoretical (Fuertes et al. 1998; Izquierdo et al. 1999; Fuertes 2001) and experimental (Fuertes et al. 2000; Fuertes 2001) approaches. Moreover, and in order to identify the most significant parameters of the phenomenon under study, a dimensionless analysis of the problem was carried out (Fuertes et al. 1999). This rigid-column model is different from others because it is valid for many entrapped air pockets and moving boundaries of the liquid columns are considered.

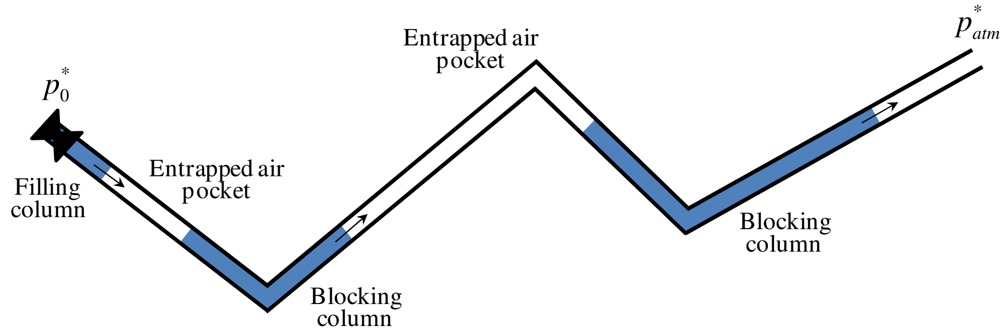

Fig. 1. Pipe with many entrapped air pockets

The main assumptions of the model are: water movement is analyzed with the rigid model approach; and air-water interfaces are well-defined cross sections. Under these hypotheses, the problem is modeled by (Fuertes et al. 1998):

1.- Mass oscillation equation for filling column (rigid column approach)

$$\frac{dv}{dt} = \frac{p_0^* - p_1^*}{\rho L} - g \frac{\Delta z}{L} - \frac{f \, v|v|}{2D} \tag{1}$$

being v = blocking column velocity, t = time, p_0^* = upstream pipe pressure, p_1^* = entrapped air pocket pressure, ρ = water density, L = blocking column length, g = gravity acceleration, Δz = piezometric head between the ends of the blocking, f = Darcy-Weisbach friction factor and D = pipe diameter, (* means absolute pressure).

2.- Interface position of the filling column

$$L = L_0 + \int_0^t v\, dt \qquad \left(\frac{dL}{dt} = v \right) \tag{2}$$

3.- Mass oscillation equation for each water blocking column *i* (*i* = 1, 2, ..., *n*)

$$\frac{dv_i}{dt} = \frac{p_i^* - p_{i+1}^*}{\rho\, L_{b,i}} - g\,\frac{\Delta z_{b,i}}{L_{b,i}} - \frac{f\, v_i\, |v_i|}{2\,D} \tag{3}$$

where v_i = velocity of the blocking column *i*, p_i^* = entrapped air pocket pressure *i*, $L_{b,i}$ = water blocking column length *i* and $\Delta z_{b,i}$ = geometric head between the ends of the blocking liquid. For the last blocking column (*i* = *n*), $p_{n+1}^* = p_{atm}^*$ applies.

4.- Behavior equation for each entrapped air pocket *i* (*i* = 1, 2, ..., *n*)

$$p_i^* \cdot \left(x_i - x_{i-1} - L_{b,i-1}\right)^k = p_{i,0}^* \cdot \left(x_{i,0} - x_{i-1,0} - L_{b,i-1}\right)^k = const. \tag{4}$$

being x_i = co-ordinate, refereed to the pipe origin, of the upstream blocking column *i*; and *k* = polytropic exponent. For the first entrapped air pocket (*i* = 1), $x_0 = 0$ and $L_{b,0} = L$.

5.- Position of each water blocking column *i* (*i* = 1, 2, ..., *n*)

$$x_i = x_{i,0} + \int_0^t v_i \, dt \qquad \left(\frac{dx_i}{dt} = v_i \right) \tag{5}$$

In summary, we have a set of 2+3n equations. By solving it, with the corresponding boundary and initial conditions, the five unknowns v, L, v_i, p_i^*, x_i (i = 1, 2, ..., n) can be determined.

The rigid column approach was selected because it provides good estimates for the maximum and minimum pressures involving air compression. The good estimates are explained by the dominant effect of air pockets in determining the unsteady flow pressures with respect to other problem features, such as the pipe wall elasticity and water compressibility.

This mathematical model has been validated by measurements in an experimental setup similar to a rising main, with a pipe (diameter 18.8 mm and length 6.9 m) of irregular profile and a centrifugal pump that acts as the energy source that raises water from the suction tank up to the upstream tank (Fuertes et al. 2000).

Table 1. Comparison between measured values and model results

Position		p^* (kPa)	t (s)
Tr5	Measured	194.38	0.174
	Calculated	191.73	0.171
Tr4	Measured	199.84	0.449
	Calculated	203.91	0.432
Tr3	Measured	172.56	0.311
	Calculated	176.02	0.319

Laboratory results show a very good agreement with theoretical results (Table 1) until the filling column reaches the highest point of the pipe. From that point, and due to the failure of the basic hypothesis, a well-defined air-water cross section interface, the discrepancies are relevant. Careful analysis of the results showed in that instant the filling water column reaching the highest pipe point, being the pressure at this point, at that time, below the atmospheric standard value. In those conditions it is clear that the hypothesis of a cross section air-water interface, valid until that moment, does not apply any longer. The water going down contains a high amount of dissolved air. Failing one of the basic hypotheses of the model, that affects the evolution of the entrapped air pockets, and being all the equations coupled in the model, there is, since then, a clear loss of agreement. This is not a surprising fact dealing with entrapped air modeling.

Thus, the mathematical model developed by the discussers aims to analyze the behavior of different entrapped air pockets in pipes of irregular profile, and has been validated through practical measurements.

In any case, the discussers would like to congratulate the authors for their important contribution to clarify and improve the understanding of mixed flows in pipeline systems.

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