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CALCULATING AIR PRESSURIZATION IN DRINKING WATER SYSTEMS UNDERGONG FILLING

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ABSTRACT

Drinking water networks (DWN) across the world undergo priming following repair procedures or when these are commissioned. In this process, water that is admitted through a valve will displace air, which will be ventilated at locations that have contact with the atmosphere. As it escapes, air phase pressurizes within distribution networks, creating a very complex two-phase flow regime as water main reaches are pressurized. There is no available methodology to provide an estimate of how much air phase pressurizes in the earlier stages of DWN priming, consisting thus in a clear knowledge gap. We propose a simple methodology applying the widely used EPANET tool to compute the velocity and air phase pressurization through modifications to the emitter coefficient used in that model. This approach is demonstrated through a sample network in which a steady water inflow is admitted as air escapes through multiple hydrants, with EPANET computing air flow velocity and pressure. Future work aims to add the ability to consider air pressurization in other system-wide water modeling tools.

Keywords: Water Distribution System; Air Pressurization; EPANET.

1. Introduction and Objectives

Filling or priming Drinking Water Networks (DWN) is crucial for their operation, especially after repairs, a necessity that is becoming more frequent due to aging infrastructure across the globe. When water re-enters the system, it displaces air, which escapes through ventilation points. The rate of water inflow and the available ventilation can cause the air to pressurize, affecting system dynamics and complicating hydraulic models. In addition to priming operations, air-water interactions are also noticed in Intermittent Water Supply (IWS) systems, which undergo periodic filling and emptying. These systems, prevalent globally, often face challenges like air pocket formation at high points in the network. These air pockets can interact with water flows, leading to pressure surges that compromise pipe integrity, cause uneven water distribution, and degrade water quality.

Rapid filling of water pipes have been studied in the context of unsteady flows for many decades. Pioneer research from Martin (1976) investigated rapid filling and air compression, liking the advance of a pressurized water front against an air pocket to a spring-mass problem. Hamam and McCorquodale (1982) and Li and McCorquodale (1999) studied air pocket entrapment driven by shear flow instabilities, linking them to water hammer events. Other related contributions linked to this type of flows include Zhou et al. (2002), Vasconcelos and Leite (2011), among others.

Stormwater systems, while designed to operate by gravity, also experience rapid filling conditions and occasional pressurization. Various contributions have explored the mechanisms of flow regime transition and air pocket entrapment, such as Vasconcelos and Wright (2006) and Chosie et al. (2014). Because stormwater systems may experience free surface and pressurized flow conditions simultaneously in different locations, numerical models such as EPA SWMM (Rossman 2017) have the ability of computing flows considering mixed flow conditions. However, most tools do not consider the dynamics of air-water compression, limiting its applicability of representing rapid filling conditions in poorly ventilated systems (Trindade and Vasconcelos 2013).

Researchers have been using stormwater modeling tools and methodologies, such as SWMM, to represent the process of DWN undergoing priming or operating intermittently. Vasconcelos et al. (2022) highlighted the potential of EPA-SWMM by applying the model to represent the cycle of an intermittent dendritic network in Guatemala. Gullotta and Campisano (2024) and Abdelazeem and Meyer (2023) also applied the EPA-SWMM model to simulate the full cycle of intermittent networks, while collecting field observations on filling, distribution, and emptying. Sarisen et al. (2024) developed an improved EPA-SWMM model for IWS networks, incorporating a genetic algorithm to calibrate minor losses and roughness coefficients. Yet, SWMM has no ability to incorporate air pressure in its calculations. Ferreira et al. (2022, 2023) recently improved the Storm Water Management Model (SWMM) to simulate air pressure variations during rapid pipe filling, but these studies did not consider air ventilation.

Another challenge is the complexity of DWN, with multiple branches, loops, and the time-varying nature of inflows during rapid filling, as pointed by Liou and Hunt (1996). Geller et al. (2025) presented an investigation in which water filling occurred in a scale model of a distribution network, and proposed a modification of the widely-used EPANET model to compute time-varying air phase pressures through a sequence of snapshot simulations. This work also proposed a modification of EPANET emitters to enable the representation of air valves. While an important initial step, the methodology was not tested with other, larger geometries that would be expected in real DWN. This work aims to demonstrate the application of EPANET in such conditions, considering the initial stages of the filling when most of the conduits are empty. The overall goal is to determine how EPANET predictions of pressure and air phase velocity are affected by water inflows and availability of ventilation.

2. Methodology

EPANET (Rossman et al. 2020) is a widely used hydraulic model to represent flows in DWN through the solution of mass balance at junctions and the energy equation at pipe reaches, assuming steady flow conditions. Unsteady flows are not explicitly modeled, though time-varying conditions can be represented through the solution of a series of steady state scenarios. In order to adapt EPANET to compute the distribution of air phase pressures during priming, the first step is to redefine how emitters, which are a node property in EPANET to represent flow through a nozzle or orifice to the atmosphere, are supposed to operate. Typically, model users calibrate an emitter coefficient to represent such flows:

$$C_{e,w} = Q \,/\sqrt{H_w} \; = C_d A_o \sqrt{2g} \qquad (1)$$

where $C_{e,w}$ [$L^{2.5}/T$] is the emitter discharge coefficient for water, C_d is the orifice discharge coefficient, A_o is the orifice area, g is the gravity acceleration and H_w is the head, expressed in units of meters of water column at the emitter node. If the emitter exponent is assumed as 0.5, it essentially behaves like a typical orifice:

$$Q_{air} = C_d A_o \sqrt{2\frac{p}{\rho_a}} \qquad (2)$$

where p is the fluid's pressure, and ρ_a is the specific mass of air. EPANET allows for the selection of an arbitrary specific gravity and relative viscosity for the fluid being studied. Yet, for the computation of flows through emitters, EPANET expresses the pressure head in units of meters of water column. Thus, if the air discharge behaves similarly to an orifice, the model can relate air discharge to water pressure head through the adjustment presented in equation 4, which represents the air escaping through a node due to the pressure in the location by calibrating the emitter coefficient at the node, as follows:

$$Q_{air} = C_d A_o \sqrt{2\frac{g\rho_w H_w}{\rho_a}} = C_{e,w}\sqrt{\frac{\rho_w}{\rho_a}}\sqrt{H_w} = C_{e,a}\sqrt{H_w} \qquad (3)$$

In addition, to perform these calculations using EPANET, the model needs to be set to pressure-driven analysis (PDA) instead of the demand-driven analysis that is default in EPANET. Figure 1 presents a typical flowchart of using EPANET for the computation of air flows in DWN.

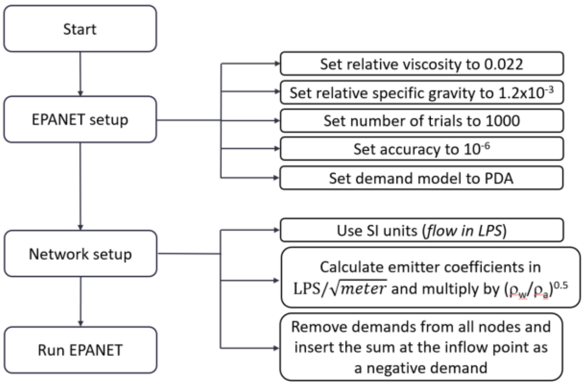

Fig. 1. Steps to apply EPANET to compute air flows in DWN during priming events.

3. Results

An example of the application of the methodology is presented in Figure 2, based on the NET1 input file that is installed with EPANET. Varying water inflows were admitted in the system at the location where the pump is placed, and these were represented through a fixed value of a negative demand (i.e., steady injection of water). Further, it is assumed that air is incompressible, so the water inflow will be balanced by air outflow rates. Figure 2a indicate the locations where 115-mm hydrants (with a 5% opening area) are placed. No other ventilation is available. The resulting emitter coefficient for each of these junctions is computed as:

$$C_{e,a} = C_d A_o \sqrt{2g\frac{\rho_w}{\rho_a}} = 0.60 \cdot \left(0.05 \cdot \frac{\pi}{4} 0.115^2 m^2\right) \sqrt{2 \cdot \frac{9.807m}{s^2} \cdot \frac{999}{1.2}} 1000(LPS/CMS) = 39.8[\frac{LPS}{\sqrt{m}}]$$

A priming inflow rate of 111 L/s is considered here and admitted through node 10. The simulation is intended to represent only the initial stages of the priming process, prior to water reach the first junction (n11). This is necessary given that at this point it is possible that complex air-water features, such as pocket formation and multiple pressurization interfaces. As expected, the flow velocity distribution is not trivial and was affected by the water main diameters. Interestingly, given the low viscosity of air, head losses for the air phase due to friction were small and by consequence the variation of pressure heads (expressed in m H_2O) did not exceed 0.06 m. Thus, at least for the early stages of priming following the establishment of air flows, it is reasonable to assume uniformity of air phase pressure escaping through various ventilation points.

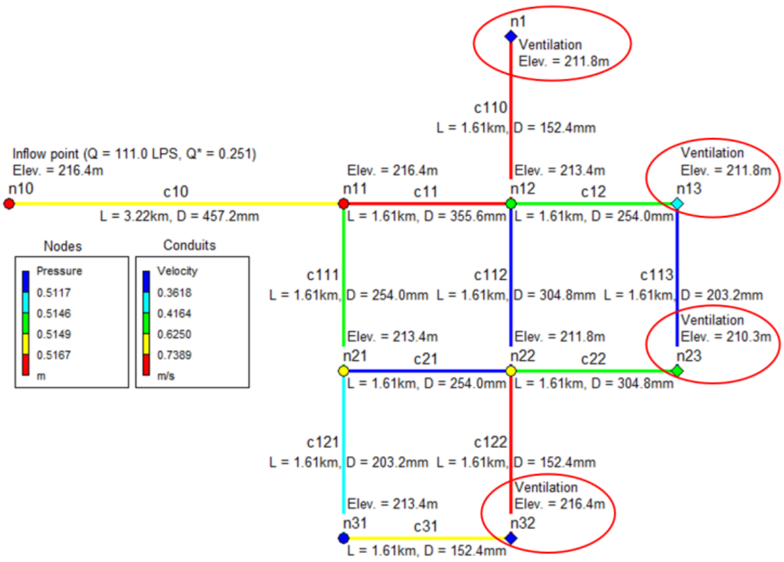

Fig. 2. Computed values for air flow velocity and pressure using EPANET with modified emitters for a priming rate of 111 L/s.

Alternatively, air phase pressures can be much higher if a larger priming inflow is used (221 L/s) and a much smaller available ventilation is considered. Figure 3 presents such a scenario, when only node n23 is open to the atmosphere (with a 12.5% opening), indicating pressures 10x larger than the results shown in Figure 2. While it is unlikely that such pressures would create structural impacts to the conduits, it is possible that air release would be characterized by strong noise.

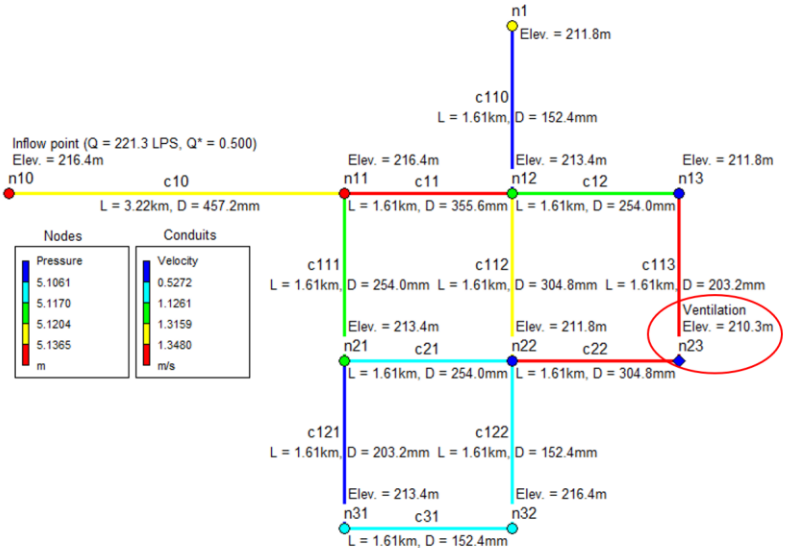

Fig. 3. Computed values for air flow velocity and pressure using EPANET with modified emitters for a priming rate of 221 L/s and a single ventilation point.

4. Final Remarks

This work demonstrated a new application of EPANET to provide estimates of air phase pressurization during early stages of priming. This is possibly one of the most complicated two-phase flow conditions in urban water systems, and this work is viewed as an initial step toward a better understanding of such operations. The formation of air pockets, air-water surging, multiple pressurization interfaces, and the variation of water inflows are all complicating factors expected to occur in real applications, but still not addressed by current research. The transients anticipated as the air pocket collapses at ventilations are also not yet considered, though these may be very intense and potentially damaging. More research is ongoing on this topic.

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