A new slow transient pressure-dependent model to simulate background leakages and inertia in water distribution networks

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***Topic*: Pressure management**

A new slow transient pressure-dependent model to simulate background leakages and inertia in water distribution networks

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Abstract. We present here a new slow-transient model including pressure-dependent background leakages. This model permits to take inertia effects into account while keeping time execution acceptable. New mathematical formulations and numerical implementations were developed to make the model both stable and accurate.
Keywords: RWC (rigid water column) model, PDM (pressure-dependent model), background leakage model

Introduction

The huge amount of non-revenue water represents each year a not only financial but also ecological and societal problem. Among these water losses, background leakages are difficult to locate and can remain undetected for a long time. Thus, it is of primary interest to estimate numerically the outflows due to background leakages in water distribution networks (WDNs) with the best possible accuracy.

Several rigid water column (RWC) models have already been developed in the last decades. Jaumouillé et al. (2007) derived a slow-transient formulation from Navier-Stokes equations, considering constant background leakages at the pipes scale. While permitting the modelling of inertial phenomena, this formulation is not pressure-dependent. Then, Brémond et al. (2009) developed a RWC model which incorporates pressure-dependent leakage, by introducing partial differential equations. However, their formulation is too cumbersome to simulate large networks. More recently, Nault J. D. & Karney B. W. (2016) developed a slow-transient model where the ordinary differential equations (ODEs) are discretized. This approach permits taking into account the inertial phenomena but doesn't deal with background leakages.

In this paper, we present the first results of a new slow-transient pressure-dependent model (PDM) which includes both background leakages and inertias.

Materials and methods

In this work, the equations defined by Jaumouillé et al. (2007) for demand-driven models (DDMs) and constant background leakages, are used. These equations are derived in order to make both the consumptions at junctions and the leakage flows along pipes to depend on the pressure at nodes. For pressure-dependent background leakages, the formulation of Giustolisi et al. (2008), are used. Then, this new model is described by a stiff differential-algebraic system of equations (DAEs).

To ease the resolution of our system, we first reduced the DAEs to ODEs. This reduction leaded to the use of an inverse pressure outflow relationship (POR), as in Deuerlein et al. (2019). Penalizations were required to prevent the consumptions and the pressure heads at junctions from taking non-physical values. Finally, we solved the system with an implicit multi-step variable-order (1 to 5) solver dedicated to stiff systems.

The model is implemented in Python and integrated in the novel object-oriented modelling framework for Water Distribution Systems developed by Steffelbauer & Fuchs-Hanusch (2015).

Preliminary results

We present here the simulation of two simple networks, to illustrate both the modelling of pressure-dependent background leakages and the capacity of the model to deal with tanks inertia.

The first network (Figure 1) is the one used by Jaumouillé et al. (2007), excepting for the head at the reservoir that we lowered to 100 m so that the system may vary from partial to normal service pressure during the simulation. This network includes demands at junctions and background leakages in pipes. Figure 2 shows the evolution of the demands and the outflows at junction J2 for 48 hours. It can clearly be observed that the model is stable and behaves realistically.

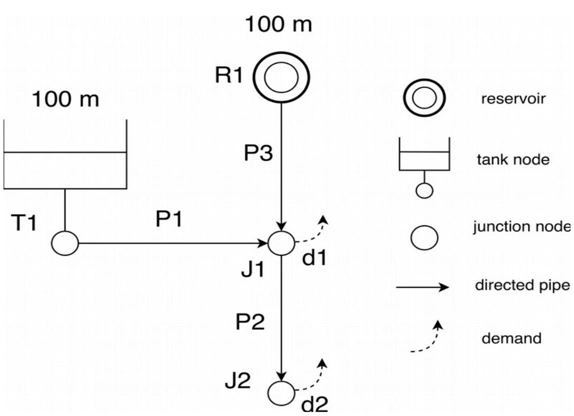

Figure 1. Simple network with background leakage (Jaumouillé et al., 2007).

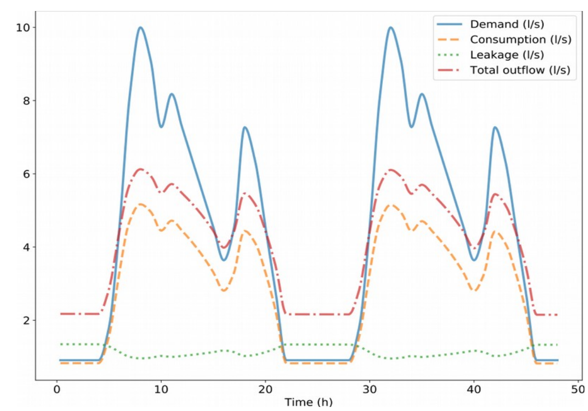

Figure 2. Demands and outflows at node J2 computed with our new PDM slow-transient model.

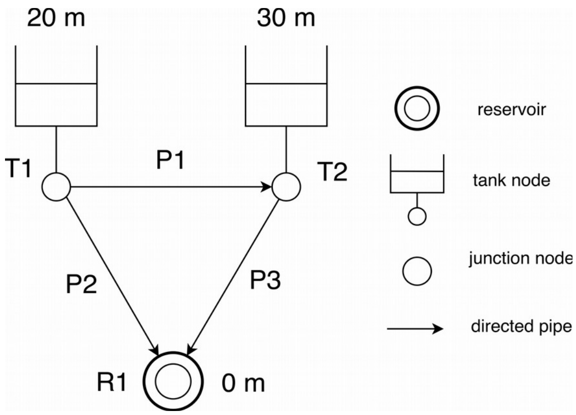

Figure 3. Network with tank inertias, used by Todini (2011).

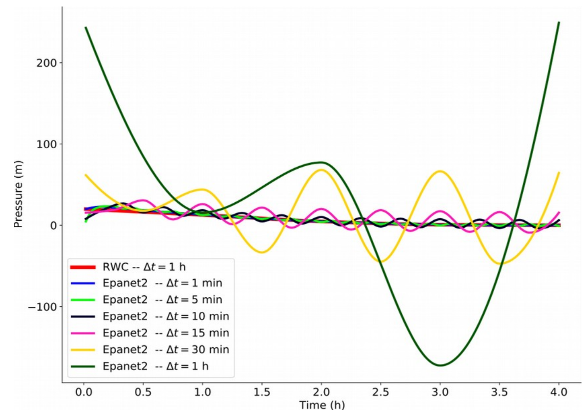

Figure 4. Comparison of the pressure heads at T1 computed by our new RWC model and by Epanet2

Figure 3 is the network used by Todini (2011) to illustrate the ability of its algorithm to deal with inertia at tanks. Figure 4 shows the pressure heads computed by our new slow-transient model at a time step of 1 hour, compared to the pressure heads computed by Epanet2 for different time steps, from 1 minute to 1 hour. We can clearly see that Epanet2 is only stable at time step of 1 minute, while our slow-transient model is already stable at a time step of 1 hour. We here confirm the results observed by Todini (2011).

We now aim at simulating real networks, observe other inertia phenomena, implement our own solver based on a theta scheme, and compare our results and benchmarks to the already published ones. Our new slow-transient model is a good compromise between accuracy and efficiency.

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