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EXTENDED ABSTRACT

Introduction

Recently, [1] estimated the global volume of non-revenue water (NRW) to be 346 million cubic metres per day, which represents a cost of at least USD 39 billion per year. Moreover, since water infrastructures are ageing and the pipe renewal rate is limited by the budget constraint, there is an important risk that the level of leakage increases in future. Thus, reducing water losses is crucial for social and economic reasons, but also because of the increasing risk of water scarcity in the context of global change [2].

Water losses in water distribution networks (WDNs) are generally classified into bursts and background leakages [3]. Bursts represent large reported water outflows. Current researches aiming at reducing bursts include the assessment of pipe deterioration state [4], the detection and localization of leaks [5], the effect of crack shapes and pipe structure on leakage dynamic [6], the relation between the leak areas and the pressure [7], and identifying the cases where pressure control is an economically suitable solution to reduce pipe bursts [8]. Conversely, background leakages are diffuse and small unreported outflows along pipes. Since they are difficult to locate, background leakages can remain undetected for a long time and cause important water losses. Thus, including background leakages in WDN models is essential to obtain accurate estimations of total losses, which may contribute to improve leakage management and system resilience through optimal control pressure in adaptively reconfigurable networks as within [9].

The existing steady state formulations to model background leakage consider that inertial effects are negligible [10, 11]. They are well suited to long-term analyses, but their assumption of insignificant dynamic effects is often invalidated by even controlled operations [12]. For correctly considering the loss of axial momentum generated by the approximation of a demand lumped at the ending nodes in steady state leakage models, [13] proposed to correct the pipe hydraulic resistance adding a new term to the momentum equation, which balances the effect of the usual friction term. [13] concluded that omitting this term could lead to a relative error as high as 250 % in certain circumstances on a simplified network, but also recommended testing the formulation in actual WDN models, to give more insights into the practical effects of the correction.

Following a different approach, [14] presented a formulation of the hydraulic network rigid water column (RWC) equations incorporating both convective inertia and constant background leakages. Through a simple example network, [14] showed the importance of considering the convection term for head prediction, considering either constant or pressure-dependent background leakage. More recently, [12] developed a new adaptive hybrid transient formulation for simulating incompressible pipe network hydraulics, which can adapt to inertially-dominated flows and those without such effects. This formulation seems very promising in term of both computational efficiency and physical accuracy, but it still does not take background leakage explicitly into account.

All existing formulations have already been evaluated on simplified networks. However, they have not been tested neither compared on large WDNs yet, which limits their reusability. Thus, there is a need to deeply analyse, test and compare these formulations, so as to clarify their range of validity and to improve them taking the most benefit of their respective advantages.

Methods and Materials

To achieve this goal, we first propose to analyse the existing formulations, discussing how they do take leakage inertia into account, and demonstrating analytically their equivalence when it is possible. We consider both steady and unsteady states modelling, but we ignore the compressibility effects (no water hammer phenomena). Also, since the elevation at each extremity of a pipe remains generally almost the same during an integration time step, we consider that background leakages are piecewise constant functions in both time and streamline direction. Like so, background leakages depend on the pressure levels in pipes at each time step, but there is no significant pressure gradient at pipe scale. This last assumption permits to simplify the equations and save computation time, since [15] show that including an explicit dependence to pressure for background leakages leads to a p-Laplacian problem which is difficult to solve for large WDNs.

Then, we run simulations on both simplified and real WDNs. We compare the results, the effect of the inertial terms, and the computation time. We quantify the uncertainties of the tested models to assess both their reliability and range of validity. To ensure test reproducibility, we choose a same Rosenbrock method (semi-implicit Runge-Kutta) for the integration of all equations. Also, we use the hydraulic simulation tool Porteau [16], to generate easily large and realistic WDNs.

Results and Discussion

A preliminary analysis shows strong similarities between [13] and [14]'s formulations. Indeed, if we rewrite the one of [13] to steady state, then we obtain an equivalence relation between the coefficient c_β defined by [13] and the Boussinesq's coefficient β used in [14]: $c_\beta = -2\beta + 1$. We can then show that if we suppose $\beta = 1$ (as did [13] and [14]), the two leakage models produce exactly the same numerical results.

This first equivalence encourages us to further explore and compare the existing formulations of background leakages. Nonetheless, we demonstrate that taking convective inertia into account using slow transient models gives the most realistic results. Moreover, considering constant background leakages at the pipe scale is an efficient strategy to simulate large networks in acceptable computation times while providing a good representation of dynamic hydraulics.

Conclusion

As a conclusion, this study is a first step toward the development of slow transient models incorporating background leakages to simulate large WDNs. Future work will consist in the calibration and global sensitivity analysis of the models.

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