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Water quality modeling considering incomplete mixing in extended periods

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Abstract

Diverse studies have shown that mixing within pipe junctions is neither complete nor instantaneous. However, these studies have focused in understanding mixing phenomena at junctions, without applying these results in water quality modeling of water distribution networks. This paper focuses on the application of both the complete and incomplete mixing models to model water quality in water distribution networks. Hydraulic networks are modelled in EPANET and EPANET-BAM, and the concentrations and their distributions are compared. Results show that there is little difference between the two mixing models, so water quality modeling might be done by using EPANET and its complete mixing model.

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Keywords: Water quality; incomplete mixing; complete mixing; chlorine residual; EPANET; EPANET-BAM; concentration; distribution.

1. Introduction

Water quality in distribution networks has become a subject of global interest. This implies a need for hydraulic and water quality modeling of distribution networks, a simulation that is performed through computer programs such as EPANET, that assume the mixture at network nodes is complete and instantaneous [1]. However, recent studies have shown that mixing processes at these nodes are neither complete nor homogeneous. Flows bifurcate at cross junctions and to a lesser extent at double tee junctions, and this results in a more spatial distribution compared to the complete mixing model. The mixing also depends on the flow [2], as well as the configuration and material of pipes

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and joints [3]. For this reason, water quality modeling in water networks must consider mixing phenomena at nodes, and flow variation due to water demand patterns.

Nomenclature

Q_i	flow entering a junction
C_i	concentration in the flow entering a junction
C_{out}	concentration in the outlet pipe of a junction
m	number of pipes connected to a junction
$C_{incomplete}$	node concentration by using the incomplete mixing model
$C_{combined}$	node concentration by using the combined mixing model
$C_{complete}$	node concentration by using the complete mixing model
n	number of nodes in the network
Δ	Average difference between both mixing models

Various programs have been designed to model networks under the assumption of incomplete mixing. Some of these programs are EPANET-BAM [1] and AZRED [4]. The results obtained with both of these programs as well as experimental tests confirm that the concentration distribution in a network is dependent on the mixing model. Moreover, comparisons on scaled networks between experimental data and simulations with the incomplete mixing model show that this model better matches the experimental data when compared to the complete mixing model.

The differences between mixing models may lead to sanitary problems. A minimum concentration of chlorine residual must exist along the network in order to avoid this. If chlorine concentration is below the minimum, an acceptable water self-purification process may not happen, and water users could receive a contaminated water supply as a result. Adequate water quality models must exist in model water networks so that these problems can be identified, thereby ensuring users receive an adequate service.

2. Complete mixing model

The complete mixing model is employed by most water quality programs such as EPANET and other water distribution network models. This model supposes complete and instantaneous mixing within pipe junctions, so concentration in the outlet flows is uniform and dependent on the flow-weighted concentrations entering the pipe [2]. The concentrations in the outlet flows can be calculated by the solute mass balance at the junction:

$$C_{out} = \frac{\sum_{i=1}^{m} Q_i C_i}{Q_{out}} = \frac{\sum_{i=1}^{m} Q_i C_i}{\sum_{i=1}^{m} Q_i} \tag{1}$$

However, this model does not adequately represent the mixing processes that have been observed in experiments and simulation with CFD models.

3. Incomplete mixing model

This model was developed as a complement to the complete mixing model. It assumes that mixing occurs due to interaction of the bulk fluid only [2]. This implies mixing will only occur if different flow rates exist in adjacent inlet or outlet pipes. The process of calculating the concentrations on the outlet flows begins by numbering the pipes as follows:

1. Calculate the total fluid momentum rate in pairs of pipes situated 180° from each other.
2. For the pair with the largest fluid momentum rate, assign “1” to the inlet and “3” to the outlet.
3. Assign “2” to the remaining inlet and “4” to the remaining outlet.