IMiST – Improving Mixing in Storage Tanks for safer water supply

Summary

Storage tanks are essential components of water supply systems to store water, to level off pressure in networks and to meet emergency storage. Nonetheless, they also are frequent sources of deterioration of drinking water quality and safety owing to inadequate tank design and operation. Mostly, existing tanks design, dimensions and operation do not account for water mixing and renewal. Tanks with inlet/outlet via single or adjacent pipes are common, thus with bulky dead zones of extended residence times. In addition, owing to temperature differences between inflowing and stored water, thermal stratification often occurs. These circumstances lead to zonal and augmented chlorine decay, biofilm development, sediment accumulation and exacerbated formation of potentially carcinogenic toxic disinfection by-products. In addition to sheltering microbial regrowth, accumulated sediments increase discolouration risks in downstream pipes. Therefore, deficient mixing also leads to increases in frequency of required tank cleaning and disinfection. Hence, there is a pressing and urgent need to understand flow dynamics in ST and to improve mixing conditions to guarantee water safety in distribution systems.

This project aims at a better understanding flow dynamics inside water supply systems' storage tanks to find practicable solutions to improve the design and the rehabilitation and to support operation of the existing tanks.

The project comprises the development of an extensive experimental programme in small-scale models, full-scale testing in a real storage tank and advanced numerical modelling. Small-scale tests are carried out in the Laboratory of Hydraulics and Water Resources of Instituto Superior Técnico, Portugal, for different tank configurations and operating conditions. Two cross-section tanks (circular and rectangular) were tested with and without interior structures (baffles), with the inlet and outlet pipes at different locations and for constant and variable water level (Figure 1). Three sets of experimental tests were carried out using different instrumentation to collect complementary data, namely traditional tracer tests, dye tracer tests (Figure 2) and velocity field measurements by Particle Image Velocimetry (PIV) (Figures 3 and 4). A methodology for assessing mixing conditions in full-scale storage tanks is developed and tested in a real tank with a rectangular cross-section and 3500 m³ capacity with inner baffles (Figure 5). Advanced numerical modelling using Computational Fluid Dynamics was carried out for the submerged and plunging get in a circular tank for better understanding velocity fields and flow patterns.

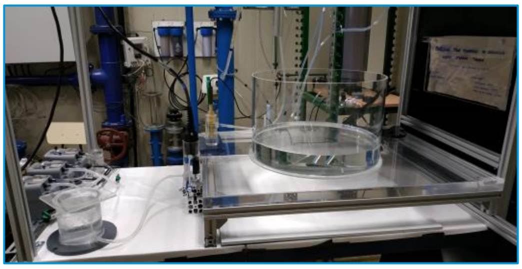

Figure 1. Experimental facility.

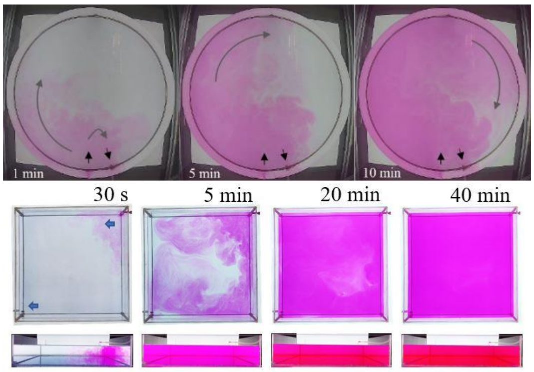

Figure 2. Dye tracer tests for circular and rectangular cross-section tanks.

Figure 3. PIV facility: experimental facility and seed particles.

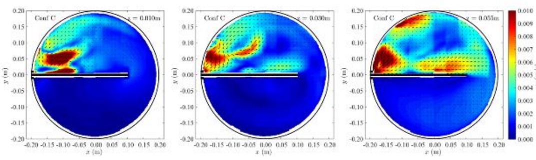

Figure 4. Velocity fields: circular C.

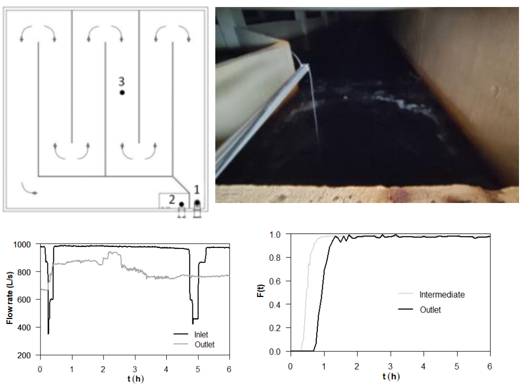

Figure 5. Full-scale tests. Time-series and cumulative distributions curves at two intermediate sections.

CERIS Civil Engineering Research and Innovation for Sustainability

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Leading institution

IST-ID – Associação do Instituto Superior Técnico para a Investigação e o Desenvolvimento (Portugal)

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The complementary experimental and numerical modelling have allowed drawing conclusions concerning improving mixing measures, by readjusting the tank configuration (e.g., location, number and diameter of inlet/outlet pipes, jet inflow, fluctuating stored water volume and geometry) and changing operating conditions (e.g., extreme tank levels). New knowledge on water storage tank hydrodynamics has been created and recommendations for improving water mixing in existing tanks are established.

Main findings

Operating the tanks with fill-and-draw cycles (Figure 6), with large water volume variation, globally improves the water mixing conditions, reduces the short-circuiting effect and reduces the renewal time for all circular cross-section tanks and for rectangular tanks without baffles. The higher the water volume variation is, the most effective this measure becomes on improving mixing and renewal conditions. Still, this measure increases slightly the short-circuiting in rectangular tanks with baffles. Operating the tanks with fill-and-draw cycles is, indeed, the simplest and the most cost-effective water mixing and renewal measure. The only disadvantage is that operating the tank with not-full storage reduces the supply system reliability in case an abnormal situation occurs at upstream the tanks that interrupts the supply during several hours.

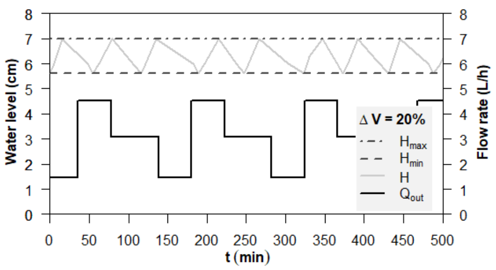

Figure 6. Fill-and-draw cycles: variation of the water level and of the flow rate.

Both the reduction of the inlet pipe diameter and the use of multiple nozzles (Figure 7) near the tank bottom far from the inlet pipe are the most efficient structural measures to improve mixing; though the short-circuiting effect can increase in circular tanks configurations A and C. Tests in circular cross section tanks have shown that the nozzles should be more than three directed to the horizontal or making a 45° angle with the horizontal. Tests in rectangular tanks carried out for 10 different nozzle locations, sizes and number have shown that: the most efficient solutions those with nozzles near the tank inlet at different water depths and pointing to the tank lateral wall, or nozzles (≥4) in the tank centre with horizontal or 45° angle jets. Few nozzles located in the centre of the tank with vertical jets should be avoided.

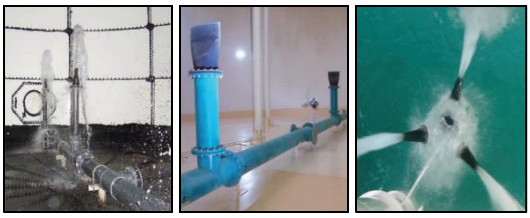

Figure 7. Inlet pipe with several flexible nozzles.

The use of baffles (Figure 8) promotes the plug-flow and, consequently, worsens the water mixing conditions; however, baffles reduce the short-circuiting effect and reduce the renewal time. These structures are very important in tanks of water transmission systems, namely at downstream water treatment works or at intermediate locations in the system, far from distribution networks; that is in tanks in locations in which the water passes and stays very few times. Conversely, in tanks located immediately at upstream distribution systems, with large volumes, with high retention times and with tendency to have lower disinfectant concentrations, it is recommendable to increase inlet water momentum by reducing the inlet pipe diameter and by using nozzles.

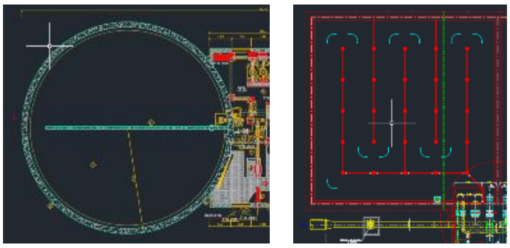

Figure 8. Examples of water storage tanks with baffles in Portugal with: a) circular cross-section; b) rectangular cross-section.

The use of smaller-size baffles (i.e., 50% of the diameter, instead of 75%) is more efficient for improving mixing conditions in tanks with close inlet/outlet pipes. The use of small holes in baffle structures (tested in rectangular tanks) has hardly any effect, which may have been due to the small size of tested holes (1-2 mm). Further research is needed to assess this measure.

The main findings of this research are that the most effective operational measure is operating tanks with fill-and-draw cycles, yet, when the tank is operated nearly full to assure the maximum reliability of the system, structural measures are recommendable. Reducing the inlet pipe diameter and installing nozzles near the tank bottom improve the mixing conditions being advisable in large storage tanks located upstream distribution network to maintain disinfectant concentration levels. The use of baffles is recommendable in large tanks located at intermediate locations of the transmission system and with the inlet and outlet pipe located very close.