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Review on water leakage control in distribution networks and the associated environmental benefits

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ABSTRACT

Water supply is the primary element of an urban system. Due to rapid urbanization and water scarcity, maintaining a stable and safe water supply has become a challenge to many cities, whereas a large amount of water is lost from the pipes of distribution systems. Water leakage is not only a waste of water resources, but also incurs great socio-economic costs. This article presents a comprehensive review on the potential water leakage control approaches and specifically discusses the benefits of each to environmental conservation. It is concluded that water leakage could be further reduced by improving leakage detection capability through a combination of predictive modeling and monitoring instruments, optimizing pipe maintenance strategy, and developing an instant pressure regulation system. The environment could benefit from these actions because of water savings and the reduction of energy consumption as well as greenhouse gas emissions.

Introduction

Human civilization is closely related to water development, as observed by the one-dimensional system whereby major cities have mostly originated along rivers. The settlement and interaction of human beings are influenced by the spatial and functional characteristics of river basins, and the direction of flow of rivers affects the movement of civilization (Delli Priscoli, 2000). The inherent driver of this phenomenon is that people need water in every aspect of life, e.g. drinking, agriculture, industry, transportation, recreation, etc.

In the early stage of the water-human relationship, people passively adapted their behaviors to the water distribution. The situation was reversed, however, in the later stages, especially when cities emerged. In urban planning, one of the most important infrastructures is the design of water systems, including the water supply system and the sewerage system. The former distributes potable water to the city habitants and the latter collects the wastewater and conveys it out. They serve as the arteries and veins of the city. The sustainable development of a city must involve the sustainable use of water.

However, it is nowadays more and more challenging to satisfy the water demand of the city inhabitants following rapid urbanization, since the per capita water use of urban inhabitants is much higher than that of rural inhabitants. Access to reliable potable water is an increasing pressure for many water supply industries, especially in developing countries. Taking China, which is the world's largest developing country, as an example, the urban population has grown much faster than the total domestic water supply, as indicated by the growth rate during 2004 to 2012 (**Fig. 1**). The urban population increased by 35.2% (from 303.4 to 410.3 million) while the total amount of urban water supply increased only by 10.2% (from 23.3 to 25.7 billion m^3) during the period. There is no surprise that this gap will hamper urban development; therefore, it is essential to

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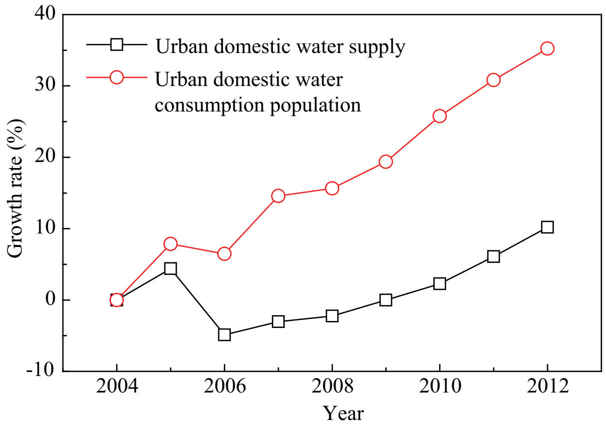

Fig. 1 Growth rates of urban domestic water supply vs. water consumption population of China from 2004 to 2012. Data from the National Bureau of Statistyics of China (http://www.stats.gov.cn/english).

bridge the growing gap between the demand and supply of water.

However, a large amount of water is lost during the delivery to customers in the meantime due to pipe failures. Each year more than 32 billion m^3 of potable water are lost from water distribution networks all over the world, which accounts for 35% of total water supplied (Farley et al., 2008). Therefore, control of water leakage is an effective measure to enhance water supply capability. The emergence of the concepts water sensitive urban development and water sensitive city demonstrates the willingness of utility managers to improve water use efficiency (Coombes et al., 2000; Ferguson et al., 2013; Morison and Brown, 2011; Wong and Brown, 2009).

In addition to the waste of potable water, there are several indirect effects of water leakage. Water supply is an energy-intensive industry, which consumes 2%–3% of the worldwide energy (James et al., 2002), thus the leakage of water is also the waste of a large amount of energy. The development of small breaks in pipes, if not detected, may lead to pipes bursting, incurring great socio-economic losses. At the same time, there is a risk of contaminating the water because pollutants may intrude into the pipe network through the breaks when negative pressure occurs.

Management of water leakage is seen to obviously benefit both the water utilities and the customers. The water utilities will get the cheapest additional water source without much investment, reduce the risk of pipe bursts, and ensure water quality for the end-users. The savings of water resources and the associated energy from water leakage control will support the sustainable development of cities. Therefore, many investigations and practices have been conducted to minimize water leakage from water distribution systems, including active leakage detection, optimal maintenance of deteriorated pipes, and water pressure regulation.

This article presents a comprehensive review on state-of-the-art water leakage control approaches, in particular the research hotspots and the associated environmental benefits.

1 Improvement of leakage detection by combining models and instruments

Leakage detection is the fundamental to control water leakage because only if the leak is located it is possible to fix it. As such, leakage detection has become routine work for the water supply industries. Efficiency of leakage detection can be significantly improved if an optimal leakage detection scheme is used, which demands a combination of detection instruments and pipe failure prediction models.

1.1 Leakage detection techniques

The available leakage detection approaches are usually classified into three categories: noise monitoring, flow and pressure monitoring, and the others. The first two categories are widely applied in water utilities.

Noise monitoring: leakage can generate noise when water flows out through a hole or fracture of a pipe and when water flows past substances outside the pipe. Noise can propagate along the pipe and the ground, thus capturing the noise will help in finding a leak. There are many kinds of acoustic equipment to capture this noise signal. The earliest form of such acoustic equipment is a stethoscope-like apparatus that connects a metal rod and earphones. Placing the metal rod in contact with a pipe, the noise can be transmitted to the listener’s ears through the earphones (Babbitt, 1920). According to the sound heard, experienced workers can give a judgment as to whether a leak exists in the pipe and the leak location can approximately be given by repeating the process at different places. Although labor-intensive, this method has been used for many years and is still the main way to detect leaks for some water utilities. New acoustic techniques have also been applied to improve the efficiency. Devices have been developed to capture and/or record the signal of leakage noise, based on which the leakage information can be calculated. In essence, the theory is the same as that of the detection by human listening. But the machine-based techniques take advantage of the enhancement of hearing capacity and the improvement of leakage-locating accuracy and precision. Although broadly used, this kind of method suffers from the disadvantage of insensitivity to large leaks that do not generate vibrations at high frequencies (Colombo et al., 2009).

Flow and pressure monitoring: leakage is an additional, but unexpected, flow out of the pipe network, which means leakage can cause changes in the hydraulic characteristics, i.e. flow increase and pressure decrease, which are noticeable if the leak is large enough. Continuously monitoring the flow and pressure of a sectorized pipe network, e.g.