HYDRAULIC PRESSURE MANAGEMENT OF YEREVAN CITY'S WATER SUPPLY SYSTEMS

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Abstract: *The system's excessive pressure management after zoning is essential for improving the existing water supply operation efficiency. Our original research proves that pressure control reduces the leaks in the water supply network, increasing the reliability level of the internal and external networks and saving energy consumed in pumping systems. In recent years, 243 pressure regulating valves (PRV) have been installed in the 97 zones of the expanded water supply network in the Yerevan city (the difference between the levels in the city reaches up to 500 meters) for pressure control in complex terrain conditions.*

Keywords: *water supply network, pressure regulating valve, network zoning, pressure management, excess pressure, water loss reduction*

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Introduction

The distribution network should be zoned in complex terrain conditions when there are differences in levels between residence boundaries. The need for zoning can arise in both pumping and gravity systems (reverse zoning) [1,4]. In this case, there is excess (unacceptable) pressure in the network before zoning and pressure management. This regulation reduces leaks and improves the conditions under which plumbing equipment and reinforcement operate, reducing the water consumption and the amount of electricity consumed in pumping systems.

Pressure management in the water supply network also reduces the probability of failures in the system and thus operational costs.

Results showed that pipe breaks could be decreased 18% to 30% by reducing the mean pressure for the investigated cohorts of asbestos cement and cast iron pipes. Pressure range reduction could provide larger impacts on both pipe materials. These results indicate that proactively controlling the hydraulic pressure may have a potentially significant impact on the reliability and sustainability of water supply networks [9]. The reliability of water supply infrastructure is critical for the continuous and uninterrupted provision of clean water. A major problem that affects the normal operation of water supply networks is the occurrence of pipe breaks. Current research suggests that pipe breaks result from complex interactions of physical, environmental and operational factors that impact the deterioration rate and breaks of pipes [8,10]. However, many causes for pipe breaks are still not fully understood and accounted for. For example, high levels or sudden changes of hydraulic pressure could be significant contributing factors for pipe breaks [11,12]. Nonetheless, there has been insufficient empirical evidence to develop methods that can quantitatively determine the impact of hydraulic pressure on pipe breaks in operational networks. Furthermore, it is unclear which metrics of the hydraulic pressure are most causative for the occurrence of pipe breaks; e.g. mean pressure, pressure range and pressure transients.

The zoning problem becomes particularly important in cases where high-rise multi-apartment buildings are built in neighborhoods inhabited by one- or two-story buildings. In the past, an ineffictive pressure control method was used to avoid excessive pressure in the Yerevan city water system: the opening of some valves of the distribution network was reduced, which resulted in all the above negative phenomena present in the network. Therefore, it is essential to implement effective network zoning or to divide the network into several zones, i.e. to isolate them hydraulically from one another, so as to maximize the controllability of the distribution network in Yerevan. Isolation can be implemented by installing existing or new valves, which will be closed during the water supply network's normal operating conditions, and can be opened if necessary. In Yerevan conditions, it is advisable to apply vertical zoning with a sequential or parallel scheme [2, 3].

Our original research showed that some additional problems arise when creating zones using existing constructed or reconstructed, prefabricated or fragmented zones. After zoning a number of town districts, it became apparent that the zone's water supply had fallen by just 8–10% and that the supply's 8–hour duration had become 12–hours rather than the intended round-the-clock. The required design pressure was also not maintained, so the frequency of failures increased. Additional studies have found that the main reason for poor zoning efficiency is the application of incorrect pressure management principles.

To overcome the mentioned shortcomings, we developed special approaches. However, these issues were not taken into account during the development of Yerevan water supply network.

Materials and Methods

The zoning of the water supply in Yerevan started in 2005. During the planning of the zone, the district's existing projects of the water supply network, as well as knowledge of experienced operators, original study results, and data obtained through pipe routing, metal detecting, and output measurement devices have been used.

Pressure meters and telecommunications software were installed at different points of the network to determine the hydraulic distribution scheme in the district water supply network. As a result of multidisciplinary original studies, the hydraulic connections of the planned zone with the neighboring zones, as well as their impact on the zone's functionality were found. To properly zone the area, it was necessary to disconnect all extra connections found supplying the district, leaving only the main one and to check out the possibility of increasing the amount of water supplied as to maintain the water supply level.

After, the availability of hydraulic connections between the different districts was investigated. It was found that each zone has many connections that link the zone under consideration to adjacent zones with lower pressure. After hydraulically isolating and demarcating the water supply zone, measurements of discharges and pressures show that there was a significant change in parameters compared to the measurements taken in the initial stage. To regulate the isolated zone pressure, to avoid excessive pressure, and to use the energy in the position rationally, the next step is to determine the amount of pressure required in the sectors created in the zone area. Based on our regulatory requirements and operational experience, we have established the following necessary pressure levels in Yerevan: in districts where 1-2-story private houses have been built - up to 20 meters, for 5-story buildings - 27-30 meters, and in multi-story buildings it is advisable to supply the required pressure with local pumping stations because higher pressure increases the network emergency and water losses.

The reduction in pressure must not result in pressure that is below the minimum regulatory pressure for serviceability, e.g. a surrogate value of 15m pressure head (1.5 bar) in water distribution pipes is used in the UK for the minimum regulatory pressure. Reliable estimation of the impact of hydraulic pressure control on pipe breaks would allow operators to quantify extra benefits of pressure management on reducing the number of pipe breaks and increasing the life cycle of ageing infrastructure [9]. Currently, the benefits from implementing pressure management are evaluated on the basis of potential leakage reduction, for which the relationships of pressure and leakage are relatively well understood [14-16]. Pressure management schemes are implemented if the benefits exceed the installation and maintenance costs [15]. Although water utilities recognise that the reduction in hydraulic pressure may decrease pipe breaks [12,15,17], the lack of empirical evidence and robust estimation methods have limited the inclusion of the potential reduction in pipe breaks in cost–benefit models for pressure management schemes [15].

The decommissioning of local pumping stations is one of the fundamental problems of pressure management in the water supply area. The reconstruction resulted in 113 of the 509 pumping stations being decommissioned in the reconstruction zones. Pumps remaining in operation were replaced with modern ones having a high-efficiency coefficient and reliability. We should also add that before the zoning, the pumps worked on an 8-hour schedule, and after the reconstruction, they worked around the clock. Meanwhile, after the reconstruction, the energy consumption in the existing pumping stations was reduced by 6 times, and in the zones, by 12 times. In some cases, the reconstructed zones' level differences are 150 meters, therefore, 243 pressure regulating valves (PRV) had to be installed once the aforementioned operations were completed.

High hydraulic pressure leading to excess pressure in water supply networks can be controlled with the use of PRVs, which commonly are membrane operated globe valves. PRVs dynamically reduce excess pressure in a network by introducing local energy losses. Recent developments in electronic pilots for PRVs allow for the implementation of different control profiles for PRVs that can either be time based (time modulation) or demand based (flow modulation) [13,14]. The control profiles can be remotely modified to significant flexibility in managing the pressure in large scale water supply networks.

Pressure management during zoning

In established water supply zones, pressure management is an important issue. To avoid excessive or insufficient pressures in the network, it was necessary to use modern computer programming for hydraulic calculations of the water supply network, which determined the calculated values of the outflows and pressures in the network sections and compared them with the actual values [5-7]. The program can be used to identify the water supply network's most crucial and susceptible locations, as well as its installation points and pressure regulators' diameters.

Rezaei et al. [12] investigated a case study of 48 DMAs and reported that pipe break rates had a positive correlation with high pressure variations. Martinez-Codina et al. [11] implemented an statistical analysis to assess differences in the pressure cumulative distribution function of pipes conditioned to break against random pipes. Their analysis comprised the evaluation of various hydraulic pressure metrics. It was observed that the pressure range, which is the difference between maximum and minimum pressure, provided the biggest difference in the presented cumulative distribution functions. Martinez-Garcia et al. [18] performed a spatiotemporally based clustering analysis to assess the correlation of consistent high pressure with pipe failure rates. Results from this study showed that there was a strong correlation between high pressure and pipe breaks in areas with high failure rates. However, weak correlations were also observed in other areas, suggesting that the effects of pressure could be spatially dependent. Further research is required to allow operators to assess the benefits of active pressure control for the reduction of pipe breaks in water distribution and transmission pipes.

While previous studies on analysing the hydraulic pressure as a factor for pipe breaks are limited [11,12,15,18–20], a multitude of published studies have investigated general models for pipe failures prediction. These models can be broadly categorised in mechanistic and data driven [21–23]. Mechanistic approaches usually require expensive, in field, data collection to analyse the deterioration state and estimate fracture of critical elements in the networks [24]. Data driven approaches make use of historical datasets and several covariates to estimate pipe breaks probabilities or breaks rates. This can later be used to assist in the allocation of resources for rehabilitation and replacement [8]. Data driven models can provide different outputs depending on how the algorithms are adapted. Support vector machines and neural networks have been applied to predict the rate of pipe breaks [25,26], while evolutionary polynomial regressions have been applied to predict the number of pipes breaks [27]. Boosted decision trees [28] and logistic regression [29,30] have been utilised to predict pipes breaks for individual pipes.

The number of water pipe failures and the probability of their occurrence depend on the following factors: the presence of excess pressure, a sharp change in the working pressure in the network, the material of the pipe, its quality, wear, as well as the pressure increase in the zone at night time. All the mentioned factors are present in Yerevan's water supply network, so pressure regulation problems are vital.

In the conditions of city area cut relief, we find it appropriate to solve the problem of pressure regulation by pressure regulating valves. With the aid of this device, the water supply network, the plumbing equipment, and reinforcement are protected from excessive pressure and hydraulic shock. The valve-sized device, after its location, reduces and stabilizes the pressure in the water supply network by means of a diaphragm and a spring (Fig.).

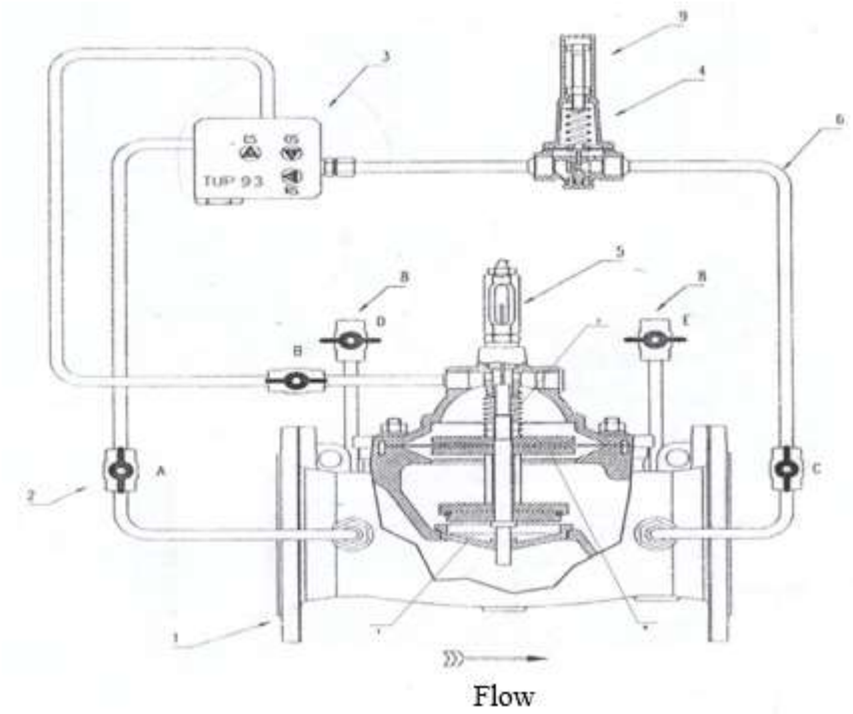

Fig. *Principle scheme of the pressure regulator operation*

1. Plate valve, 2. Isolating ball valve (A-B-C), 3. Central control panel, 4. Pilot valve, 5. Valve position indicator, 6. Diaphragm, 7. Spring, 8. Manometer mounting ball valve (D-E), 9. Pilot-operated valve cover

The pressure regulator operation principle is based on the activation of the diaphragm as a result of pressure changes, above and below of which the main and additional springs are installed. The spring is in a free position before starting and is adjusted by the pilot valve screw within permissible pressure limits for the given spring. After the pressure regulating valve installation point, the pressure in the pipeline is regulated within the permissible limit defined for controlling the system. If the pressure rises above the set point, the diaphragm presses the main spring, allowing the plate valve to pull the additional spring up and restrict the water flow through the adjustment/control valve. The main valve closes with pressure increase in the static part of the pressure regulating valve. Thus, the control valve inhibits the increase in pressure rise after itself, returning the pressure to the preset value. The valve closing rate can be adjusted via the central control panel.

Results and Discussion

The number of water pipe failures and the probability of their occurrence depend on the following factors: the presence of excess pressure, a sharp change in the working pressure in the network, the material of the pipe, its quality, wear, as well as the pressure increase in the zone at night time.

Considering that the regulator diameter is selected according to the output, therefore, it is selected approximately at the design stage of the water supply pressure zone, as reducing the losses, the output will further decrease.

In the conditions of Yerevan, it is recommended to choose the regulator diameter with the minimum output of water demand: Kc = Kmin, where Kc is the conditional throughput of the regulator (m^3/h), Kmin is the minimum output recorded at the installation point (m^3/h), which is mainly recorded at night, between $1^{00} – 5^{00}$.

After selecting the device, its operation should be checked under the conditions of maximum water consumption outputs based on the device's technical documentation. Practically, it is sometimes necessary to reduce the diameter of the regulator after loss reduction.

The estimated pressure drop value determination through the regulator is quite an important and complex issue because the cavitation phenomenon in the regulator, as well as durability, quality and noiseless operation depend on that value. Based on the above, we recommend to observe the following conditions when choosing a regulator:

- the water flow rate in the regulator should not exceed 4m/s,
- the pressure in the regulator should not decrease more than 3 times: $h_{inlet} \leq 3h_{outlet}$,
- the output pressure in the regulator must ensure the pressure in the network after the regulator: $h_{output} = H_p + h_{pipe} + h_{reg}$, where h_{pipe} is the pressure loss in the pipelines to the first consumer (m), h_{reg} is the pressure loss in the regulator (m), H_p is the required pressure in the network after the regulator (m).

We can also add that it is preferable to regulate the pressure (reduce) after the start, at least within a week, since a sudden drop in pressure results in a very unfavorable reaction from the consumer.

The installation of a pressure regulator, besides the primary functions, can also contribute to the durability of plumbing equipment and reduce water consumption.

Conclusion

The studies showed that using the existing distribution system and considering the position of reservoirs, placement, relief of the site, and the number of floors in the buildings, Yerevan city water supply network should be converted into 97 hydraulically isolated zones. After the zoning, it became necessary to develop principles of excess pressure management and determination of optimal pressure in zones, as a result of which 243 pressure regulating valves were installed in recent years.

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