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DEVICE FOR INCREASING PRESSURE IN WATER SUPPLY SYSTEMS WITH MEASUREMENT OF ACCUMULATED DRINKING WATER QUALITY

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Abstract: Low pressure in water supply systems, affecting both residential and industrial facilities, is a common issue in water distribution networks. Water sourced from municipal systems or shallow wells can experience pressure fluctuations or even complete drops, particularly during summer months. Supply from rooftop or overflow reservoirs often fails to maintain sufficient pressure to adequately supply all taps and appliances. Low pressure can also disrupt household devices such as washing machines, dishwashers, and water heaters. To address these problems, pressure-boosting systems are installed, which include additional pumps connected inline with pipelines or accumulation tanks for cases when water supply is interrupted. +The simplest solutions involve hydrophore units (a booster pump combined with a pressure vessel controlled by a pressure switch). However, noise generated by water pipes or booster pumps can cause discomfort for residents, often due to improper pump selection or inadequate regulation. Older centrifugal pumps with fan-cooled motors can create system-wide vibrations, increasing overall noise levels. This paper presents a technical solution for a pressure-boosting device in

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water supply systems, featuring reservoirs, recirculation pumps, water quality measurement systems, pressure-increasing pumps with PID control, compact electronic pressure transmitters, and expansion tanks. The design ensures silent operation while maintaining constant pressure in the water supply network. The device has been installed and tested in the Tonanti Hotel, Vrnjačka Banja, Serbia.

Keywords: water pressure maintenance, water quality, pumps, water reservoirs

Introduction

In order to achieve a stable supply of drinking water for sanitary needs and household appliances, water pressure-boosting pumps are often installed at the base of buildings to increase the pressure of the municipal water supply network. Every house, apartment, and car contain several different pumps, ranging from washing machines, dishwashers, vacuum cleaners, and hair dryers to water, fuel, and oil pumps in vehicles. The fundamental operation of these devices is based on the fact that the pressure of the fluid (liquid or gas) at the pump’s or compressor’s inlet is lower than at its outlet. The pressure difference between the inlet and outlet can be significant, ranging from a few millibars to several thousand bars. To achieve this difference, the pump and compressor designs vary, offering several structural solutions depending on the desired outcome, particularly regarding the pressure difference and the fluid flow rate through the discharge pipeline.

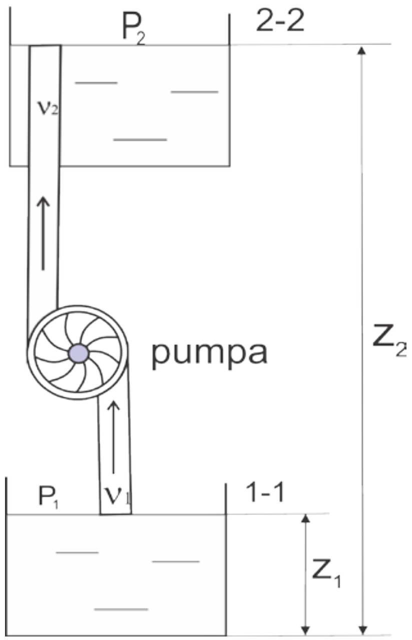

Figure 1. Block diagram of pump operation.

A lack of understanding of how pumps and compressors function often leads to poor selection of the pump or compressor type for specific operating conditions, i.e., fluid transport. The consequences of an improper selection include increased energy consumption for operation, overload of the network through which the fluid flows, excessively high or low pressure at critical points along the system, reduced efficiency, and other issues. Poor selection can also result in the malfunctioning of other devices that depend on the operation of pumps and compressors, ultimately leading to lower-quality products or services provided by the overall system.

The basic operating parameters for pumps are:

Flow rate, volumetric $\dot{V}$ (m^3/s) or mass $\dot{m}$ (kg/s), $\dot{m} = \rho\dot{V}$

Head H (m) or specific work Y (J/kg)

Power P (W)

Efficiency η_p (%)

The total energy of the fluid in a pumping system between two cross-sections—points (1) and (2) (Figure 1)—can be expressed using the Bernoulli equation for real fluids:

$$\frac{p_1 + p_b}{\rho g} + \frac{v_1^2}{2g} + gz_1 + H = \frac{p_2 + p_b}{\rho g} + \frac{v_2^2}{2g} + gz_2 + \xi_{1-2}$$

This equation accounts for pressure energy, kinetic energy, and potential energy, while also including additional energy introduced by the pump and losses caused by system friction.

From the equation, it can be seen that the difference between the Bernoulli equation for ideal and real fluids lies in the definition of losses that occur due to fluid motion, represented by the ξ_{1-2} term. The head loss represents the sum of longitudinal losses (caused by pipe roughness) and local losses (caused by flow through elbows, branches, valves, faucets, etc.) in the pipeline where the pump is installed. If both the discharge and suction lines are of the closed type, the required lifting height H_{pot} can be calculated as:

$$H_{pot} = \frac{p_2 - p_1}{\rho g} + \frac{v_2^2 - v_1^2}{2g} + (z_2 - z_1) + \xi_{1-2},$$

where p_2 is the pressure in the reservoir on the discharge side of the pump, and p_1 is the pressure in the reservoir on the suction side of the pump. The elevation difference $(z_2 - z_1)$ refers to the difference in fluid levels between the reservoir on the discharge side and the reservoir on the suction side. The term ξ_{1-2} represents pipeline losses expressed as head loss. If the operating point of the pump is properly defined in the project requirements—that is, if the lifting height and flow rate are determined—then it is possible to select a pump type from the catalog that meets the project's specifications. Achieving and maintaining the parameters of the operating point can be managed using measurement and control components. Measurement and regulation are carried out using a pressure transmitter coupled with a frequency converter. The pressure maintenance system relies on adjusting the pump's rotational speed according to the required flow rate, which depends on the current pressure drop on the pump's discharge side as a result of the instantaneous water consumption in the system. Maintaining pressure through frequency regulation introduces the following improvements:

Maintaining system pressure at a set value thanks to closed-loop pressure control, regardless of the current water consumption.

Energy savings due to continuous pressure regulation by adjusting the pump's rotational speed.

Reduction of hydraulic shocks in the system, extending the lifespan of pumps, pipelines, and fittings.

Reduced number of pump starts and stops and an adjustable "sleep mode," ensuring optimal pump operation during low consumption periods.

Protection of the pump from dry running, motor overload protection, and protection of the system from short circuits and ground faults.

The pump draws liquid from Reservoir 1, which is at atmospheric pressure (observed at level "1-1"), and discharges it into Reservoir 2 (observed at level "2-2"), where the static pressure P_2 is significantly higher than the static pressure P_1. The fluid levels in the reservoirs are not at the same geographical elevation; the level "1-1" in Reservoir 1 is lower than the level "2-2" in Reservoir 2, while the flow velocity at the observed levels "1-1" and "2-2" is zero (Figure 2). Thus, all the energy provided by the pump is defined by the lifting height H, which is "spent" on increasing the elevation and static pressures. The mathematical formulation of Bernoulli’s equation in this case is:

$$H = \frac{p_2 + p_b}{\rho g} + \quad z_2 - (\frac{p_1 + p_b}{\rho g} \quad + z_1) + \xi_{1-2}$$

The term ξ_{1-2}, which defines longitudinal and local losses, is very small because the fluid is not moving, and it is essentially equal to zero. This case is common in practice when a hydro-pneumatic tank is being replenished from a well while all water consumption taps are closed.

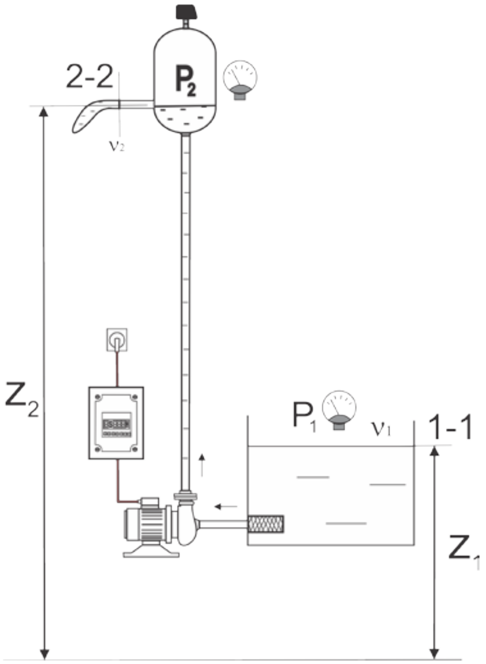

Figure 2. Example of converting the mechanical work of the pump into static and elevation fluid pressure.

Results and Discussion

The new technical solution for pressure increases actually consists of two systems: a smaller one with three pumps and a larger one with two pumps (Figure 3). The integration of two old booster stations with the new pressure boosting station allows for the following operational modes:

The old station can operate as it previously did while the new pressure boosting station either remains inactive or circulates water through reservoirs R1, R2, R3, and R4.

The new station can draw water from the water supply pipe or from reservoirs R1, R2, R3, and R4 and pump it into the hotel's pipeline, while the old station circulates water through the reservoirs.

Both booster stations (or individually) can operate together—boosting pressure using water from reservoirs R1, R2, R3, and R4.

Both stations (or individually) can increase the pressure in the hotel's water supply network by drawing water directly from the supply pipe and pumping it toward the hotel.

Both systems can supply compensation tanks for heating and cooling.

A connection is provided for a potential potable water supply from a private well located beneath the hotel.

If the pressure in the water supply network exceeds 5.5 bar, the pressure boosting system will not activate, and the water supply will directly provide drinking water to the hotel.

All these possibilities are made possible through a combination of valves and hydraulic connections, as illustrated in Figure 3. The new pressure boosting system consists of two stainless steel pumps (AISI 304) mounted on a hot-dip galvanized base with 2.5" stainless steel suction and discharge pipeline sections, as well as a control cabinet that operates the pumps based on a working + standby principle. The cabinet contains frequency inverters that control pump operation. It also provides necessary protections, including phase asymmetry protection, motor protection, signaling, dry-run protection, and overload protection. Additionally, two 24-liter, 16-bar pressure vessels are installed. An expansion tank with a volume of 300 liters is supplied with the device and should be connected to the discharge pipe during installation. These tanks ensure smoother system operation and prevent hydraulic shocks (water hammer) in the plumbing system. The device is controlled using pressure switches and transmitters, allowing a pressure of 5.5 bar to be continuously maintained with the help of frequency regulators that enable smooth start/stop operation. The water pressure on the top floor will be 3.0 bar, which is sufficient for all sanitary needs of the hotel’s users. Furthermore, a water quality monitoring system, *Hipogen Con*, is installed to measure residual chlorine levels, ensuring they remain within the prescribed range defined by the Regulation on the Chemical and Bacteriological Safety of Drinking Water. According to the regulation, the allowable concentration of residual chlorine in drinking water ranges from 0.2 mg/L to 0.5 mg/L. An ORP measuring probe is installed on the water recirculation pipeline. If the residual chlorine concentration drops below 0.2 mg/L, a dosing system activates and injects sodium hypochlorite from the dosing tank into the pipeline or reservoirs R1, R2, R3, and R4 until the residual chlorine concentration reaches 0.5 mg/L, at which point the dosing system turns off. Recirculation and residual chlorine measurement occur twice a day over 24 hours, lasting 30 minutes each time. Reservoirs R3 and R4 are supplied with fresh water from the pipeline using float switches Vp1 and Vp2 (Figure 3). If one of the two float switches fails, the water level in all reservoirs will rise only to the level of the high-level relay switch. When this switch closes, it activates the EMS1 solenoid valve, stopping further water supply to all reservoirs. In this case, a red signal light on control cabinet door Ko4 will turn on to alert of the high-water level in the reservoirs. The reservoir refilling system can continue to function in this way, but it is recommended to check and repair the Vp1 and Vp2 float switches. To prevent condensation on the outer surfaces of reservoirs R1, R2, R3, and R4, self-adhesive Armaflex polyurethane insulation panels have been installed.

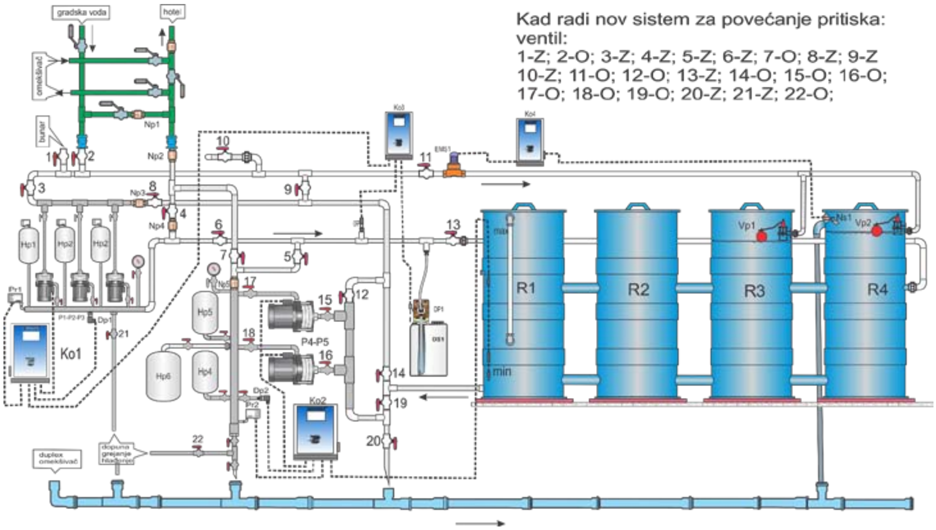

Figure 3. The implemented state of the coupled system for pressure increase.

After the installation of the equipment shown in Figure 3, the system was tested for a period of one and a half months during the peak water consumption season at the Tonanti Hotel in Vrnjačka Banja. The results of water pressure measurements in the pipeline and residual chlorine concentration during this period are shown in Figure 4.

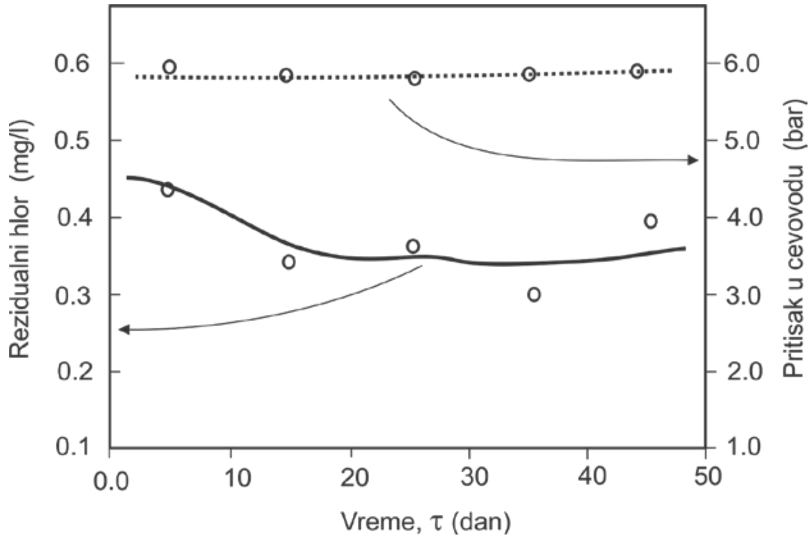

Figure 4. Dependence of residual chlorine concentration and pressure as a function of time.

As seen in Figure 4, over the 45-day period, the pipeline pressure remained practically constant at approximately 6 bar, while the residual chlorine concentration ranged between 0.3 and 0.45 mg/L, which complies with the Regulation on the Chemical and Bacteriological Safety of Drinking Water.

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Conclusion

Based on the presented results, the following conclusions can be drawn:

The water pressure boosting device, combined with the measurement of the quality of stored drinking water, operated reliably over a 45-day period.

The continuous measurement and maintenance device for residual chlorine, *Hipogen Con*, successfully maintained the prescribed levels of residual chlorine in reservoirs R1, R2, R3, and R4.

The chemical analysis of the output water showed that the water quality meets the requirements of the *Regulation on the Chemical and Bacteriological Safety of Drinking Water* and can therefore be used for household purposes.

The pressure boosting station, equipped with PID regulation, frequency controllers, and a pressure transmitter, maintained the set pressure of 6 bar silently and effectively.

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