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Fountains Their Main Types and Hydraulic Calculations

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Abstract: This paper investigates fountains and their main types with a focus on hydraulic design principles and calculation methods. Fountains play an important role in urban infrastructure and landscape architecture, providing aesthetic, microclimatic, and recreational benefits. However, stable and energy-efficient operation of fountain systems largely depends on the correct hydraulic calculation of flow rate, pressure head, jet velocity, and hydraulic losses. Improper design may lead to insufficient jet height, excessive energy consumption, or unstable operating conditions. In this study, fountains are classified according to their operating principles into free-flow, pressurized, and combined systems. For each type, the relationship between hydraulic parameters is analyzed using classical fluid mechanics equations. Mathematical models describing jet height, discharge velocity, and head losses in pipelines and nozzles are presented. The influence of pump characteristics and system losses on the achievable fountain height is evaluated through analytical calculations. The obtained results demonstrate that accurate hydraulic calculations allow optimization of pump selection and operating режимес, reduction of energy losses, and improvement of overall system efficiency. The proposed approach can be used in the design and modernization of fountain systems in urban and recreational areas, contributing to reliable operation and sustainable water use.

Keywords: fountain, hydraulic calculation, jet height, flow rate, pressure head, hydraulic losses, pump system.

Introduction

Fountains are hydraulic installations widely used in urban environments, public spaces, and recreational areas, where they perform not only decorative but also environmental and functional roles. By creating dynamic water jets, fountains contribute to the improvement of microclimatic conditions, reduction of ambient temperature, and enhancement of aesthetic quality in densely populated areas. From an engineering perspective, a fountain represents a hydraulic system in which water is supplied under controlled pressure to form stable jets of a predefined height and geometry. The reliability and efficiency of such systems depend directly on the correctness of hydraulic design and calculation. In practical operation, fountain systems are often affected by hydraulic inefficiencies caused by inaccurate estimation of flow rate, pressure head, and hydraulic losses in pipelines and nozzles. Insufficient pump head may result in reduced jet height and unstable flow patterns, while excessive pressure leads to unnecessary energy consumption and accelerated wear of hydraulic components. Therefore, the hydraulic calculation of fountain systems is a critical stage in their design, directly influencing operational stability, energy efficiency, and service life.

Existing studies in hydraulics and water engineering mainly focus on general jet flow theory, pump performance, and pipeline hydraulics. However, fountain systems combine these elements into a compact and highly dynamic hydraulic configuration, where local losses, nozzle geometry, and pump characteristics interact in a complex manner. In many practical projects, simplified empirical approaches are still applied, which do not fully account for the combined influence of hydraulic losses, discharge velocity, and jet breakup phenomena. This creates a gap between theoretical hydraulic models and real fountain operation conditions. Another important aspect is the classification of fountains according to their hydraulic operating principles. Free-flow fountains, pressurized fountains, and combined systems differ significantly in terms of flow formation, pressure requirements, and energy consumption. Without a systematic classification supported by hydraulic analysis, the selection of system parameters and equipment often relies on experience rather than engineering justification.

In this context, a comprehensive study of fountain types and their hydraulic calculations is necessary to improve design accuracy and operational efficiency. This paper aims to analyze the main types of fountains from a hydraulic point of view and to present calculation methods for determining key parameters such as flow rate, jet velocity, pressure head, and hydraulic losses. The presented approach is based on classical fluid mechanics equations and is intended to support rational pump selection, optimization of operating regimes, and energy-efficient design of fountain systems.

Methods

The methodological framework of this study is based on analytical hydraulic calculations and system-level analysis of fountain installations operating under steady-state conditions. The research focuses on determining the key hydraulic parameters governing fountain performance, including flow rate, jet velocity, pressure head, and hydraulic losses in pipelines and nozzles. Classical fluid mechanics principles are applied to establish mathematical relationships between these parameters and to evaluate their influence on fountain jet height and energy efficiency.

Hydraulic model of a fountain system. A typical fountain system is considered as a closed hydraulic circuit consisting of a water reservoir, a centrifugal pump, supply pipelines, fittings, and a nozzle forming the water jet. The working fluid is assumed to be incompressible, and its physical properties are taken as constant under operating conditions. Flow is considered steady and fully developed in pipelines, while energy losses are accounted for through friction and local resistance coefficients. The total head required for fountain operation is expressed as the sum of the geometric head, velocity head at the nozzle outlet, and hydraulic losses along the flow path:

$$H_{\mathrm{req}} = H_g + \frac{v^2}{2g} + \sum h_l$$

where H_{req} is the required pump head, H_g is the geometric elevation head, v is the jet exit velocity, g is gravitational acceleration, and $\sum h_l$ represents total hydraulic losses.

Determination of jet velocity and fountain height. The fountain jet height is determined from the kinetic energy of the water jet leaving the nozzle. Neglecting air resistance and jet breakup effects, the theoretical maximum jet height is calculated as:

$$H_j = \frac{v^2}{2g}$$

The jet exit velocity is related to the volumetric flow rate and nozzle cross-sectional area:

$$v = \frac{Q}{A}$$

where Q is the flow rate and A is the nozzle area. To account for non-ideal flow conditions, a discharge coefficient is introduced, allowing correction of the actual jet velocity.

Hydraulic losses in pipelines and nozzles. Hydraulic losses in the fountain system are divided into distributed losses along pipelines and local losses caused by fittings, bends, valves, and the nozzle. Distributed losses are calculated using the Darcy–Weisbach equation:

$$h_f = \lambda \frac{L}{D}\frac{v^2}{2g}$$

where λ is the friction factor, L is the pipeline length, and D is the pipe diameter. Local losses are evaluated as:

$$h_l = \sum \zeta \frac{v^2}{2g}$$

where ζ denotes local resistance coefficients associated with individual hydraulic elements. The total hydraulic loss is obtained by summing all distributed and local losses.

Pump operating conditions and efficiency assessment. Pump selection is based on matching the calculated required head and flow rate with the pump characteristic curves. The operating point of the system is determined by the intersection of the pump head curve and the system resistance curve. Hydraulic efficiency is evaluated by analyzing the ratio between useful hydraulic power and the electrical power input to the pump:

$$\eta = \frac{\rho g Q H_{\mathrm{req}}}{P_{\mathrm{in}}}$$

where ρ is the fluid density and P_{in} is the pump input power. This approach allows assessment of energy consumption under different operating regimes and fountain configurations.

Comparative analysis of fountain types. The described calculation methodology is applied to different fountain types, including free-flow, pressurized, and combined systems. For each configuration, hydraulic parameters are calculated and compared in terms of required pump head, achievable jet height, and energy efficiency. This comparative approach enables identification of optimal design solutions depending on functional and aesthetic requirements.

Results

The results presented in this section are obtained from hydraulic calculations performed for typical fountain systems operating under steady-state conditions. The analysis focuses on the influence of flow rate, pressure head, and hydraulic losses on the achievable jet height and overall system efficiency. Calculations were carried out for different operating regimes and fountain configurations in order to evaluate performance characteristics and compare design alternatives.

Relationship between flow rate, jet velocity, and fountain height. The primary performance indicator of a fountain is the jet height, which is directly related to the exit velocity at the nozzle. Table 1 presents the calculated jet velocity and corresponding fountain height for different flow rates, assuming a fixed nozzle diameter and neglecting air resistance.

Table 1. Effect of flow rate on jet velocity and fountain height

Flow rate, Q (m^3/s)	Jet velocity, v (m/s)	Fountain height, Hj (m)
0.010	7.1	2.6
0.015	10.6	5.7
0.020	14.1	10.1
0.025	17.7	15.9

The results show a nonlinear increase in fountain height with increasing flow rate, which follows the quadratic relationship between velocity and kinetic energy. This confirms that even moderate increases in discharge require a significant increase in supplied hydraulic energy.

Figure 1 illustrates the relationship between flow rate and fountain height, demonstrating a rapidly rising trend that highlights the importance of accurate flow control in fountain design.

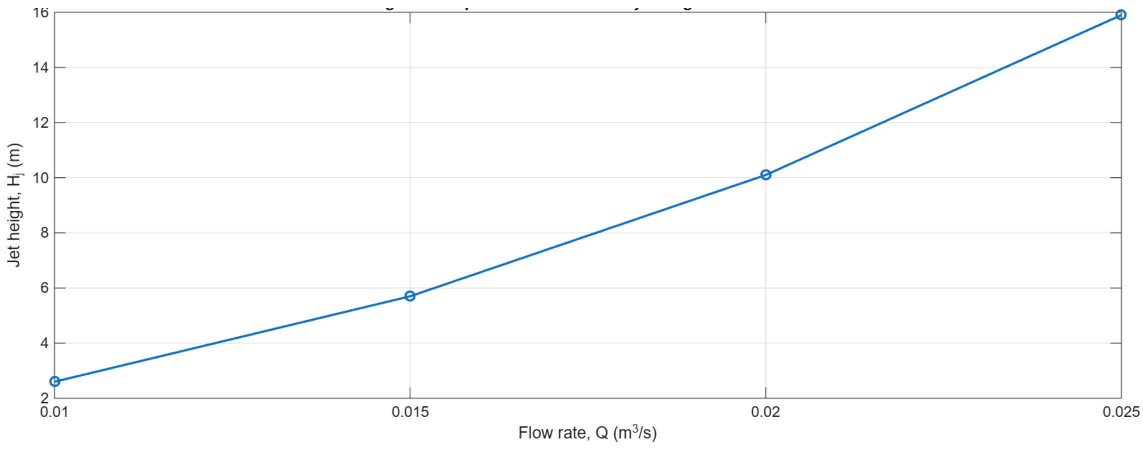

Figure 1. Dependence of fountain jet height on flow rate.

Influence of hydraulic losses on required pump head. Hydraulic losses in pipelines and fittings significantly affect the total head required from the pump. Table 2 summarizes calculated head losses for different pipeline lengths under identical flow conditions.

Table 2. Hydraulic losses as a function of pipeline length

Pipeline length, L (m)	Distributed losses, hf (m)	Local losses, hl (m)	Total losses, hΣ (m)
10	0.8	0.6	1.4
20	1.6	0.6	2.2
30	2.4	0.6	3.0
40	3.2	0.6	3.8

The results indicate that distributed losses increase proportionally with pipeline length, while local losses remain nearly constant for a given system configuration. As a consequence, extended pipeline layouts require substantially higher pump head to maintain the same fountain height.

Figure 2 presents the variation of total hydraulic losses with pipeline length.

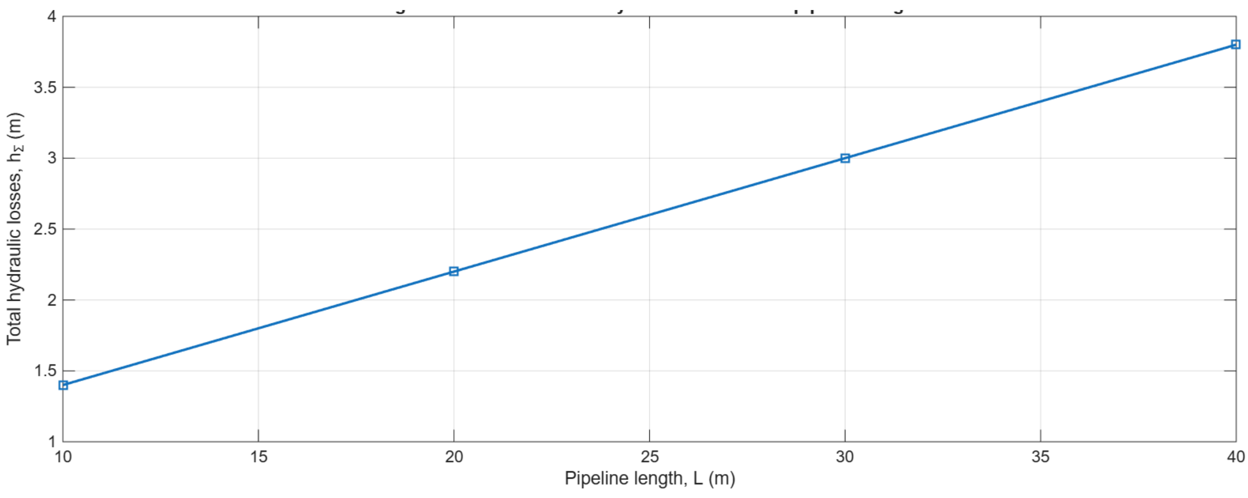

Figure 2. *Variation of total hydraulic losses with pipeline length.*

Pump head requirement and operating point analysis. By combining the required jet head and total hydraulic losses, the overall pump head was calculated for different operating regimes. Table 3 shows the required pump head and corresponding hydraulic power.

Table 3. Required pump head and hydraulic power

Fountain height (m)	Total losses (m)	Required pump head (m)	Hydraulic power (kW)
5	1.8	6.8	0.67
10	2.5	12.5	1.23
15	3.2	18.2	1.94
20	4.0	24.0	2.80

These results demonstrate that the pump head requirement increases not only with the desired fountain height but also due to cumulative hydraulic losses. Consequently, improper estimation of losses may lead to incorrect pump selection and inefficient system operation.

Figure 3 shows the system resistance curve and pump characteristic curve, indicating the operating point of the fountain system.

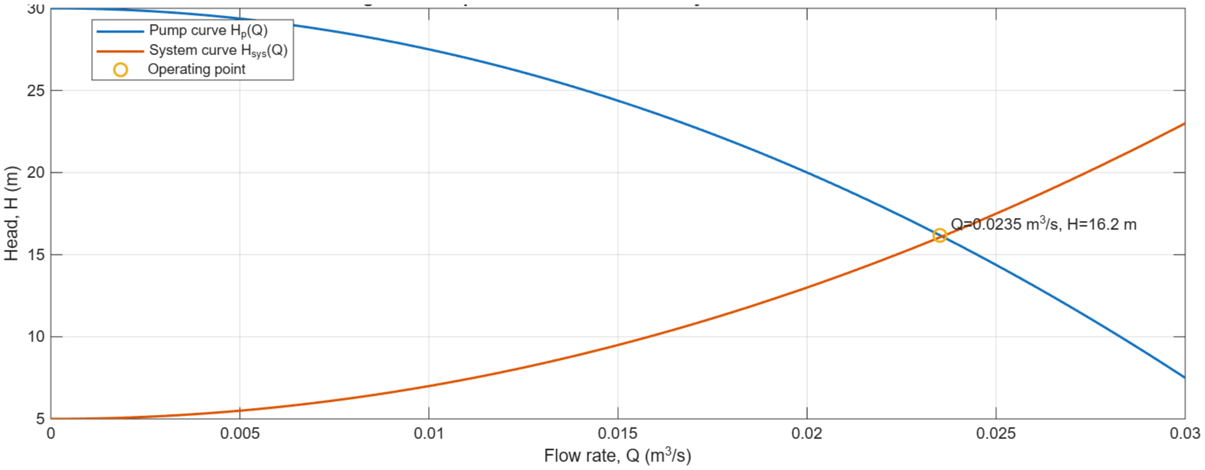

Figure 3. *Intersection of pump characteristic curve and system resistance curve.*

Comparative performance of fountain types. A comparative analysis was performed for free-flow, pressurized, and combined fountain systems. The results indicate that pressurized systems achieve greater jet heights at lower flow rates but require higher pump head, while free-flow systems are characterized by lower energy consumption and simpler hydraulic layouts. Combined systems provide a compromise solution, offering flexibility in operation and improved visual effects.

Conclusion. This study has examined fountains as hydraulic systems by analyzing their main types and the fundamental principles governing their hydraulic design. Based on analytical calculations, the relationships between flow rate, jet velocity, pressure head, and hydraulic losses were established, allowing a systematic evaluation of fountain performance under steady operating conditions. The results confirm that fountain height and visual stability are primarily determined by the balance between kinetic energy at the nozzle outlet and total hydraulic losses within the system. The conducted analysis demonstrates that hydraulic losses in pipelines and fittings play a significant role in defining the required pump head, particularly in systems with extended pipe lengths or complex layouts. Neglecting these losses may lead to underestimation of pump capacity, resulting in insufficient jet height and unstable operation, while overestimation increases energy consumption and reduces system efficiency. The comparative evaluation of free-flow, pressurized, and combined fountain systems indicates that each configuration exhibits distinct hydraulic characteristics, requiring tailored calculation approaches depending on functional and aesthetic objectives.

The obtained results highlight the importance of accurate hydraulic calculations for rational pump selection and energy-efficient fountain design. By applying classical fluid mechanics equations and system resistance analysis, it is possible to optimize operating regimes, reduce unnecessary energy losses, and improve the overall reliability of fountain installations. The presented methodology can be effectively used in the design, modernization, and technical assessment of fountain systems in urban and recreational environments. Overall, the findings of this study provide a practical and theoretically grounded framework for hydraulic design of fountains and may serve as a basis for further research focused on transient flow effects, jet aerodynamics, and automated control of fountain systems.

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