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Numerical Analysis and Comparison of Frictional Head Loss in Water Transmission Networks Using the Darcy-Weisbach and Hazen-Williams Equations

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Extended Abstract

Introduction

The study of head loss in pipes, which results from the conversion of the fluid's mechanical energy into heat due to friction and turbulence, is a fundamental topic in fluid engineering. This loss is divided into two main categories: "major" (continuous along the pipe length) and "minor" (caused by fittings and valves). The theoretical foundations were laid by Bernoulli's equation (18th century) and Stokes' definition of the Reynolds number (19th century). The classic Darcy-Weisbach equation and the Moody chart (1944) were developed for precise calculation of frictional loss based on the Reynolds number and surface roughness. In contrast, the empirical Hazen-Williams formula with a constant coefficient was provided for simpler calculations. Recent research comparing these two methods shows that choosing the appropriate formula depends on the pipe material and flow conditions, and the difference in their results can be up to 25%. For instance, a 2025 study led to a new relationship for irrigation pipes that is independent of the roughness coefficient and offers greater accuracy for high Reynolds numbers. Consequently, despite the high accuracy of the Darcy-Weisbach equation, the development of new empirical relationships for specific operational conditions continues.

Main Body of the Article

This paper analyzes head loss in the desalination industry, with the case study being the Kaveh South Kish Steel Plant desalination unit, featuring a 1700-meter long seawater intake line with a capacity of 6600 m³/h. A numerical analysis of frictional head loss in the seawater transmission lines was conducted using fiberglass pipes with diameters ranging from 500 to 1100 mm and a length of 1700 meters, at different flow rates (3960, 5280, 6600, and 7920 m³/h). The analysis was performed using both the Darcy-Weisbach and Hazen-Williams equations, and the results from the two methods were compared.

This process examined the effects of parameters such as flow turbulence, fluid flow rate, pipe diameter variations, and fluid behavior in pipes with different internal linings. Charts were plotted to illustrate the influence of these parameters relative to each other, all within the framework of the two mentioned equations. Subsequently, using real-world data from the desalination industry in the Persian Gulf region (with a 1700-meter pipeline length), the discrepancy between the results of the two equations was evaluated in an operational environment. Furthermore, by analyzing the impact of internal pipe coatings (such as epoxy and polyethylene) on the surface roughness coefficient, strategies for reducing head loss were proposed. Finally, by integrating the findings into the energy conservation equation and Bernoulli's equation, the required pump head to overcome the frictional loss was calculated. This approach enables the optimal design of seawater transmission systems with minimal operational costs and maximum hydraulic efficiency.

Results

Based on the direct relationship of the Darcy-Weisbach equation with the Reynolds number, it was determined that the fluid flow is fully turbulent in all regions—even at a temperature of 35°C in January. This turbulence,

characterized by zero velocity near the walls, increases mixing intensity and converts kinetic energy into internal (thermal) energy, thereby intensifying the frictional head loss. These losses, which are directly related to the pipeline length, can be reduced by increasing the pipe diameter and decreasing the flow velocity. Furthermore, as the Reynolds number increases, the discrepancy between the results of the Hazen-Williams equation (which uses a constant friction factor) and the Darcy-Weisbach equation (which is Reynolds number dependent) becomes more significant; in fully turbulent flow, the Hazen-Williams model is closer to real-world conditions. Finally, in deteriorated pipes, the reduction in the effective cross-sectional area due to sediment buildup (with a thickness of 1 to 10 mm) and increased surface roughness significantly elevate the frictional head loss, highlighting the importance of periodic pipeline maintenance to prevent a decrease in system efficiency.

Conclusion

A comparative study of the Darcy-Weisbach and Hazen-Williams methods for calculating frictional head loss in seawater transmission pipelines revealed that the discrepancy between their results increases significantly with higher flow turbulence. This phenomenon is primarily due to the Darcy-Weisbach equation's dependence on the Reynolds number and pipe wall roughness, whereas the Hazen-Williams equation lacks this dependency and uses a constant empirical coefficient (dependent on pipe material). In flows with moderate turbulence (low Reynolds number), the maximum observed difference between the two methods' results was approximately 1 meter. However, as turbulence increased to a Reynolds number of 10,000,000, this difference reached 30 meters. On the other hand, pipe deterioration over time (due to corrosion, sedimentation, and changes in surface roughness) was identified as a key factor in exacerbating head loss. These findings highlight the importance of optimal pipeline system design (considering appropriate diameter and anti-corrosion coating) and periodic maintenance to reduce energy losses and increase the service life of transmission lines. Ultimately, this study demonstrates that selecting the appropriate computational model (Darcy-Weisbach for turbulent flows and Hazen-Williams for laminar flows) plays a decisive role in accurately predicting head loss and optimizing operational costs.

Key words: Hazen Williams, Darcy Weisbach, friction head, seawater transfer line, Moody diagram

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