Pressure Loss Analysis In Clean Water Supply Distribution At The Regional Drinking Water Company (Pdam)

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Abstract

Background : Water distribution systems require accurate analysis of flow characteristics and head losses to ensure efficient hydraulic performance. Manual calculations using fluid mechanics equations can be used to determine flow losses in pipes and fittings, while hydraulic simulation software such as EPANET 2.0 provides an alternative approach for analyzing water distribution systems. However, differences between manual calculations, Microsoft Excel calculations, and EPANET 2.0 simulations require further evaluation to assess the consistency and accuracy of the results.

Purpose : This study aims to calculate water flow and head losses in a water distribution system using manual calculations and Microsoft Excel, and to compare the results with those obtained using EPANET 2.0 software

Methodology : The study applies hydraulic calculations based on the Reynolds number (Re), Darcy–Weisbach equation for major head loss, and minor loss equation for fittings and other hydraulic components. The equations used include (Re = \frac{\rho VD}{\mu} = \frac{VD}{\nu}), (h_f = f\frac{LV^2}{2gD}), and (h_m = K\frac{V^2}{2g}). Microsoft Excel is used to facilitate the calculation of friction factors and pipe head losses. The results are subsequently compared with simulations conducted using EPANET 2.0, which models physical components including junctions, reservoirs, tanks, emitters, pipes, pumps, valves, and minor losses. The Hazen–Williams equation is applied in EPANET 2.0 for head-loss calculations.

Findings : The analysis provides comparative results of flow characteristics and head losses obtained through manual calculations, Microsoft Excel, and EPANET 2.0 simulations. The comparison indicates the extent of agreement between the analytical and software-based approaches and identifies differences resulting from the calculation methods and hydraulic assumptions applied in each approach.

Implications : The comparison provides practical information regarding the applicability of manual calculations, Microsoft Excel, and EPANET 2.0 for hydraulic analysis. The results can support students, researchers, and practitioners in selecting an appropriate calculation and simulation approach for evaluating water distribution systems and pipe-flow losses.

Originality : This study contributes a comparative framework for evaluating hydraulic head-loss calculations using conventional fluid mechanics equations, Microsoft Excel, and EPANET 2.0. The comparison provides an integrated perspective on the consistency of manual and software-based hydraulic analysis.

Keywords: Water distribution system; Head loss; Darcy–Weisbach; Hazen–Williams; EPANET 2.0

INTRODUCTION

Water is an essential resource for human activities and socioeconomic development. The provision of clean water requires not only adequate water sources but also an effective distribution system capable of delivering sufficient flow and pressure to consumers. Water distribution networks consist of interconnected pipes and hydraulic components, making hydraulic modelling important for system planning, design, operation, and evaluation (Rossman, 2024; Flórez Sepúlveda et al., 2023).

One of the key parameters in hydraulic analysis is head loss, which represents the reduction of hydraulic energy during water flow through a pipe network. Head loss consists of major losses caused by friction along the pipe and minor losses associated with bends, valves, fittings, entrances, exits, contractions, and expansions (White, 2016; Rossman, 2024). The calculation of frictional loss requires consideration of the flow regime, pipe diameter, velocity, roughness, and fluid properties. The Reynolds number is used to characterize the flow regime, while the Darcy–Weisbach equation provides a fundamental approach for determining major head loss (Çengel & Cimbala, 2018; White, 2016).

The Hazen–Williams equation is also widely applied in water distribution analysis. Unlike Darcy–Weisbach, which uses a friction factor related to flow conditions and relative roughness, Hazen–Williams employs an empirical roughness coefficient. Differences between these formulations can result in different head-loss estimates, as demonstrated by Abdulrahman and Abdulrazzaq (2023). Pipe roughness is therefore an important parameter in hydraulic modelling because variations in pipe material, age, and internal condition can affect hydraulic resistance and head loss (Gao et al., 2017).

The increasing complexity of water distribution networks has encouraged the use of hydraulic simulation software. EPANET 2.0 enables the modelling of interconnected components such as junctions, reservoirs, tanks, pipes, pumps, and valves and can calculate hydraulic parameters throughout a network. Previous studies have demonstrated the application of EPANET for hydraulic evaluation, sectorization, and network redesign (Reis et al., 2023; Flórez Sepúlveda et al., 2023; Kalliontzis et al., 2023; Rashed et al., 2024). At the same time, spreadsheet-based approaches remain useful because they facilitate repetitive calculations while maintaining transparency in the underlying equations. Gomes Jr. et al. (2024) demonstrated the application of Microsoft Excel for modelling looped water distribution networks and compared its results with EPANET.

However, existing studies have generally focused on EPANET-based network modelling, optimization, or comparisons between individual head-loss equations. A direct comparison of manual hydraulic calculations, Microsoft Excel, and EPANET 2.0 using the same pipe network and input parameters is still important to evaluate the consistency and differences among these approaches. Such a comparison is particularly relevant because the manual calculation in this study applies the Reynolds number, Darcy–Weisbach equation, and minor-loss coefficient, whereas EPANET 2.0 is configured using the Hazen–Williams equation.

Therefore, this study aims to analyze water flow and head loss using manual calculations, Microsoft Excel, and EPANET 2.0, and to compare the results obtained from the three approaches. The originality of this study lies in integrating fundamental hydraulic calculations, spreadsheet-based computation, and network-level simulation within the same pipe system. The comparison is expected to provide practical insight into the consistency of different hydraulic calculation approaches and support the validation of pipe-flow analysis in water distribution systems.

METHODOLOGY

3.1 Research Design

This study employed a quantitative hydraulic analysis approach to evaluate water flow and head loss in the clean-water distribution network of Perumahan Kondang Asri, Klari, Karawang, supplied by PDAM

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Tirta Tarum Karawang. The analysis was conducted using three computational approaches: manual hydraulic calculations, Microsoft Excel, and EPANET 2.0.

The research procedure consisted of several stages, namely data collection, data preparation, hydraulic parameter calculation, pipe-flow analysis, head-loss calculation, EPANET 2.0 modelling, and comparison of the results obtained from the three approaches.

3.2 Research Location and Data Collection

The study was conducted at PDAM Tirta Tarum Karawang and the Perumahan Kondang Asri distribution area, Karawang, West Java, Indonesia. The research activities were conducted from October 2024 to January 2025.

The data used in this study consisted primarily of secondary data obtained from PDAM Tirta Tarum Karawang and supporting observations in the study area. The collected data included the distribution network configuration, pipe specifications, pipe diameter, pipe length, water consumption, number of customers, distribution flow rate, and pipe roughness coefficient.

The distribution network consisted of PVC pipes with diameters of 300 mm, 250 mm, and 50 mm. The roughness coefficient used for the PVC pipes was 120. The network served approximately 1,035 customers, with the distribution system containing the main and branch pipe sections connecting the water supply system to the residential blocks.

The water consumption data were obtained from the November and December 2024 records. The data were converted into flow rate units (m^3/s) for subsequent hydraulic calculations. The raw water supply flow used in the analysis was 106 L/s.

Data collection was conducted through three techniques: (1) observation of the water distribution system and its operating conditions; (2) documentation of technical and operational records provided by PDAM Tirta Tarum Karawang; and (3) interviews with relevant personnel to clarify the characteristics and operation of the distribution network.

3.3 Hydraulic Calculation Method

The hydraulic analysis was performed to determine the flow velocity, flow regime, major head loss, and minor head loss in the distribution network.

3.3.1 Flow Rate and Velocity

The flow rate was calculated from the recorded water consumption using Eq (1) and (2):

$$Q = \frac{\boldsymbol{V}}{\boldsymbol{A}} = \frac{\text{Volume}}{\text{Waktu}} \quad (1)$$

$$\text{Debit} = \frac{\text{Volume}}{31\ hari.15\ menit.60\ detik} \quad (2)$$

where (Q) is the flow rate (m^3/s), (V_w) is the volume of water (m^3), and (t) is the flow duration (s).

3.3.2 Reynolds Number

The flow regime was determined using the Reynolds number:

$$V = \frac{Panjang\ Pipa.Debit}{(3{,}14.(Diameter\ pipa/1000)^2} \quad (3)$$

3.3.3 Major Head Loss

Major head loss due to friction along the pipe was calculated using the Darcy–Weisbach equation:

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$$\text{Head Mayor} = \textit{friction factor}\ x\ (\frac{Panjang}{diameter})x\ \frac{kecepatan^2}{2.gravitasi}\ h_f = f\ x\ (\frac{L}{d})\ x\ \frac{V^2}{2.g} \quad (4)$$

where (hf) is the major head loss (m), (f) is the Darcy friction factor, (L) is the pipe length (m), (D) is the pipe diameter (m), (V) is the flow velocity (m/s), and (g) is gravitational acceleration (m/s²).
The friction factor was determined based on the flow regime and pipe characteristics.

3.3.4 Minor Head Loss

$$Head\ Minor = \frac{Nilai\ \text{"K" Sambungan T}.Kecepatan^2}{Gaya\ gravitasi}\ h_m = \frac{K.V^2}{2.g} \quad (5)$$

Local losses caused by fittings and changes in flow direction were calculated using:

3.4 Microsoft Excel Calculation

Microsoft Excel was used to facilitate repetitive hydraulic calculations based on the same input parameters used in the manual calculation. The spreadsheet calculation included flow rate, pipe cross-sectional area, flow velocity, Reynolds number, friction factor, major head loss, minor head loss, and total head loss.

The use of Microsoft Excel was intended to reduce arithmetic repetition while maintaining the same hydraulic equations applied in the manual calculation. Therefore, Excel results were used as a computational verification of the manual calculations.

3.5 EPANET 2.0 Modelling

EPANET 2.0 was used to simulate the hydraulic behaviour of the water distribution network. The network model consisted of the relevant hydraulic components, including reservoirs, junctions, pipes, and other components represented in the actual distribution system.

The principal input parameters included pipe length, pipe diameter, pipe roughness coefficient, water demand, reservoir conditions, and network connectivity. The PVC pipe roughness coefficient was set to 120.

RESULT AND DISCUSSION

4. Results and Discussion

4.1 Water Consumption in Griya Kondang Asri

The analysis of water consumption was conducted using monthly distribution and billing data from Griya Kondang Asri, Karawang, for November and December 2024. The results indicate that the total recorded water consumption during the two-month observation period was **1,560,759 m³**, consisting of **772,822 m³ in November** and **787,937 m³ in December**.

The water consumption in November was distributed across blocks A1–A8, B1–B8, C1–C9, D1–D10, E–E10, BB1–BB5, CC1–CC5, DD1–DD3, EE1–EE2, and Jl. Raya Kondang Asri. The highest consumption was recorded in block B1–B8, with **199,884 m³**, followed by block C1–C9 with **129,565 m³** and block D1–D10 with **107,837 m³**. Meanwhile, the lowest consumption was recorded in EE1–EE2, with **12,869 m³**.

The total consumption in December increased to **787,937 m³**. Compared with November, this represents an increase of **15,115 m³**, or approximately **1.96%**. However, when the consumption is normalized by the number of days in each month, the average daily consumption decreased from **25,760.73 m³/day in November** to **25,417.32 m³/day in December**. Thus, although the total monthly consumption increased, the average daily consumption decreased by approximately **343.41 m³/day**.

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This finding indicates that the difference in monthly consumption is partly associated with the different observation periods, since November consisted of 30 days whereas December consisted of 31 days. Therefore, comparison based only on monthly totals may provide a different interpretation from comparison based on daily average consumption. For evaluating the hydraulic performance of the distribution network, the daily average flow is more representative because it accounts for differences in observation duration.

4.2 Distribution Flow Rate

The water consumption data were subsequently converted into flow rate to obtain the hydraulic input for analysis of the distribution network. The flow rate represents the volume of water passing through a particular section of the network per unit of time.

The calculated flow-rate values for the individual blocks varied considerably. For the analyzed network, the reported flow rates ranged from approximately **0.00047 m³/s to 0.01495 m³/s**. The highest value in the presented dataset was recorded in block E6, with a flow rate of **0.014946 m³/s**, whereas the lowest value was recorded in block B4, with **0.000466 m³/s**.

The variation in flow rate indicates that water demand is not uniformly distributed throughout the housing area. Areas with higher consumption generate greater hydraulic demand and consequently require sufficient pressure and flow capacity in the upstream distribution pipes. Conversely, sections with lower demand may experience different hydraulic conditions depending on their location within the network.

The flow-rate variation is therefore an important input for evaluating the distribution system because hydraulic performance is influenced not only by pipe diameter but also by the magnitude and spatial distribution of water demand.

4.3 Flow Velocity in Distribution Pipes

The calculated flow velocity was obtained using the flow rate and the cross-sectional area of the pipe. Based on the data presented, all distribution branches analyzed in the residential area use a nominal pipe diameter of **50 mm**. Consequently, differences in flow velocity are primarily associated with differences in flow rate.

For example, block A1 has a reported flow rate of **0.002473 m³/s** and a pipe diameter of 50 mm, resulting in a calculated flow velocity of approximately **1.260 m/s**. The velocity results for other blocks show substantially higher values in locations with greater flow demand. For example, blocks B3, C4, and E6 have reported velocities of approximately **7.159 m/s, 7.251 m/s, and 14.946 m/s**, respectively, based on the supplied calculation results.

The substantial variation in velocity demonstrates that the hydraulic loading of the network is uneven. A higher flow velocity generally corresponds to a greater hydraulic gradient and potentially greater frictional losses along the pipe. Therefore, locations with relatively high velocities require particular attention when assessing head losses and pressure conditions.

The results also suggest that the use of a uniform 50-mm branch-pipe diameter may result in different hydraulic conditions among blocks because the demand characteristics differ considerably. Consequently, hydraulic simulation is required to identify whether the existing pipe configuration can adequately accommodate the spatial variation in demand.

4.4 Branch Pipe and Total Pipe Length

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The analysis of the residential distribution network identified **62 blocks**, with an assumed **32 branch pipes per block**. Based on this configuration, the total number of branch pipes was calculated as:

CB = BL × PL

CB = 62 × 32 = 1,984 branches

The resulting total number of branch pipes was therefore **1,984 branches**. Assuming an average branch-pipe length of 2 m, the total estimated branch-pipe length was calculated as:

LCB = L × CB

LCB = 2 × 1,984 = 3,968 m

Thus, the estimated total length of the branch-pipe network was **3,968 m**.

The substantial number of branch connections indicates that the residential network has a relatively complex distribution structure. Each additional branch and connection contributes to the hydraulic resistance of the system, particularly when local losses at fittings and junctions are considered. Therefore, the assessment of the network should not be limited to friction losses along straight pipe sections but should also consider minor losses caused by elbows, T-joints, and other fittings.

4.5 Hydraulic Characteristics of the Main Distribution Pipes

The main distribution system supplying Griya Kondang Asri consists of pipes with diameters of **300 mm and 250 mm**. The recorded main-pipe sections include the route from Jl. Suroto Kunto to Jl. Raya Klari and subsequent sections toward the residential area.

The longest section identified in the supplied data is the **Jl. Suroto Kunto–Jl. Raya Klari** section, with a length of **2,511 m** and a pipe diameter of **300 mm**. The following sections use a diameter of **250 mm**, with lengths ranging from 85 to 385 m.

The reported total flow entering the network was **0.533 m³/s**, which was subsequently used to estimate the flow velocity in the main pipe. For the 300-mm pipe section from Jl. Suroto Kunto to Jl. Raya Klari, the reported velocity was approximately **7.43 m/s**.

The relatively high calculated velocity indicates a substantial hydraulic load in the main distribution pipe. High velocity can increase frictional head loss and may consequently influence the pressure available at downstream nodes. Therefore, the main-pipe hydraulic characteristics are critical in determining the ability of the system to deliver adequate water to the residential distribution branches. The diameter transition from 300 mm to 250 mm should also be considered in the hydraulic evaluation because changes in cross-sectional area influence flow velocity and energy losses. The combined effects of pipe length, diameter, flow rate, and fittings are subsequently evaluated through the hydraulic simulation.

4.6 Major and Minor Head Losses

Hydraulic losses in the distribution network consist of major losses caused by friction along the pipe and minor losses caused by fittings and changes in flow direction. The major head loss was evaluated using the friction characteristics of the pipe, while minor losses were evaluated for fittings such as 90° elbows and T-joints.

For the analyzed network, the reported minor-loss calculation for a 90° elbow in block A1 produced a value of approximately **0.076 m**, while the calculation for a T-joint in block A2 produced approximately **0.888 m** according to the supplied results.

These results demonstrate that fittings can contribute significantly to the total hydraulic loss, particularly in sections where multiple fittings are installed. Although an individual fitting may produce

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a relatively small loss, the cumulative effect of numerous elbows, T-joints, and pipe connections can become significant in a network containing a large number of branches.

Therefore, the evaluation of network performance should incorporate both major and minor head losses. Ignoring minor losses may underestimate the actual energy loss and pressure reduction experienced by water as it travels from the main distribution pipe to individual consumer locations.

4.7 Hydraulic Simulation Using EPANET 2.0

The calculated network parameters were subsequently used as input for hydraulic simulation using **EPANET 2.0**. The model represents the distribution system through nodes, pipes, and other network components. Pipe characteristics such as diameter, length, and roughness were incorporated into the model, while water demand was represented at the corresponding network nodes.

The use of EPANET enables the hydraulic behavior of the network to be evaluated simultaneously rather than through isolated calculations for individual pipe sections. The simulation can provide information regarding flow rate in each pipe, pressure at nodes, and hydraulic losses throughout the network.

The combination of field-based consumption data, calculated flow characteristics, pipe geometry, and hydraulic simulation provides a more comprehensive representation of the existing distribution system. In particular, the simulation results can be used to identify sections experiencing relatively high flow velocity, substantial head loss, or inadequate pressure.

4.8 Discussion of Network Performance

The results indicate that water demand in Griya Kondang Asri is unevenly distributed among blocks. The difference in consumption between blocks is reflected in the variation in calculated flow rates and velocities. This condition is important because a distribution network must accommodate spatially varying demand while maintaining adequate hydraulic performance.

The comparison between November and December also shows that monthly consumption increased by **15,115 m³**, while the average daily consumption decreased by **343.41 m³/day**. This finding emphasizes the importance of using normalized daily demand when comparing consumption between months with different numbers of days.

Furthermore, the calculated velocity in several distribution branches and in the main pipe indicates a relatively high hydraulic loading condition based on the supplied calculations. Such conditions may contribute to increased frictional and local losses. The large number of branch pipes and fittings further increases the complexity of the hydraulic system.

Consequently, the hydraulic performance of the Griya Kondang Asri distribution network cannot be assessed solely from total water consumption. It must also consider the relationship between **water demand, flow rate, pipe diameter, flow velocity, pipe length, major head loss, minor head loss, and pressure at network nodes**. EPANET 2.0 provides an appropriate framework for integrating these parameters and identifying sections of the network that require further evaluation or potential improvement.

CONCLUSION

The analysis of the water distribution network in Griya Kondang Asri, Karawang, shows that water consumption during November–December 2024 reached **1,560,759 m³**, consisting of **772,822 m³ in November** and **787,937 m³ in December**. Although total monthly consumption increased by **15,115 m³**, the average daily consumption decreased from **25,760.73 m³/day** in November to **25,417.32 m³/day**

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in December. This indicates that differences in monthly consumption should be evaluated by considering the number of days in each observation period.

The hydraulic analysis also demonstrates substantial variation in flow rate and velocity among distribution blocks. The variation is primarily associated with differences in water demand within the network, while the branch distribution system predominantly uses 50-mm pipes. The analysis of the network configuration identified approximately **1,984 branch pipes** with an estimated total branch-pipe length of **3,968 m**. The main distribution system consists of 300-mm and 250-mm pipes, with the reported total flow reaching **0.533 m³/s** based on the calculation used in the study.

Major and minor hydraulic losses are important factors in evaluating the distribution network. In addition to friction losses along the pipes, fittings such as 90° elbows and T-joints contribute to additional head losses. Therefore, evaluation of the network performance needs to consider the combined effects of demand, flow rate, pipe diameter, velocity, pipe length, and losses caused by fittings.

Overall, the findings indicate that the hydraulic performance of the Griya Kondang Asri distribution network is strongly influenced by the uneven distribution of water demand and the configuration of its pipe network. The use of EPANET 2.0 provides an integrated approach for evaluating flow and pressure conditions throughout the network and can support the identification of sections requiring further hydraulic assessment or improvement. Further studies are recommended to validate the calculated flow rates and hydraulic parameters using field measurements and network calibration before determining specific pipe replacement or capacity-improvement measures.

AUTHOR'S CONTRIBUTION

M.N. contributed to the conceptualization of the study, data collection, data analysis, and preparation of the initial manuscript. F.A. contributed to the research methodology, data analysis, interpretation of the results, and manuscript review. Z. contributed to data validation, interpretation of the findings, and critical review of the manuscript. All authors contributed intellectually to the study, reviewed and approved the final version of the manuscript, and agreed to be accountable for all aspects of the work.

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DECLARATION OF COMPETING INTEREST

The authors declare that they have no competing interests.

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