Hydraulic Analysis of Clean Water Distribution System in Plumbing Laboratory for Determining Pump Capacity

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Abstract.
The plumbing laboratory serves as practical learning facility design to simulate building water supply systems and support competency based-education in vocational institution. A reliable water distribution system is essential to ensure effective laboratory activities to provide hydraulic conditions that adequately represent actual building plumbing systems. This study aims to analyze the clean water distribution system of the plumbing laboratory by evaluating the design flow rate, hydraulic characteristic of the piping network, and the total dynamic head (TDH) required for pump selection. A descriptive quantitive approach was employed based on the existing laboratory conditions. Hydraulic analysis was conducted by estimating the design flow rate, hydraulic characteristic of the piping network, and the by estimating the design flow rate using the Plumbing Fixture Unit (PFU) method, calculating major head loss using the Hazen-Williams equation, and determining minor head loss based on the loss coefficients of pipe fittings. The result indicate that the total plumbing fixture unit of 31.5 corresponds to a design flow rate of 0.00132 m3/s. The hydraulic analysis yielded a major head loss of 6.23 m, a minor head loss of 29.50 m, and TDH of 38.03 m. Theses finding provide the hydraulic parameters required for selecting an appropiate pump to improve the laboratory water distribution system. The proposed approach can serve as a reference for developing plumbing laboratory facilities and enhancing practice-based learning in vocational education.
Keywords: *plumbing laboratory, clean water distribution system, head loss and pump.*

I. INTRODUCTION

Vocational education aims to produce competent and work-ready graduates through practice-based learning aligned with the needs of business and industry. The implementation of Outcome-Based Education (OBE) emphasizes that student competency attainment is determined not only by classroom learning processes but also by the effectiveness of learning facilities, particularly laboratories, in supporting the achievement of graduate learning outcomes (GLOs). Therefore, the laboratory must provide a learning environment that represents actual working conditions so that students gain relevant practical experience.

In the field of piping engineering, the laboratory serves as a learning medium for simulating plumbing systems in buildings. Through practical activities, students learn the installation, operation, and testing of clean water distribution systems using various plumbing fixtures such as washbasins, urinals, and water closets (WCs). In addition to understanding piping network configurations, students also learn flow characteristics, pressure, and the performance of water distribution systems as applied in actual buildings.

The plumbing system is an important part of building utilities that functions to supply clean water with adequate quantity, quality, and pressure. In Indonesia, its design refers to SNI 8153:2015, which regulates water demand, Plumbing Fixture Units (PFUs), piping network dimensions, reservoir capacity, and pump selection. Various studies show that pump capacity, pipe dimensions, and the hydraulic characteristics of the network affect the performance of the water distribution system, making hydraulic analysis an important stage in designing clean water distribution systems [2].

Unlike operational buildings, a plumbing laboratory primarily functions as a learning facility, so its water distribution system must be able to support various practical scenarios. Laboratories are an important component of vocational education because they provide practice-based learning environments that enable students to apply theoretical concepts to real conditions. In a plumbing laboratory, the clean water

distribution system not only functions to deliver water to plumbing fixtures but also serves as a simulation medium for studying flow characteristics, pressure measurement, head loss, and the operation of various plumbing fixtures. Therefore, the clean water distribution system must be able to provide adequate flow rate and pressure so that practical activities can run optimally [3], [12].

In the existing condition, the clean water distribution in the laboratory still uses gravity flow from the upper tank. Although this system is simple and easy to operate, the service pressure produced depends on the elevation difference and the water level in the tank, potentially causing flow rate and pressure variations during practical activities. These conditions can affect the representativeness of the plumbing system simulation used as a learning medium. One alternative for improving the performance of the clean water distribution system is the use of a pump. However, pump capacity selection cannot be made empirically; it must be based on an analysis of flow rate requirements, head loss, and Total Dynamic Head (TDH).

Various studies have discussed the analysis of clean water distribution systems and pump capacity selection in multi-story buildings, hospitals, hotels, apartments, and educational facilities using the PFU approach, hydraulic analysis, and head loss evaluation. Gani et al. [4] determined the design flow rate based on the number of plumbing fixtures to plan a building's clean water distribution system, while Gustiawan et al. [5] used flow rate requirements as a basis for determining the type of pump in a residential area. On the other hand, Asmarawati et al. [1] showed that optimizing centrifugal pump design can improve water distribution efficiency, so pump selection needs to consider the characteristics of the system being served. Such studies generally focus on meeting the water needs of building occupants and improving distribution system efficiency. However, studies that specifically discuss pump capacity requirements in plumbing laboratories as learning facilities remain limited. In fact, laboratories have different operational characteristics because the water distribution system is used to support various practical scenarios and plumbing system simulations.

Based on these conditions, this study analyzes the clean water distribution system requirements in a plumbing laboratory through flow rate requirement calculation using the PFU method, head loss analysis in the piping network, and TDH calculation as the basis for determining pump capacity [12]. The results are expected to provide technical recommendations regarding appropriate pump capacity and serve as a reference for developing plumbing laboratory facilities to support practical learning in vocational education.

II. METHODS

This study uses a hydraulic analysis approach to evaluate the characteristics of the clean water distribution system and determine the appropriate pump capacity for the plumbing laboratory. Based on the flowchart in Figure 3, the analysis stages are carried out systematically through two main stages: identification of existing conditions and hydraulic analysis.

The first stage begins with identification of the existing conditions in the plumbing laboratory room on the 2nd floor, measuring . In the initial condition before the development of learning media (Figure 1), the laboratory room was still an open area with piping installations mounted on the walls and ceiling area. Based on the clean water system distribution plans for the 2nd floor (Figure 2) and 3rd floor, the existing system still relies on gravity flow sourced from a roof tank with a capacity of . A summary of the existing condition parameters is presented in Table 1.30×9 m350 L



Fig. 1. Existing conditions before the development of learning media

These conditions indicate that the existing piping network uses a main pipe measuring ¾ inch with a critical path length of , and serves washbasins, water closets (WCs), and urinals. The limitations of the gravity system and the permanent piping configuration underlie the need for developing practical cubicles that are more flexible and representative of actual field conditions.10 m557

The second stage continues with hydraulic analysis referring to the SNI 8153:2015 standard. This analysis begins with calculating flow rate requirements using the Plumbing Fixture Unit (PFU) method based on the type and number of fixtures, which is then converted into the design flow rate (). Next, the flow velocity () is calculated from the ratio of the design flow rate to the pipe cross-sectional area. The head loss calculation is divided into two types: major head loss using the Hazen-Williams equation by considering the critical path length (), pipe diameter (), PVC roughness coefficient (), and flow rate (), and minor head loss calculated based on the loss coefficient () for each fitting such as elbows, tees, and check valves, referring to Crane Technical Paper No. 410. These parameters are summed to determine the Total Dynamic Head (TDH) [14], which is then used together with the design flow rate to establish optimal pump specifications for supporting practical learning activities.$QvLDCQK$



TABLE 1. Existing Conditions of the Clean Water Distribution System in the Plumbing Laboratory

Parameter	Value
Water Source	Roof Tank 350 L
Distribution System	Gravity
Main Pipe Diameter	¾ inch (inner Ø 21.4 mm)
Critical Pipe Path Length	10 m
Washbasin	5 units
Water Closet (WC)	5 units
Urinal	7 units

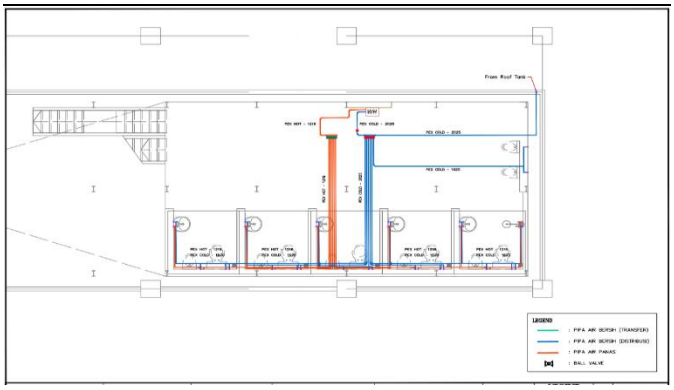

Fig. 2. Clean Water Distribution System Plan for the Plumbing Laboratory, 2nd Floor

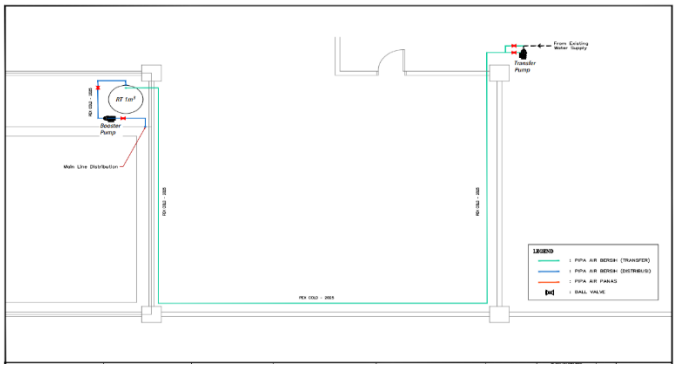

Fig. 3. Clean Water Distribution System Plan for the Plumbing Laboratory, 3rd Floor

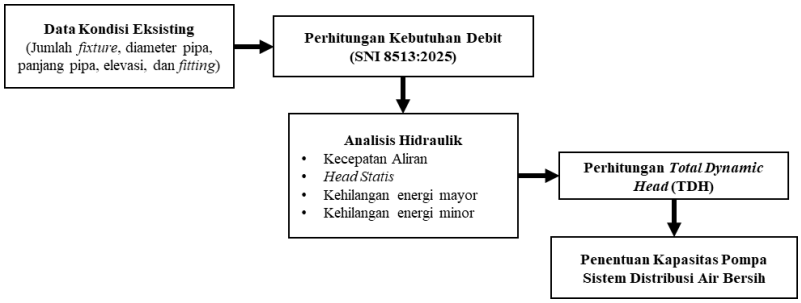

Fig. 3. HYDRAULIC ANALYSIS FLOWCHART

The flowchart in Figure 3 shows the analysis stages carried out in this study. The analysis begins with identifying the existing conditions of the clean water distribution system, followed by calculating flow rate requirements using the Plumbing Fixture Unit (PFU) method in accordance with SNI 8153:2015 based on the number and type of plumbing fixtures in the laboratory. The PFU value is then converted into the design flow rate using the curve relating PFU to design flow rate in accordance with the standard. The hydraulic characteristic analysis includes calculating flow velocity, static head, and head loss to obtain the Total Dynamic Head (TDH) [14]. Flow velocity () is calculated from the ratio of the design flow rate () to the pipe cross-sectional area (). The head loss calculated consists of major and minor head losses. Major head loss is calculated using the Hazen-Williams equation by considering pipe length based on the critical path (), pipe diameter (), PVC roughness coefficient (), and flow rate (). The major head loss calculation uses the Hazen-Williams equation because this study analyzes a clean water distribution system in a smooth-surfaced PVC piping network, making the method suitable for use in building plumbing system design.$vQALDCQ$

$$h_f = 10.67 \frac{LQ^{1.852}}{C^{1.852} D^{4.87}}$$

Meanwhile, minor head loss is calculated based on the loss coefficient () for each fitting through which the flow passes, such as elbows, tees, and check valves, referring to Crane Technical Paper No. 410. These parameters are then summed to determine the Total Dynamic Head (TDH) [14]. The TDH value obtained, together with the design flow rate of the distribution system, is then used to determine the pump capacity capable of meeting the operational needs of practical activities for the clean water distribution system in the plumbing laboratory.K

III. RESULT AND DISCUSSION

The results of the analysis are divided into four discussion subsections in sequence. The discussion is presented in sequence, starting from the analysis of water requirements and design flow rate, followed by the analysis of hydraulic characteristics, through to the determination of pump capacity as a recommendation for developing the clean water distribution system in the plumbing laboratory.

Analysis of Water Requirements and Design Flow Rate

Based on the inventory of plumbing fixtures in the Plumbing Laboratory, the clean water distribution system serves 5 washbasins, 5 water closets, and 7 urinals. These quantities and types form the basis for

determining the design flow rate of the clean water system used in the plumbing laboratory. The recapitulation data can be seen in Table 2.

TABLE 2. Recapitulation of Fixtures and PFU Values

Plumbing Fixture	Quantity	PFU Value	Total PFU
Washbasin	5	1	5
Urinal	7	2	14
Water Closet (WC)	5	2.5	12.5
	Total		31.5

Based on Table 2, a fixture unit value of 31.5 was obtained, yielding a design flow rate of 79 L/min according to the conversion from the fixture unit-to-flow relationship curve in SNI 8513:2015. The same approach was used by Gani et al. (2021) in designing a building plumbing system to determine flow rate based on the number of plumbing fixtures. This flow rate indicates the flow capacity that must be met by the clean water distribution system so that all plumbing fixtures can operate simultaneously in accordance with practicum learning needs. The design flow rate is then used as a parameter in the hydraulic characteristic analysis of the piping network to determine head loss and TDH values. (Gani et al., 2021)

Hydraulic Characteristic Analysis of the Piping Network

TABLE 3. Results of Hydraulic Characteristic Analysis

Parameter	Value
Flow rate (Q)	79 L/min = 0.001317 m³/s
Pipe internal diameter (D)	21.4 mm
Flow velocity (v)	3.66 m/s
Static head (hs)	2.30 m
Major head loss (hf)	6.23 m
Minor head loss (hm)	29.5 m
Total Dynamic Head (TDH)	38.03 m

Referring to the calculation results in Table 3, a flow velocity of was obtained in a pipe with an internal diameter of . This value indicates that the water flow velocity in this system is above the recommended range. In building plumbing system design, the recommended flow velocity according to SNI 8153:2015 is in the range of -- so that head loss, noise, and the potential for water hammer can be minimized. Thus, the water flow velocity produced in this distribution system indicates flow characteristics that tend to increase head loss in the piping network.3,66 m/s21,4 mm1,02,5 m/s

This condition affects the calculation results of head loss occurring in the entire system. Research by De Corte and Sörensen [3] shows that pipe diameter selection is one of the main parameters in water distribution network optimization, while Matlakala et al. [9] explain that pipe dimensions also affect the operational performance of centrifugal pumps. The major head loss that occurred was , while the minor head loss was . Major head loss is head loss due to friction between the water flow and the inner wall of the pipe along the distribution path, whereas minor head loss originates from local resistance due to fittings such as elbows, tees, and check valves. In this hydraulic parameter calculation, the major head loss value is smaller than the minor head loss. This indicates that the piping network configuration—especially the number of connections and changes in flow direction—contributes more dominantly to head loss than the pipe length itself [12].6,23 m29,50 m90°

When compared with the Total Dynamic Head (TDH) value, the minor head loss in this system contributes , the major head loss contributes , while the static head of contributes . This is consistent with previous research showing that a piping network with many branches causes local head loss to become the dominant factor in TDH calculation. Thus, optimizing the piping network layout or reducing the number of fittings will have a more significant effect on reducing head requirements than changing the system elevation.77,6%16,4%2,3 m6,0%

The accumulation of static head, major head loss, and minor head loss yields a TDH of , which represents the total energy that must be supplied by the pump to distribute water at the design flow rate of optimally to all plumbing fixtures. Therefore, precision in calculating TDH strongly determines the accuracy of pump selection [14]. Pump selection cannot be based solely on flow rate requirements; it must consider all head losses occurring in the distribution network. This TDH value is then used as the main basis for determining the appropriate pump capacity to support the operational activities of the Plumbing Laboratory.38,03 m79 L/menit

Determination of Pump Capacity

The hydraulic analysis results show that the clean water distribution system in the Plumbing Laboratory requires a design flow rate of 79 L/min and a TDH of 38.03 m. These two obtained parameters form the basis for determining the pump capacity needed to optimize the clean water distribution system to all plumbing fixtures in accordance with practicum learning needs (Hirrel, 1989; Takács, 2021). A recapitulation of the pump requirement parameters is presented in Table 4

TABLE 4. Parameters for Pump Capacity Requirements of the Clean Water Distribution System

Parameter	Value
Design Flow Rate (Q)	79 L/min = 0.001317 m^3/s
Total Dynamic Head (TDH)	3.66 m/s
Pump Capacity Criteria	Able to produce a flow rate ≥ 79 L/min with a head ≥ 38.03 m

Referring to the results in Table 4, determining pump capacity cannot be based solely on flow rate requirements; it must consider the pump's ability to produce head in accordance with the system's hydraulic characteristics. The pump should operate as close as possible to the best efficiency point so that head loss can be minimized. This approach is known as system analysis in centrifugal pump selection [7].

Besides system characteristics, pump performance is also affected by internal design parameters such as impeller diameter, suction pipe diameter, discharge pipe diameter, and blade configuration. These parameters affect flow capacity, head, and pump efficiency, so they must be considered in the selection process [8]. Other research also shows that changes in suction diameter can improve pump performance by improving flow characteristics toward the impeller and reducing the potential for cavitation. This indicates that the piping network configuration has a direct influence on the pump's operational performance [9].

Flow rate () represents the flow requirement that must be supplied to all plumbing fixtures, while Total Dynamic Head (TDH) indicates the total energy required to overcome elevation differences and head loss in the piping network. Therefore, both parameters must be met simultaneously so that clean water distribution can proceed according to plan. This approach is in line with the system curve concept, which states that pump specifications must be determined based on the system's hydraulic requirements, not merely on flow capacity [10].Q

Based on the hydraulic analysis results obtained in this study, the pump selected to serve the clean water distribution system in the Plumbing Laboratory must be able to deliver water at a minimum flow rate of at a head of . Lower pump capacity may cause insufficient pressure at service points, making water distribution to plumbing fixtures suboptimal. Conversely, using a pump with a capacity far exceeding system requirements can increase inefficient operational energy consumption. This finding is consistent with previous research showing that evaluation of head loss and TDH is the main basis for determining pump capacity in clean water distribution systems [4].79 L/menit38,03 m

The results of this study provide a technical basis for planning and developing clean water distribution systems in the Plumbing Laboratory. Unlike several previous studies generally applied to operational building distribution systems, this study adapts hydraulic analysis for a learning facility, thus producing design parameters that can be used as a reference for pump selection to support optimal practicum operations. The research results of Asmarawati et al. [1] show that optimizing centrifugal pump design based on system requirements can improve water distribution efficiency. This principle aligns with this study, in

which pump capacity is determined based on flow rate requirements and the hydraulic characteristics of the network.

The approach of evaluating pump capacity based on system requirements is also applied by Rosytha et al. [11] and Sumaryanto et al. [13], although in flood control systems. This common principle shows that pump capacity must always be adjusted to the hydraulic characteristics of the system being served so that pump performance remains optimal. This approach allows water distribution systems to be designed according to actual hydraulic conditions, thereby reducing the risk of capacity mismatch (under-design or over-design). Thus, hydraulic analysis can serve as a systematic planning procedure in the development of laboratory facilities and clean water distribution systems in buildings with similar characteristics.

After pump capacity is determined, the aspect of operational reliability also needs attention. Wicaksono et al. [16] emphasize that planned pump maintenance plays an important role in maintaining centrifugal pump performance, while Musnal and Fitrianti [10] show that matching pump capacity to system characteristics will improve overall operational effectiveness.

From a learning perspective, implementing a water distribution system designed based on hydraulic analysis results enables the Plumbing Laboratory to provide practicum media that are more representative of piping installation conditions in the field. Students not only learn how to install piping components but can also understand the relationship between water demand, flow characteristics, head loss, and pump capacity determination as an integrated system (rather than relying solely on the concept of gravity-based flow distribution, which is less relevant to pressurized application conditions in the field).

Although this study has produced technical parameters for determining pump capacity, the results obtained still depend on the piping network configuration of the Plumbing Laboratory analyzed. Changes in pipe diameter, distribution path length, or the number of fittings used in the system can affect the TDH value, so the required pump capacity may also change. Therefore, the hydraulic analysis approach needs to be repeated if there are changes in the configuration of the piping network used.

IV. CONCLUSION

The analysis results obtained in this study lead to the following conclusions:

1. Hydraulic analysis of the clean water system in the Plumbing Laboratory produced a design flow rate of 79 L/min and a total dynamic head (TDH) of 38.03 m, which are the main parameters in determining pump capacity.
2. The flow rate and TDH parameters must be considered simultaneously so that flow and energy requirements can be met and operate in accordance with the design conditions.

The hydraulic analysis approach used can serve as a systematic technical basis for determining pump capacity and can be used as a reference in planning the development of clean water distribution systems in the Plumbing Laboratory or similar learning facilities.

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