JAITA

JOURNAL OF ADVANCED INDUSTRIAL TECHNOLOGY AND APPLICATION
e-ISSN: 2716-7097

Vol. 7 No. 1 (2026) 15-25
https://publisher.uthm.edu.my/ojs/index.php/jaita

Investigation of Viscosity Effects on Flow Rate and Pressure Drop in a PVC Fluid Transfer System Using Different Water Sources

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DOI: https://doi.org/10.30880/jaita.2026.07.01.002

Article Info

Received: 11 June 2025
Accepted: 12 November 2025
Available online: 18 June 2026

Keywords

Reynolds number, fluid transfer system, viscosity, fluid, flow rate

Abstract

Fluid transfer systems are essential in domestic and industrial settings, requiring efficient design for fluid conveyance. This study developed a fluid transfer system with centrifugal pumps, gate valves, and PVC plumbing, ensuring structural stability with a metal frame weighing 28.9 kg and tank guides weighing 67.7 N and 47.6 N. Flow analysis showed turbulent conditions with a Reynolds number of 9160. Pressure drops were highest in the longest pipeline (0.171 N/m^3) and significant at 90° elbows (0.1174 N/m^3), compared to gate valves (0.0214 N/m^3). Tests with rainwater, tap water, and stream water indicated rainwater had the highest flow volume (48.65 L in 20 min) and flow rate (2.43 L/min), while tap and stream water had lower rates (2.07 and 1.83 L/min). The experimental results confirms established fluid dynamics principles that higher viscosity fluids flow more slowly through pipes, substantiating the dependence of flow rate on fluid viscosity.

1. Introduction

1.1 Background of the Study

Fluid transfer systems, which consist of transfer lines conveying fluid from a filling reservoir to a receiving tank, are widely used not only in domestic applications but also extensively in industries such as petroleum, oil production, and foam manufacturing, making the study of flow dynamics and viscosity effects within these systems crucial for optimizing performance [1]. Over the years, numerous experimental studies have analyzed the complex dynamics of fluid flow using pipes and valves, focusing on factors such as pressure drop, turbulence, and flow regimes; however, only a limited number have specifically examined fluid flow rates within purpose-built fluid transfer systems designed to simulate real-world applications, with the primary aim of understanding how variations in fluid viscosity influence flow behavior and efficiency. Fluid transfer systems are engineered setups used to move fluids from a filling reservoir to a receiving tank through a dedicated transfer line connecting the outlet of the reservoir to the inlet of the receiving tank [2]. These systems are essential not only for everyday domestic uses, such as water supply and household fluid management, but are also critically important in industrial sectors including petroleum extraction, oil production, and foam manufacturing, where precise control of fluid flow rates and understanding viscosity effects are vital for operational safety, process optimization, and energy efficiency [3].

Currently, pipes are considered the most economical and efficient method for transporting large volumes of substances such as oil, water, refined petroleum products, or natural gas over land. They offer significant advantages over alternatives like railroad shipping by providing continuous, reliable flow with lower operational costs, reduced transit times, minimized environmental impact, and enhanced safety through controlled pipeline networks [3]. Katrin et al. [4] demonstrated that as fluid moves through a pipe, the internal roughness of the pipe wall creates localized eddy currents within the fluid. This leads to increased turbulence and frictional resistance, which strongly hinder fluid flow and cause greater energy losses and pressure drops throughout the pipe. This effect is more pronounced in pipes with rougher surfaces such as concrete or cast iron than in smoother materials like glass or copper, where frictional resistance caused by roughness-induced turbulence can substantially reduce flow efficiency and increase pumping costs [5].

Pipes with smooth walls such as glass, copper, brass, and polyethylene cause minimal frictional resistance because their smooth surfaces reduce turbulence and eddy formation [6]. In contrast, rougher pipes made of concrete, cast iron, or steel generate larger eddies, significantly increasing friction and pressure loss. Fluid flow within pipes is classified as laminar (smooth, orderly flow at low Reynolds numbers) or turbulent (chaotic flow at high Reynolds numbers) [17]. In laminar flow, friction depends mainly on fluid viscosity and velocity, with little effect from pipe roughness, whereas in turbulent flow, both the Reynolds number and pipe roughness influence friction, with rough pipes causing higher resistance [7]. These factors are key to designing efficient piping systems, as smooth pipes reduce frictional losses while rough pipes increase energy consumption due to greater turbulence. Turbulent flow is defined by the chaotic and irregular motion of fluid particles, whereas laminar flow is known as smooth, orderly, or viscous flow.

Unlike many existing studies that predominantly analyze isolated pipe or valve flow, this research develops and tests a complete fluid transfer system incorporating actual industrial elements such as centrifugal pumps, gate valves, and PVC plumbing, designed according to standard engineering procedures. By testing fluids from different natural sources with varying viscosities under controlled conditions, this study extends the understanding of how viscosity variations influence overall flow behavior and system efficiency. The findings offer practical insights to better predict performance in similar industrial systems, contributing to improved design and operational strategies that enhance system reliability and reduce energy costs. Hence, the effect of fluid viscosity on volume flow rate in a purpose-built fluid transfer system mimicking real industrial practices was systematically investigated. By employing various water sources with differing viscosities, the study aims to quantify flow patterns, pressure losses, and turbulence effects, thereby providing data to optimize fluid transfer processes under diverse operational scenarios. This approach enabled a systematic evaluation of the relationship between fluid viscosity and flow rate within the designed transfer system, providing valuable insights into fluid dynamics and the impact of viscosity on flow performance.

Nomenclatures	
Q	Volume flow rate
μ	Dynamic viscosity
ρ	Fluid density
P	Pressure
ΔP	Pressure drop along the pipe
D	Pipe diameter
L	Length of the pipe
v	Fluid velocity
Re	Reynolds number
f	Darcy-Weisbach friction factor

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1.2 Limitations and Strengths of the Study

The study's strengths include its use of a complete, industrial-relevant fluid transfer system and varied natural fluids under controlled conditions, providing practical insights for industry, while its limitations involve scale constraints, limited fluid diversity, potential natural fluid variability, fixed system components, and measurement tool restrictions.

2. Materials And Methods

2.1 Materials

The developed system, as recommended by the American Water Works Association [9], comprises six main components. These include a metal base that supports the entire assembly, a flow meter to measure volume and flow rate, gate valves to control fluid flow, a strainer to filter the fluid being transferred, PVC pipe fittings (such as pipes, elbows, back nuts, nipples, and unions), and a centrifugal pump that drives fluid movement. All materials used in this study were locally sourced. The quantities and sizes of these materials are detailed in Table 1.

Table 1 *The size and quantity of the materials used*

S/No	Material	Quantity	Size
1	Angle Iron	20 ft	2” x 2”
2	Flat bar	7 ft	½”
3	Electrode	100	Gauge 10
4	Centrifugal pump	1	0.5 hp
5	Bolt and Nut	4	M10
6	Water Flow meter	1	10 bar
7	Tank Bank Nut	5	1”
8	PVC Nipple	13	1” and ¾”
9	Tee (tiger)	3	1”
10	Elbow (tiger-type)	10	1”
11	Union (tiger-type)	4	1”
12	Plug	1	1”
13	pipe (tiger)	10 ft	1”
14	Tank	2	50 litres
15	Fitter (Strainer)	1	1”
16	Drill bit	1	M8
17	Electric Wire	3 yards	2.5mm
18	Electric-Socket	1	13Amp
19	Electric Fuse-Plug	1	13Amp
20	Grinding Stone	1	-
21	Plastic Tap	2	¾”
22	Thread Tape	10	3.5 mm (big)
23	Gate valve ballpoint	4	1”
24	Measuring container	1	10 litres

2.2 Methods

2.2.1 System Design and Construction

The primary purpose of an engineering design is to develop a system that not only operates with high efficiency but also achieves economic viability and success in its intended application [10]. The system’s design focused on creating a highly efficient and economically viable structure. During the conceptualization and design phases of such systems, multiple critical factors are carefully evaluated and integrated to ensure that the final product aligns closely with the ideal standards and performance expectations. Among these factors are the availability and skill level of human resources, which influence the system’s operability and ease of use; productivity considerations, to maximize output and effectiveness; maintainability, ensuring that the system can be easily serviced and repaired over its lifespan to minimize downtime; reduction of weight, which can improve efficiency and reduce material costs; and overall cost-effectiveness, balancing performance with affordability to ensure the system is economically sustainable. By taking all these elements into account, the design process aims to produce a system that meets technical requirements while also being practical and financially feasible.

2.2.1.1 Design of Metal Base and Tank Guides

The design of the metal base involved a thorough engineering analysis, which included determining the weight and surface areas of the metal frame along with the two circular tank guides. This was done to ensure that the design adheres strictly to standard engineering practices and safety requirements. Specifically, the circular tank guides and the surface areas of the metal frame were determined by applying the formulas represented as Equation 2 and Equation 3, respectively. These calculations provided precise measurements of the material coverage needed for the structural components. Subsequently, the overall weight of the metal base was calculated using Equation 1, which took into account the density of the metal material and the previously computed surface areas. This comprehensive approach ensured that the metal base design was both structurally sound and optimized for material usage, contributing to the stability and durability of the entire system.

$$\text{Weight of frame} = \text{Mass of frame } (m) \text{ x acceleration due to gravity } (g) \tag{1}$$

$$\text{Area (tank guide)} = \frac{\pi d^2}{4} \tag{2}$$

$$\text{Area (frame)} = \text{length } (l) \text{ x width } (w) \tag{1}$$

Where, $\boldsymbol{d}$ is the diameter of the tank guide ($\boldsymbol{m}$).

2.2.1.2 Fabrication

The fabrication of the metal base, measuring 1150 mm in length and 765 mm in width, along with the circular tank guides, each having a diameter of 360 mm, involved a series of precise manufacturing steps carried out in accordance with the recommendations of the American Water Works Association [9]. Initially, the individual components were carefully cut to their specified dimensions using manual tools, specifically a hacksaw and chisel, ensuring accuracy and adherence to design specifications. Following the cutting process, the various parts were assembled and joined together through welding. This welding operation was performed using an electric arc welding machine (ESAB ORIGO, 400A) operating at a circuit voltage range of 28 to 30 volts, with 10 mm cast iron electrodes employed to create strong, durable joints between the metal components.

After welding, the fabrication process proceeded to the finishing stage, where the welded joints were ground using an electric grinding machine. This step was crucial to remove any rough edges or excess material from the welds, resulting in smooth and uniform welded sections that not only improved the structural integrity but also enhanced the overall appearance of the fabricated parts. Finally, to complete the fabrication and provide a protective and visually appealing finish, the tank guides, once securely attached to the metal base, were coated with paint. This painting process aimed to protect the metal surfaces from corrosion and wear while also giving the final product an aesthetically pleasing look suitable for its intended application.

2.2.2 Flow Meter Installation and Plumbing Process

The plumbing of the system involved the comprehensive installation of various components including pipes, valves, plumbing fixtures, strainers, and tanks, all designed to facilitate the efficient conveyance of fluids for operational use. During this process, all plumbing materials—such as pipes, elbows, tanks, the flow meter, connectors, valves, and the centrifugal pump were carefully gathered and systematically assembled to form a cohesive fluid transfer network.

A critical component of the system, the flow meter (BASE 165, with a maximum pressure rating of 10bar and operating temperature up to 45°C), was installed strategically close to the outlet tank. This placement was chosen to accurately measure the volume of fluid entering the outlet tank. Special attention was given during the installation of the flow meter to ensure that it remained completely filled with liquid at all times. This precaution was necessary because the presence of vapor within the flow meter can distort its internal geometry, leading to inaccurate measurements and compromised system performance [11].

To secure the pipes and other system components, a pipe wrench was used for tightening. To prevent leakage within the piping system, thread tape was meticulously wrapped around all threaded pipe joints before tightening. This measure ensured a tight seal and enhanced the overall integrity of the plumbing network. Finally, once all components were assembled and secured, the entire system was firmly mounted onto the fabricated metal base to provide structural stability. The two polyvinyl chloride (PVC) tanks were carefully supported by the previously

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fabricated tank guides, ensuring proper alignment and preventing undue stress on the plumbing system. This meticulous assembly process ensured that the plumbing system was robust, leak-proof, and capable of reliable fluid transport during operation.

2.2.3 Calculation of Fluid Flow Parameters

The following fluid parameters were considered during the design of the system Reynolds Number.

2.2.3.1 Reynolds Number

The Reynolds number (Re) of the flowing fluid is a dimensionless quantity that characterizes the flow regime and was obtained by dividing the kinematic **v**iscosity (viscous force per unit length) by the inertia force of the fluid (velocity x diameter) as shown in Equation 4 [12].

$$\text{Reynolds number} = \frac{\rho v D}{\mu} = \frac{vD}{\mu} \quad (4)$$

where ρ represents the fluid density in kg/m^3, v represents the fluid velocity in m/s, D represents the pipe diameter in meters, μ represents the dynamic viscosity in Pa·s or N·s/m^2, and v represents the kinematic viscosity in m^2/s.

Where the Kinematic viscosity and fluid velocity were calculated using Equation 5 and 6 respectively.

$$\text{Kinematic viscosity (V)} = \frac{Dynamic\ viscosity\ (\mu)}{Fluid\ density\ (\rho)} \quad (5)$$

$$\text{Fluid velocity (v)} = \frac{Maximum\ flowrate\ (Q)}{\pi\ x\ square\ of\ Pipe\ radius\ (R^2)} \quad (6)$$

When the Reynolds number is below 2300, the flow remains laminar, and the flow resistance is unaffected by the roughness of the pipe walls. However, when the Reynolds number rises above 4000, the flow becomes turbulent, and the frictional pressure drop is influenced by the pipe's roughness [13].

2.2.3.2 Pressure Loss in Circular Pipes Due to Fluid Flow

The pressure drop due to friction in a pipe is given by the Darcy-Weisbach equation presented in Equation 7 [14].

$$\Delta P = \lambda x \frac{L}{D} x \frac{\rho}{2} x v^2 \quad (7)$$

where ΔP represents the pressure drop in Pa or N/m^2, D represents the pipe diameter in meters, v represents the flow velocity in m/s, L represents the length of the pipe in meters, ρ represents the density of the fluid in kg/m^3, and λ represents the Darcy friction factor.

Dmitrenko [8] reported that if the flow is turbulent, the Pipe friction coefficient (λ) is can be estimated using the Colebrook-White equation presented in Equation 8 but if the flow is laminar, the Pipe friction coefficient (λ) is calculated using Equation 9:

$$\text{Pipe friction coefficient for turbulent flow } (\lambda) \rightleftarrows \frac{1}{\sqrt{\lambda}} = -2log_{10}\left(\frac{\varepsilon}{3.7D} + \frac{2.51}{Re\sqrt{\lambda}}\right) \quad (8)$$

$$\text{Pipe friction coefficient for laminar flow } (\lambda) \rightleftarrows = \frac{64}{R_e}\ (Re < 2300) \quad (9)$$

Where ε is the absolute pipe roughness (for PVC pipes, typically $\varepsilon = 1.5 \times 10^{-6}$m) [18]. Colebrook and White [19] also stated that when valves, elbows, or other fittings are present in the pipe, the pressure drop associated with these elements is calculated using their specific resistance coefficients. These coefficients are typically obtained from vendor tests or specification documents. Once the resistance coefficient is known, the pressure drop for the element can be determined using Equation 10:

$$\text{Pressure drop } (\Delta P) = \xi\ x\ \frac{\rho}{2}\ x\ v^2 \quad (10)$$

Where ξ is Resistance coefficient, ρ is density of the fluid (kg/m^3) and v is flow velocity (m/s). According to Idel'chik [15], the resistance coefficients (ξ) for 90° elbows and gate valves are 1.10 and 0.2 respectively. These values were applied to calculate the pressure drop in the system caused by the presence of the 90° elbow and gate valves.

Calculation Path for λ =0.00175 and Re=9160;

- First, the fluid velocity v from measured flow rate Q and pipe diameter D was computed.
- The Reynolds number Re= $\frac{vD}{V}$ with kinematic viscosity V were calculated using Equation 4 and 5 respectively.
- The Colebrook-White implicit formula in Equation 8 with known pipe roughness ε (PVC roughness = 1.5×10^{-6}m) and computed Re were used to obtain the friction factor λ.
- Thereafter, the pressure drops ΔP using Darcy-Weisbach equation presented in Equation 7.
- Finally, the local pressure drops for fittings was calculated using Equation 10.

2.2.4 Viscosity Effects on Flow Rate

The impact of viscosity on the flow rate was investigated using three water sources: rainwater, tap water, and stream water. The tap water and stream water were sourced from the Minna Water Board and Gurara Dam in Nigeria, respectively. The experiment involved filling the system's inlet tank with a fixed volume of 20 liters from each water source and measuring the volumetric flow rate by recording the fluid transfer at intervals of 5, 10, 15, and 20 minutes.

3. Results And Discussions

3.1 Metal Base and Tank Guides

The tank guides are composed of two main sections: the inlet tank guide and the outlet tank guide. The weight of the inlet tank guide was calculated to be 67.689 Newtons, while the outlet tank guide was found to weigh 47.5785 Newtons.

In addition to these individual components, the total weight of the metal base supporting the entire system was determined to be 446.35 Newtons. Furthermore, the surface area covered by the metal base was calculated to be approximately 19.5335 × 105 square millimeters. These measurements were essential in ensuring that the structural design of the tank guides and metal base met the necessary strength and stability requirements for the system's operation.

Area of metal frame = length (1150mm) x width (765mm) = 8.7975 x 10^5mm^2

Weight of frame = mass (28.9 kg) x 9.81 (g) = 283.504N

Cross sectional area of each tank guide = $\frac{\frac{22}{7}x360^2}{4}$ = 1.018 x 10^5mm^2

3.2 Fluid Transfer System

The isometric and orthographic views of the developed fluid transfer system is shown in Figure 1 and 2 respectively.

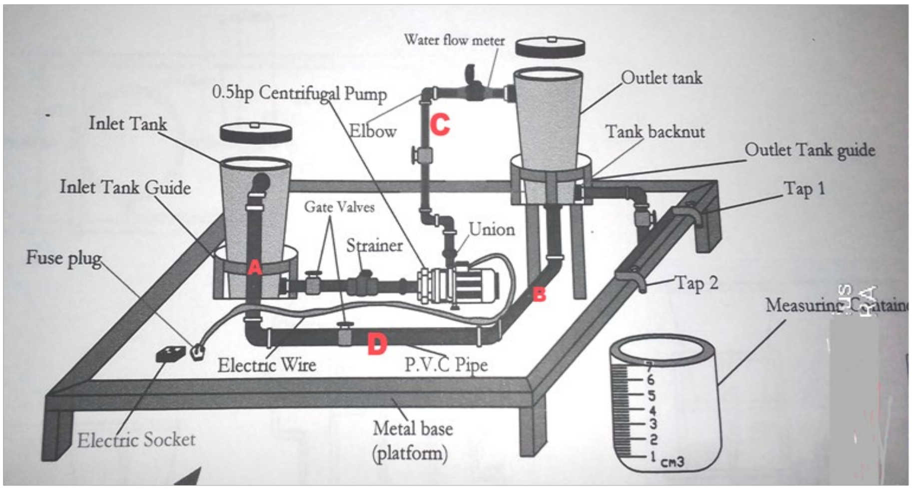

Fig. 1 *Isometric view of constructed fluid transfer system*

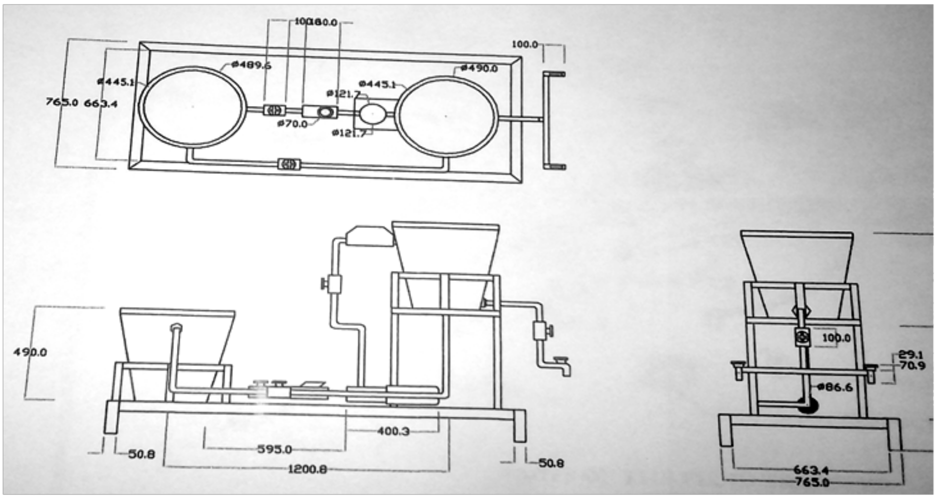

Fig. 2 *Orthographic view of the constructed fluid transfer system*

3.3 Reynolds Number

The Reynolds number for each pipeline (A, B, C, and D) connected in series was determined using Equation 4, incorporating relevant fluid and pipe parameters such as velocity, diameter, density, and viscosity. The necessary data for these calculations were collected and applied to assess the flow regime in each section of the pipeline system.

Table 2 *Reynolds number calculation*

Parameter	Value
Dynamic viscosity of water with 1000 Kg/m³ density	1.519×10^{-3}(kgm^{-1}s^{-1})
Density of fluid (water)	1000Kg/m³
maximum flow rate (Q_{max}) of pump	50liter/min (From the pump manufacturer manual)
Pipe diameter (D)	0.0254m (radius = 0.0127m)
Line D (Total length)	2320 cm
Line C (Total length)	34 cm
Line B (Total length)	96.5 cm
Line A (Total length)	50 cm

The results presented in Table 2 provide essential details for analyzing fluid flow through the pipeline system driven by a pump with a maximum flow rate of 50 litres per minute (approximately 5.83×10^{-4} m^3/s). The pipe diameter is 0.0254 m (radius 0.0127 m), which is a critical factor in determining flow characteristics such as velocity and Reynolds number. In addition, the fluid utilized in this study was water, with a density of 1000 kg/m^3 and a dynamic viscosity of 1.519×10^{-3} kg·m^{-1}·s^{-1}, typical values that influence the flow regime and resistance within the pipes. The dynamic viscosity is especially important in calculating viscous losses and understanding how the fluid's resistance to flow affects the overall system performance.

The pipeline lengths vary significantly:

- Pipeline A is 0.5 m
- Pipeline B is 0.965 m
- Pipeline C is 0.34 m
- Pipeline D is much longer at 23.20 m

Pipelines A (0.5 m) and B (0.965 m) are likely within the range of developing or partially developed flow, while pipelines C (0.34 m) and especially D (23.2 m) exceed typical entrance lengths, so the flow can be assumed fully developed in these. These lengths may impact the total head loss due to friction, with longer pipelines (like D) contributing more significantly to pressure drops. The pipe diameter, fluid properties, and pipeline length collectively enable the calculation of key parameters such as flow velocity, Reynolds number, and friction factor.

These parameters help determine whether the flow is laminar or turbulent and assess the efficiency of fluid transport. In this case, the Reynolds number calculated for each pipeline (A, B, C, and D) is 9160, which exceeds the threshold of 4000, indicating turbulent flow. This means the fluid particles in the pipes move irregularly, following chaotic paths without any distinct layers or predictable patterns.

3.4 Pressure Loss in the Fluid System

The pressure loss or drop (ΔP) along each pipeline is shown in Table 3.

Table 3 *Pressure drops along each pipeline*

Pipe line	Length of pip (m)	Fluid velocity (m/s)	Coefficient	Pressure drop (N/m^3)
D	23.20 m	0.01461	λ=0.00175	0.171
C	0.34m	0.01461	λ=0.00175	0.0025
B	0.965m	0.014e61	λ=0.00175	0.003677
A	0.5m	0.01461	λ=0.00175	0.00368
90º elbow		0.01461	*ξ = 1.10*	0.1174
Gate valves		0.01461	*ξ =0.2*	0.0214

The data in Table 3 indicate that pressure drop in the pipeline system increases with pipe length and is notably influenced by fittings. Pipeline D exhibits the highest pressure drop at 0.171 N/m^3, exceeding those of lines A, B, and C, leading to greater pressure losses. Components like 90° elbows cause more significant localized pressure drops compared to gate valves, which aligns with typical fluid dynamics behavior in pipe flow systems.

Additionally, fluid motion is substantially impacted by 90° elbows, as evidenced by a pressure drop of 0.1174 N/m^3 associated with their presence. In contrast, gate valves contribute only minimal pressure drops. These results also suggest that shorter pipe lengths experience negligible pressure loss compared to longer pipes, especially when elbows are present.

3.5 Cumulative Volumes of Investigated Fluid

The results of the cumulative volumes and the instantaneous (interval-averaged) flow rates computed from these volumes for the three sources of water transferred over the specified time intervals are shown in Table 4 and Table 5, respectively. These results are presented in Figure 3 and 4, respectively.

Table 4 *Cumulative volumes of various water sources*

Time of flow (min)	Cumulative volumes (litre)		
	Rain water	Tap water	Stream water
20	48.65	41.36	36.49
15	36.49	31.02	27.37
10	24.33	20.68	18.25
5	12.16	10.34	9.12

Table 5 *Instantaneous flow rates of different sources of water*

Time Interval (min)	Rainwater (litre/min)	Tap Water (litre/min)	Stream Water (litre/min)
0–5	12.16	10.34	9.12
5–10	(24.33-12.16)/5 = 2.43	(20.68-10.34)/5 = 2.07	(18.25-9.12)/5 = 1.83
10–15	(36.49-24.33)/5 = 2.43	(31.02-20.68)/5 = 2.07	(27.37-18.25)/5 = 1.83
15–20	(48.65-36.49)/5 = 2.43	(41.36-31.02)/5 = 2.07	(36.49-27.37)/5 = 1.82

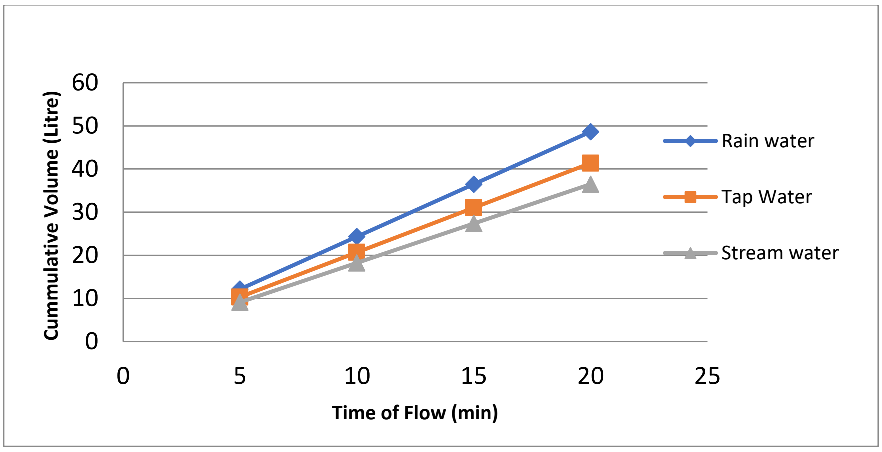

Fig. 3 *Variation in cumulative volume of different sources of water*

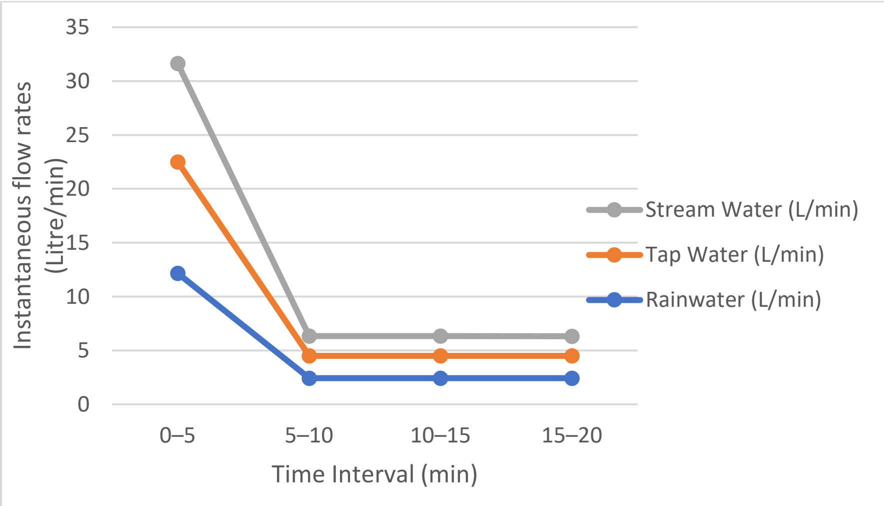

Fig. 4 *Variation in instantaneous flow rates of different sources of water*

The experimental results shown in Tables 4 and 5 provide complementary insights into the flow characteristics of the three water sources within the system. Table 4 shows the cumulative volumes of rainwater, tap water, and stream water transferred at 5, 10, 15, and 20-minute intervals. As expected, the cumulative volume increases with time for all sources, with rainwater consistently recording the highest transferred volumes and stream water the lowest, indicating differing flow efficiencies.

Also, Table 5 presents the instantaneous (interval-averaged) flow rates calculated from the differences in cumulative volumes over each 5-minute time interval. The flow rates for rainwater remain steady at approximately 12.16 L/min during the first interval and around 2.43 L/min for subsequent intervals, while tap water and stream water display lower but stable flow rates in similar patterns. This consistency suggests that the system achieves near steady-state flow after the initial filling period. These results indicate that fluid properties, particularly viscosity and possible particulate content influence flow rates, with rainwater likely having the lowest viscosity or fewer impurities, enabling higher flow rates.

4. Conclusion

This study investigates the flow rate influence of various fluid sources. A fluid transferring system was designed and constructed following standard procedures to examine the volume flow rate of fluids passing through it. Based on the results obtained, the following conclusions are presented.

1. Fluid viscosity affects flow rate and efficiency; lower-viscosity fluids like rainwater had higher flow rates (up to 12.16 L/min) compared to higher-viscosity stream water (9.12 L/min).
2. The flow within the system was turbulent (Re = 9160) having increasing pressure drops with pipeline length, with the longest pipe (23.2 m) having the highest drop of ~0.171 N/m^3.

3. Localized pressure drops caused by fittings showed that 90° elbows (resistance coefficient ξ = 1.10) induced substantially higher-pressure losses (0.1174 N/m^3) than gate valves (ξ = 0.2) with pressure drops around 0.0214 N/m^3.
4. The cumulative volumes of different water sources vary significantly, with rainwater exhibiting the highest value, followed by tap water, and then stream water with the lowest. This variation is attributed primarily to differences in fluid viscosity and possibly particulate content, where higher viscosity or impurities reduce flow efficiency.
5. Overall, the findings highlight the need to consider fluid viscosity, pipe length, and component losses in designing efficient industrial fluid transfer systems, recommending smooth pipes, minimizing fittings, broader fluid and scale testing and smart sensor integration to optimize safety, cost, and sustainability.

Acknowledgement

The authors sincerely express their deep appreciation to Engr. S. N. Mohammed and the entire staff of the Department of Mechanical Engineering, Federal University of Technology, Minna, Nigeria, for their moral support, encouragement, and valuable guidance throughout the course of this project.

Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Abutu, Joseph, Oladosu Temidayo Lekan, Emmanuel James Abakpa;* ***data collection:*** *Abutu, Joseph, Oladosu Temidayo Lekan, Emmanuel James Abakpa;* ***analysis and interpretation of results:*** *Abutu, Joseph, Oluleye Modupe Atinuke, Oruonye Emeka Daniel.* ***draft manuscript preparation:*** *Abutu, Joseph, Ogwuche Christian Ike. All authors reviewed the results and approved the final version of the manuscript.*

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