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Assessment of Friction Losses and Friction Factor in Polypropylene Pipes

Ahmed Abdulatif Jadoua *[a], **Raad Hoobi Irzooki** [b]

a Civil Engineering Department, Tikrit University, Tikrit, Iraq.
b Environmental Engineering Department, Tikrit University, Tikrit, Iraq.

Keywords:
Friction factor; Friction losses; Galvanized iron pipes; PPR pipes.

Highlights:

- *The evaluation of the friction factor and friction losses in PPR pipes revealed how the pipe's diameter, length, and flow velocity affected the friction losses in these pipes.*
- *Finding the difference in friction losses between PPR and galvanized iron pipes with identical pipe specifications and flow conditions.*
- *Creating a simple and reliable equation to estimate the friction losses in PPR pipes.*

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*Corresponding author:

Ahmed Abdulatif Jadoua
Civil Engineering Department, Tikrit University, Tikrit, Iraq.

Abstract: Recently, polypropylene (PPR) pipes have been increasingly used to replace galvanized iron pipes in most water transmission systems due to their ease of installation and perceived health safety. Also, PPR has engineering features that do not deteriorate over time. Despite the good properties of these pipes, there is a lack of in-depth studies on calculating the friction factor and friction losses within them. The present study calculates the friction losses in PPR pipes and the variables that influence them, whether they are associated with the pipes themselves or the internal flow properties. The experimental work was conducted using three diameters of PPR pipes: 0.0131 m, 0.01675 m, and 0.021 m, with four lengths for each diameter: 3 m, 10 m, 20 m, and 30 m. For each model, nine discharges were studied, and the head loss, for each run, was measured using pressure sensors. The number of experiments conducted was 108, and for comparison purposes, 36 experiments were conducted on a galvanized iron pipe with a diameter of 0.0171 m and the same length as the PPR pipes. The results showed that the internal surface of the PPR pipes was very smooth, with an internal roughness height of approximately 0.00001mm. The friction losses increased with flow velocity in a nonlinear relationship and pipe length in a linear relationship, where the rate of increase in friction losses was 9.75 times when the pipe length increased from 3 to 30m. The friction losses decreased with the pipe diameter in a linear relationship, with a 40% decrease observed when the pipe diameter increased from 0.0131 m to 0.01675 m for a 30 m long pipe and a flow velocity of 1.53 m/s. The percentage of losses decreased by 55% when the diameter increased from 0.0131 m to 0.021 m. Regarding low flow velocity, 0.380 m/s, the decrease was very small compared to high velocities, as the percentage of decrease does not exceed 17% when the diameter increases from 0.0131m to 0.021m. The results also showed that the friction losses in PPR pipes were approximately 20% lower than those in galvanized iron pipes. Using a statistical program (SPSS), an easy and reliable empirical equation was derived to measure the friction losses in PPR pipes.

تقييم خسائر الاحتكاك ومعامل الاحتكاك في أنابيب البولي بروبلين

احمد عبد اللطيف[1]، رعد هوبي ارزوقي[2]
[1] قسم الهندسة المدنية / كلية الهندسة /جامعة تكريت / تكريت – العراق.
[2] قسم هندسة البيئة / كلية الهندسة /جامعة تكريت / تكريت – العراق.

الخلاصة
تزايد استخدام أنابيب البولي بروبلين في الآونة الأخيرة (PPR) لتحل محل أنابيب الحديد المغلون في معظم أنظمة نقل المياه بسبب سهولة تركيبها والسلامة الصحية الملموسة بسبب ميزاتها الهندسية التي لا تتغير بمرور الوقت. على الرغم من هذه الخصائص الجيدة لهذه الأنابيب، إلا أنه لا توجد دراسة متعمقة حول حساب معامل الاحتكاك وخسائر الاحتكاك داخل هذه الأنابيب. تهدف الدراسة الحالية إلى تقدير خسائر الاحتكاك في أنابيب PPR والمتغيرات التي تؤثر عليها، سواء كانت متعلقة بالأنابيب نفسها أو بخصائص الجريان داخلها. تم إجراء العمل التجريبي باستخدام ثلاثة أقطار مختلفة من أنابيب PPR (٠,٠١٣١، ٠,٠١٦٧٥، ٠,٠٢١) م، بأربعة أطوال مختلفة لكل قطر (٣، ١٠، ٢٠، ٣٠) م. لكل نموذج تم تمرير تسعة تصاريف مختلفة، وتم قياس فقدان الضغط لكل اختبار باستخدام أجهزة استشعار الضغط. بلغ عدد التجارب التي أجريت في هذه الدراسة ١٠٨ تجربة، ولأغراض المقارنة، تم إجراء ٣٦ تجربة على أنابيب الحديد المغلون بقطر ٠,٠١٧١ م بنفس أطوال أنابيب PPR. أظهرت النتائج أن السطح الداخلي لأنابيب PPR ناعم للغاية وارتفاع الخشونة الداخلية يساوي تقريبًا ٠,٠٠٠٠١ ملم، وأن خسائر الاحتكاك تزداد مع زيادة سرعة االجريان في علاقة غير خطية وتزداد مع زيادة طول الأنبوب في علاقة خطية، حيث يبلغ معدل الزيادة في خسائر الاحتكاك ٩,٧٥ مرة عندما يزداد طول الأنبوب من ٣ إلى ٣٠ م، وتتناقص خسائر الاحتكاك بزيادة قطر الأنبوب في علاقة خطية، حيث كان هناك انخفاض بنسبة ٤٠٪ عندما يزداد قطر الأنبوب من ٠,٠١٣١ م إلى ٠,٠١٦٧٥ م لطول أنبوب ٣٠ م وسرعة جريان ١,٥٣م/ثانية، بينما تقل نسبة الخسائر بنسبة ٥٥٪ عندما يزيد القطر من ٠,٠١٣١ م إلى ٠,٠٢١ م. أما بالنسبة لسرعة الجريان المنخفضة، ٠,٣٨٠ م/ثانية، فإن الانخفاض ضئيل جداً مقارنة بالسرعات العالية حيث لا تتجاوز نسبة الانخفاض ١٧٪ عندما يزداد القطر من ٠,٠١٣١ م إلى ٠,٠٢١ م. كما أظهرت النتائج أن خسائر الاحتكاك في أنابيب PPRأقل بحوالي ٢٠٪ من خسائر الاحتكاك في أنابيب الحديد المغلون. وباستخدام برنامج إحصائي (SPSS) تم استنباط معادلة تجريبية سهلة وموثوقة لقياس خسائر الاحتكاك في أنابيب PPR.

الكلمات الدالة: معامل الاحتكاك، خسائر الاحتكاك، الانابيب الحديدية المغلونة، أنابيب البولي بروبلين.

1.INTRODUCTION

The pipes are used for various purposes, including transporting water for drinking, irrigation, and wastewater disposal, among others. The pipes are manufactured in different sizes, most of which are circular. These pipes are made of different types of materials. When a fluid flows through a pipe, it encounters resistance from the pipe's surface due to shear forces within the fluid and turbulence occurring along the inner wall of the pipe, resulting in energy loss in the form of a pressure drop. In addition to the energy lost due to frictional forces, there will be a loss of energy as the fluid flows through fittings and valves. The loss of pressure as a result of the friction of fluid with the pipe walls is usually referred to as (Major losses), while the losses or pressure loss that occurs in connections, bends, and valves are called minor losses. The amount of friction losses in pipes depends on several factors, including the velocity of the fluid inside the pipe, the roughness of the pipe walls, the diameter and length of the pipe, and the viscosity of the fluid. On this basis, losses due to friction result in a decrease in pressure along the length of the pipe, thereby increasing the amount of energy that the pump must provide to maintain the flow. These losses can become significant in systems that utilize long stretches of pipe, such as heat exchangers, oil pipelines, and fire protection systems. Therefore, it is essential to minimize friction loss in piping systems, as it significantly impacts the flow rate, pressure, and energy efficiency of the system. Engineers often consider frictional loss when designing piping systems to ensure the system operates efficiently and effectively. The friction loss is usually measured using the Darcy-Weisbach equation [1]; this equation is expressed as follows:

$$H_L = f.\frac{L}{D}.\frac{V^2}{2g} \quad (1)$$

where H_L is the frictional Head loss (m), f is the coefficient of friction, L is the pipe length (m), D is the pipe diameter (m), V is the velocity of fluid flow inside the pipe (m/s), and g is the ground acceleration (m/s^2). When the pipe is circular, the coefficient of friction (f) depends on determining its value based on the type of flow inside the pipe. If the flow is laminar (Re ≤ 2000), it depends only on the Reynolds number (Re) of the fluid that flows inside the pipe, where it is equal to (64/Re). However, if the flow is turbulent (Re > 4000), then its value depends on determining the Reynolds number and the roughness of the inside pipe wall (e), due to the increase in flow velocity and the fluid reaching a state of turbulence. The effect of this roughness on energy loss is evident, as the roughness of the pipe walls varies from one type to another, depending on the material used in its manufacture. The most important factor in calculating flow pressure loss in pipes is the friction coefficient. When the flow is turbulent, the value of the coefficient of friction is obtained using the Moody Diagram or the Colebrook Formula, Eq. 2 [2, 3], which represents all the curves in the Moody Diagram.

$$\frac{1}{\sqrt{f}} = -2.0\log_{10}\left(\frac{\frac{e}{D}}{3.7} + \frac{2.51}{\mathrm{Re}\sqrt{f}}\right) \quad (2)$$

where the parameter $(\frac{e}{D})$ is referred to as relative roughness. Blasius developed an approximation, which is utilized to calculate the value of the friction factor for turbulent flow in circular pipes, as shown in the following formula [4]:

$$f = (0.3164\ Re^{-0.25}) \quad (3)$$

Selecting pipe materials was a routine and crucial task because the majority of designers selected iron pipes as the de Facto standard for all water transport systems. However, through extensive research and real-world testing, it was determined that using iron pipes for an extended period would cause rust and an increase in impurities, resulting in a rougher surface. Additionally, exposure to bacterial and microbiological buildup would have a detrimental effect on human health. Based on this, efforts were made to develop new pipe types that are safer for human health and whose specifications enable water transport systems to function for an extended period without experiencing property changes. The usage of plastic pipes has increased recently because these pipes are suitable from the perspective of human health and do not deteriorate over time in terms of their engineering features. Plastic pipes made from various plastic materials, such as polyvinyl chloride (PVC), polyethylene (PE), and polypropylene (PPR), have been used to replace galvanized iron pipes in numerous applications, such as drinking water, irrigation, and ventilation systems. Propylene pipes, as shown in Fig. 1, are made from a developed binary plastic compound called propylene, which provides them with higher resistance to shocks and pressures, as well as a high tolerance to heat. Their use is the most appropriate and effective solution currently available for use within water transport systems because they are characterized by specifications that make them continue to operate for no less than fifty years, in addition to their other characteristics [5]:

1) Rust resistance
2) The smoothness of its internal surface reduces its effectiveness in reducing system pressure.
3) High resistance to electric current.
4) It can maintain water temperature.
5) Not harmful to human health.
6) Flexibility in terms of its use or resistance to external influences.

Fig. 1 Propylene Pipes and Fittings

In light of the above discussion, the main losses due to friction resulting from the passage of fluids inside the plastic pipes are assumed to be small because the coefficient of friction will be of a small value (very little roughness). However, systems containing such pipes must be effectively studied to understand and measure the energy losses, which are necessary to improve the performance and cost efficiency of these systems. Most research studies on PPR pipes have focused on the material's characteristics and how environmental factors, including heat, freezing, and pressure, affect it. Meddah [6] investigated the mechanical properties of PPR pipes using tensile tests. After the system elements are separated, the partial differential equations are converted into algebraic equations using the finite element method, which is used to analyze and compute the unknown variables. It is possible to model these equations using both experimental and numerical methods, as well as with reduced assumptions. As a result of this inquiry, crucial parameters, including yield stress, Poisson's ratio, and Young's modulus, were determined. Ouardia et al. [7] focused on evaluating the effect of axial and circumferential defects on the behavior of PPR pipes. This evaluation was based on burst tests performed on both virgin pipes and previously damaged pipes. The results revealed that both types of defects resulted in a reduction in the ultimate burst pressure of the pipes compared to their virgin counterparts, with axial defects proving to be more severe than circumferential defects. Zheng [8] experimentally studied the frost failure mechanism of PPR water pipes. This study not only provides experimental data but also creates a theoretical model that can be used to determine the appropriate pipe wall thickness for these applications. Wu et al. [9] emphasized in their research the importance of studying the ice-bulge failure mechanism of random-coupled polypropylene (PPR) water pipes to ensure the safety and reliability of field irrigation and urban water supply. Ramadan and Tanase [10] conducted an experimental study to analyze the performance of welded and unwelded PPR pipes when exposed to different aggressive environments. The unwelded pipes were simulated in chemical environments, such as benzene and sodium hypochlorite (NaClO), a mixture of water and sodium hypochlorite (NaClO) at a concentration of 20% by volume of NaClO, for 3 weeks (21 days). The results showed that the presence of sodium hypochlorite insignificantly affected the mechanical properties of PPR pipes, whereas benzene significantly reduced the stress value at break. As for PPR welded pipes, they have been found to fail under pressures of around 180 bar, even when setting the optimum welding parameters recommended by the manufacturer. Understanding the process underlying frost heave failure of water pipes is essential to guaranteeing the dependability and safety of urban water supplies and agricultural irrigation in winter. The study of polypropylene random copolymer (PPR) pipe frost heaves in residential buildings serves as the foundation for this paper. The PPR water pipe's frost heave failure mechanism is thoroughly examined based on theoretical analysis and model testing. The formula for ice expansion pressure was developed based on associated mechanical theories and the ASTM E28-02 standard. Ahmed et al. [11] estimated the friction factor as a function of the Reynolds number in PPR pipes. They compared it with previous data using an experimental model consisting of a PPR pipe with a nominal outer diameter of 16 mm and a length of 8.5 m, along with eighteen elbows connected to it. The results showed that the practical friction factor was less than the value calculated using the Basilius equation (Eq. 3) for smooth pipes, indicating that PPR pipes were smoother than those calculated. The numerical formula similar to the Basilius equation was ($1.9231Re^{-0.509}$). Finally, the researchers demonstrated that the amount of energy lost due to the friction factor in PPR pipes was smaller than in other types of pipes, primarily because the extrusion process creates a smooth inner wall. However, this effect cannot be neglected in fluid flow through pipes. Abdalla et al. [12] estimated the loss coefficient of polypropylene elbow losses using an experimental model consisting of 18 elbows, having K = 1.77. The researcher demonstrated that the energy losses of real fluid flow are influenced by various factors, including friction, connections, and diameter, and that good welding in PPR fittings results in small coefficients, whereas poor welding leads to large coefficients. The study concluded that the model yielded a simple result, indicating that all PPR fitting parameters cannot be neglected in fluid calculations and fluid network design. Rakhimov et al. [13] presented a method for determining the hydraulic friction factor in plastic pipes. The hydraulic friction factor of water supply plastic pipes was found to vary with a wide variety of Reynolds numbers as a consequence of the laboratory experiments conducted. Zhao et al. [14] examined two common drainage pipe materials: acrylonitrile-butadiene-styrene (ABS) and polypropylene-random (PPR) to differentiate between their anti-scaling performances through a landfill leachate immersion experiment. The findings demonstrated the scaling propensity of PPR and ABS pipe materials submerged in the younger-aged leachate. The corresponding weight increment, which was 33% more than that associated with ABS during the trial time, indicates that the scaling on the surface of the PPR pipe material is severe than that of the ABS pipe material. Thus, ABS performed better against scaling, and it may be an optional choice. Shabani et al. [15] aimed to investigate the contribution of polymeric pipes to the formation of trihalomethanes (THMs) in desalinated water. A three-pipe loop system consisting of polyvinyl chloride (PVC), polyethylene (PE), and polypropylene (PPR) pipes was created to investigate the effects of calcium hypochlorite concentration, organic dosage, and pipe material on THM production. The creation of THMs was found to be strongly correlated with pipe material, organic dosage, and the use of calcium hypochlorite, according to the results of 33 full factorial planned trials. The present study aims to estimate friction losses in PPR pipes by investigating the factors that affect friction losses, whether related to the pipes themselves or the flow characteristics within them, through a combination of experimental research and theoretical analysis. The study also aims to provide simple empirical equations for calculating friction losses in PPR pipes. The importance of this study lies not only in its contribution to the body of knowledge related to PPR pipes but also in its ability to provide significant benefits to water transmission system professionals, engineers, and industries that rely on PPR pipe systems. Enhancing the understanding of friction losses in this type of pipe will pave the way for more efficient design, installation, and operation of these systems, ultimately leading to reduced energy consumption, cost savings, and improved sustainability.

2.EXPERIMENTAL WORK

To calculate frictional losses, three diameters of Egyptian PPR pipes were used: 0.0131 m, 0.01675 m, and 0.021 m. For each diameter, four lengths were tested: 3, 10, 20, and 30 m. A digital vernier with an accuracy of 0.2 mm was used to measure the inside diameter of the pipes, as shown in Fig. 2. The available length of the PPR pipes on the market was 4m; therefore, the small lengths used in practical experiments were carefully and accurately cut. Their edges were cleaned to remove any contaminants. Regarding the long lengths of pipes, connectors were used to join multiple pieces together. Water was supplied to the pipes using a pump with a maximum discharge of 4 m^3/hr taken from a large tank prepared for this purpose. The different discharge amounts were selected using a valve placed after the pump and before the water enters the pipes. The volumetric method was used to measure the discharge passing through the pipe, with the average of three readings taken for each run. To calculate the water pressure at different locations along the pipes, six devices in the form of water pressure sensors were used, as shown in Fig. 3. The data from these devices were transferred to a laptop or mobile device via the Bluetooth feature, including water pressure and temperature readings. These sensors were validated in two steps:

- First: by verifying the consistency of the readings of these sensors at any discharge, as more than one discharge was flowed through the pipe, and the pressure reading of the first sensor was taken at a certain point of the pipe, and then the other sensors were used instead of the first sensor, and their readings were taken at the same discharge. The results showed that the pressure values were completely identical.
- Second: the readings of these sensors were verified using a piezometer placed near where they were installed on the pipe, as shown in Fig. 4. The verification results showed a very high match between the sensor reading and the piezometer reading. Figure 5 shows the relationship between the sensor readings and the piezometer readings for the pipe with a diameter of 0.021m and various discharges.

It is worth mentioning that the lengths used for the pipes represent the distance between the center of the device at the beginning of the pipe and the center of the other device at the end of the pipe.

Fig. 2 Dimensions of Inner Diameter of Pipes Used in the Study.

Fig. 3 Pressure Sensor Used in Practical Experiments

Fig. 4 Piezometer Used for Verification of Pressure Sensors

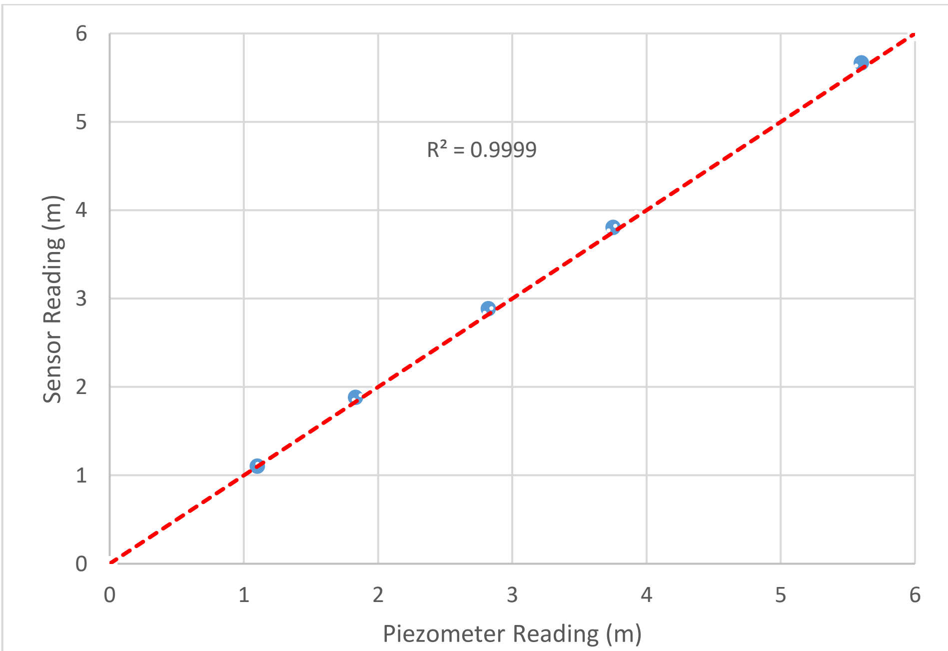

Fig. 5 Relation between the Readings of the Pressure Sensor and the Piezometer

3.METHODOLOGY

The context that was followed in conducting the experiments was as follows:

- First, the length of the pipes is measured, which is 3 m, and their internal diameter is 0.0131m. Pressure measuring devices are installed at the beginning and end of the pipe. A certain discharge is passed through this pipe, and after the flow stabilizes, the discharge is measured by a volumetric method at least three times. The average of these discharges is then taken.
- Pressure and temperature readings are taken from the sensors located at the beginning and end of the pipe to determine the drop in pressure through the pipe as well as to calculate the viscosity of the water.
- After that, the discharge is increased, and the process of calculating the discharge and reading the sensors is repeated as in the previous steps, noting that nine discharges are used for each model.
- The length of the pipe is changed to 10, 20, and 30m, maintaining the same diameter. The same previous steps are then repeated for each length.
- Repeat the same previous steps on pipes with diameters 0.01675m and 0.021m.

4.RESULTS AND DISCUSSION

4.1.Results of Head Loss and Friction Factor

The total number of experiments for the present study was 108. The results of these runs are presented in Table 1, where the head loss for each model was calculated as the difference between the pressure sensors located at the beginning and the end of each model. In addition, the flow rate and temperature were measured for each run. The friction factor values for each model in this investigation are displayed in Table 2, which was produced using Eq. (1) and the data from Table 1. Additionally, the temperature of the water for each run was used to determine the kinematic viscosity (υ), which was then used to calculate the Reynolds number (Re). To confirm the study's findings, the friction factor (*f*) for a pipe with an internal diameter of 0.0127 m, as depicted in Fig. 6, was compared to the friction factors determined by (Ahmed et al., 2022) [10] and the one derived using the Blasius equation [3]. This figure illustrates that the results of this study align well with those of other studies. Based on the data in Table 2, the friction factor and Reynolds number have a relationship that the following formula can represent:

$$f = 1.3465\ \mathrm{Re}^{-0.396} \qquad \textbf{(4)}$$

Figures 7, 8, and 9 illustrate the relationship between the Reynolds number and the average friction factor for the diameters of PPR pipes, 0.0131 m, 0.01675 m, and 0.021 m, respectively. The curves of these relationships were projected onto the Moody diagram, where it is noted that their extensions intersect the axis of relative roughness $(\frac{e}{D})$ at a value of approximately 0.0000005, i.e., the average roughness height (e) was 0.00001mm, which seems to indicate a relatively smooth pipe.

Table 1 Results of Head Loss in PPR Pipes.

D (m)	Q ×10⁻³ (m³/sec)	V (m/sec)	T °C	υ (m²/sec)	H_L (m) L=3m	L=10m	L=20m	L=30m
0.0131	0.312	2.313	19.8	1.0082E-06	1.487	4.468	9.902	14.472
	0.281	2.088	20.8	0.9860E-06	1.157	3.625	7.419	11.066
	0.241	1.788	22.5	0.9519E-06	0.868	2.785	6.458	8.380
	0.203	1.508	25.5	0.8917E-06	0.681	2.280	4.536	6.759
	0.159	1.180	23.7	0.9278E-06	0.445	1.373	2.741	4.208
	0.132	0.978	24.6	0.9097E-06	0.332	1.067	2.430	3.180
	0.111	0.813	26.3	0.8756E-06	0.245	0.738	1.523	2.260
	0.089	0.664	22.5	0.9519E-06	0.147	0.506	1.250	1.696
	0.060	0.446	26.3	0.8756E-06	0.127	0.304	0.569	0.874
0.01675	0.388	1.763	18.45	1.0489E-06	0.675	2.203	3.880	6.063
	0.341	1.547	20	1.002E-06	0.573	1.829	3.386	5.270
	0.328	1.489	19.8	1.008E-06	0.510	1.666	3.306	5.045
	0.313	1.423	17.85	1.0689E-06	0.510	1.657	3.194	4.679
	0.295	1.338	19.8	1.008E-06	0.437	1.574	2.906	4.368
	0.231	1.050	15.8	1.1318E-06	0.313	1.023	1.995	2.971
	0.150	0.681	17.2	1.0889E-06	0.153	0.493	0.962	1.441
	0.106	0.481	18.3	1.0546E-06	0.077	0.271	0.615	0.882
	0.069	0.312	18.9	1.0361E-06	0.034	0.140	0.341	0.473
0.021	0.533	1.538	18.5	1.0484E-06	0.379	1.188	2.565	3.896
	0.493	1.422	21.7	0.9679E-06	0.370	1.169	2.408	3.632
	0.455	1.312	17.4	1.0825E-06	0.358	1.127	2.211	3.317
	0.413	1.191	21.25	0.9769E-06	0.259	0.886	1.784	2.722
	0.337	0.972	15.3	1.1475E-06	0.213	0.634	1.409	2.216
	0.279	0.806	20.9	0.9840E-06	0.109	0.424	1.033	1.557
	0.189	0.546	16.4	1.1134E-06	0.078	0.308	0.662	0.980
	0.151	0.435	14.9	1.1598E-06	0.040	0.199	0.498	0.656
	0.132	0.381	16.75	1.1026E-06	0.025	0.143	0.332	0.528

Table 2 Results of Friction Factor for PPR Pipes.

D (m)	Q $\times 10^{-3}$ (m^3/sec)	V (m/sec)	υ (m^2/sec)	Re	*f*				
					L=3m	L=10m	L=20m	L=30m	Average
	0.312	2.313	1.0082E-06	30054	0.0238	0.0215	0.0238	0.0232	0.0231
	0.281	2.088	0.9860E-06	27741	0.0227	0.0214	0.0219	0.0217	0.0219
	0.241	1.788	0.9519E-06	24606	0.0233	0.0224	0.0260	0.0225	0.0236
	0.203	1.508	0.8917E-06	22154	0.0257	0.0258	0.0256	0.0255	0.0257
0.0131	0.159	1.180	0.9278E-06	16661	0.0274	0.0253	0.0253	0.0259	0.0260
	0.132	0.978	0.9097E-06	14084	0.0297	0.0287	0.0326	0.0285	0.0299
	0.111	0.813	0.8756E-06	12163	0.0318	0.0287	0.0296	0.0293	0.0299
	0.089	0.664	0.9519E-06	9138	0.0286	0.0295	0.0364	0.0329	0.0319
	0.060	0.446	0.8756E-06	6673	0.0382	0.0393	0.0368	0.0377	0.038
	0.388	1.763	1.0489E-06	28154	0.0238	0.0233	0.0205	0.0214	0.0223
	0.341	1.547	1.002E-06	25861	0.0262	0.0251	0.0233	0.0241	0.0247
	0.328	1.489	1.008E-06	24743	0.0252	0.0247	0.0245	0.0249	0.0248
	0.313	1.423	1.0689E-06	22299	0.0276	0.0269	0.0259	0.0253	0.0264
0.01675	0.295	1.338	1.008E-06	22234	0.0267	0.0289	0.0267	0.0267	0.0273
	0.231	1.050	1.1318E-06	15539	0.0311	0.0305	0.0297	0.0295	0.0302
	0.150	0.681	1.0889E-06	10475	0.0362	0.0349	0.0341	0.0340	0.0348
	0.106	0.481	1.0546E-06	7640	0.0367	0.0385	0.0437	0.0417	0.0402
	0.069	0.312	1.0361E-06	5044	0.0387	0.0472	0.0575	0.0532	0.0492
	0.533	1.538	1.0484E-06	30807	0.0220	0.0207	0.0233	0.0226	0.0222
	0.493	1.422	0.9679E-06	30852	0.0251	0.0238	0.0245	0.0247	0.0245
	0.455	1.312	1.0825E-06	25452	0.0286	0.0269	0.0264	0.0264	0.0271
0.021	0.413	1.191	0.9769E-06	25602	0.0251	0.0257	0.0259	0.0263	0.0258
	0.337	0.972	1.1475E-06	17788	0.0310	0.0276	0.0307	0.0322	0.0304
	0.279	0.806	0.9840E-06	17201	0.0232	0.0269	0.0328	0.0329	0.0290
	0.189	0.546	1.1134E-06	10298	0.0359	0.0425	0.0456	0.0432	0.0418
	0.151	0.435	1.1598E-06	7876	0.0289	0.0434	0.0542	0.0476	0.0435

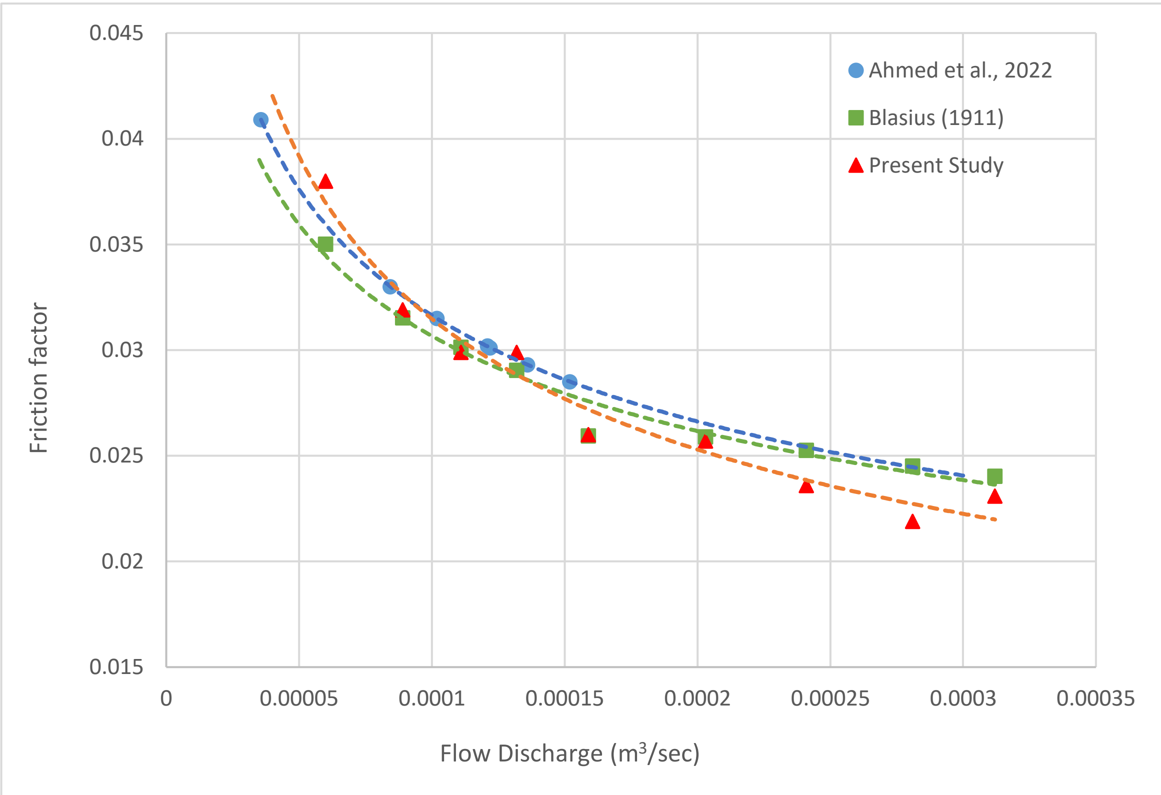

Fig. 6 Friction Factor Comparison for PPR Pipe of Diameter 0.0127m.

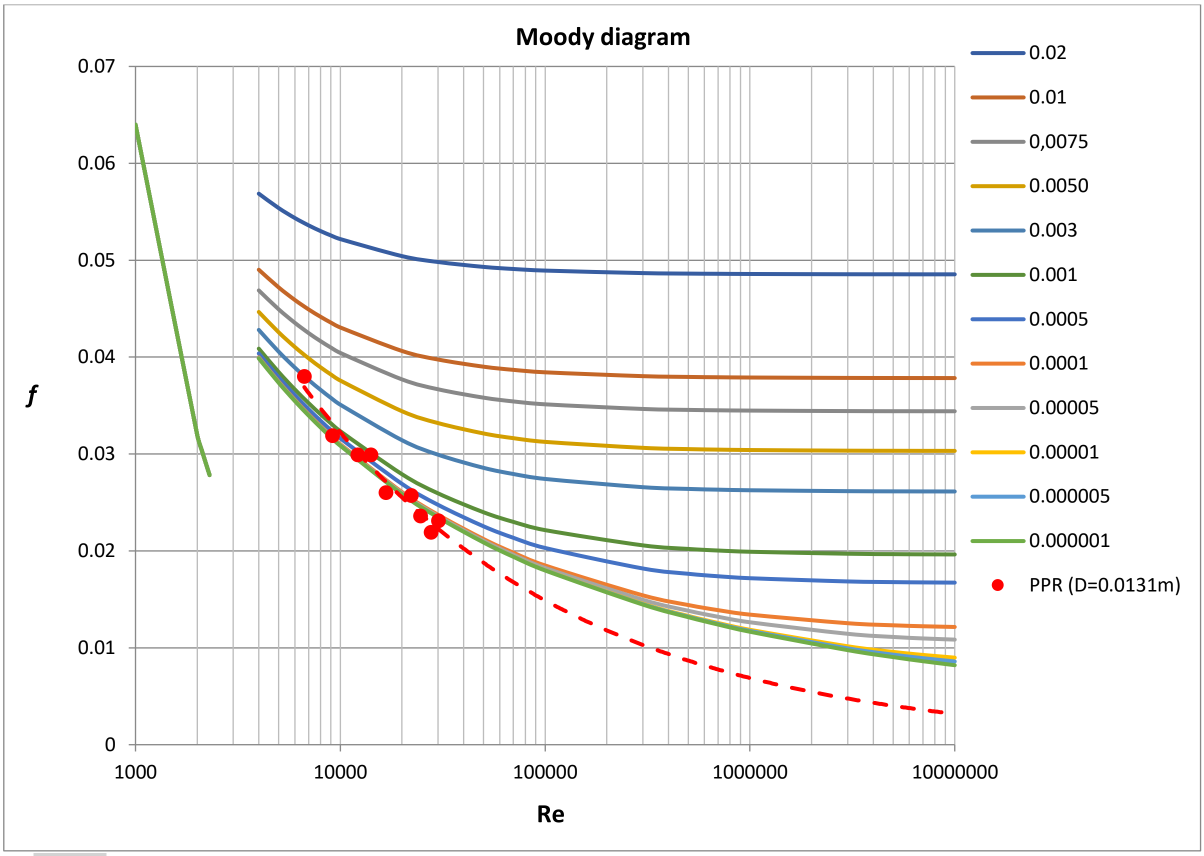

Fig. 7 Relationship of the Reynolds Number with the Average Friction Factor for the PPR Pipe of Diameter 0.0131 m.

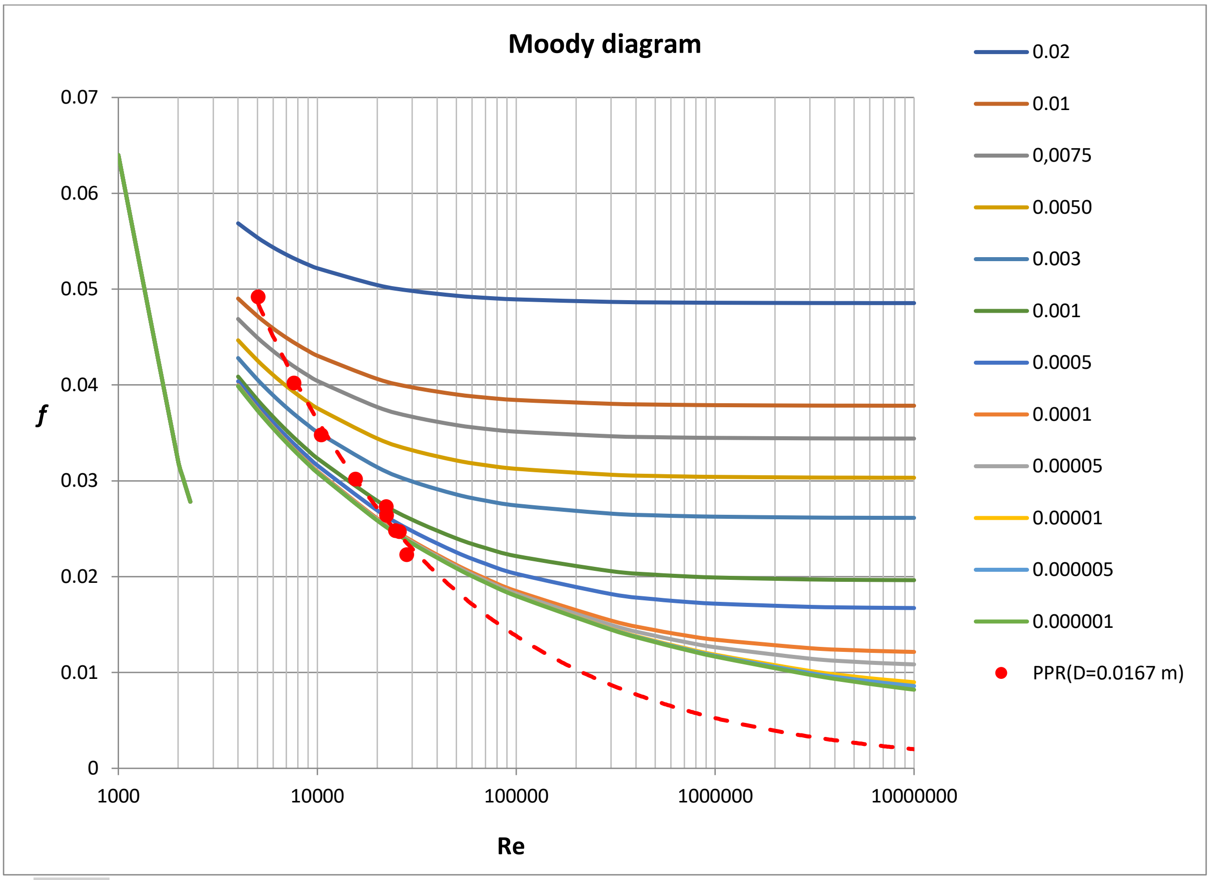

Fig. 8 Relationship of the Reynolds Number with the Average Friction Factor for the PPR Pipe of Diameter 0.01675 m.

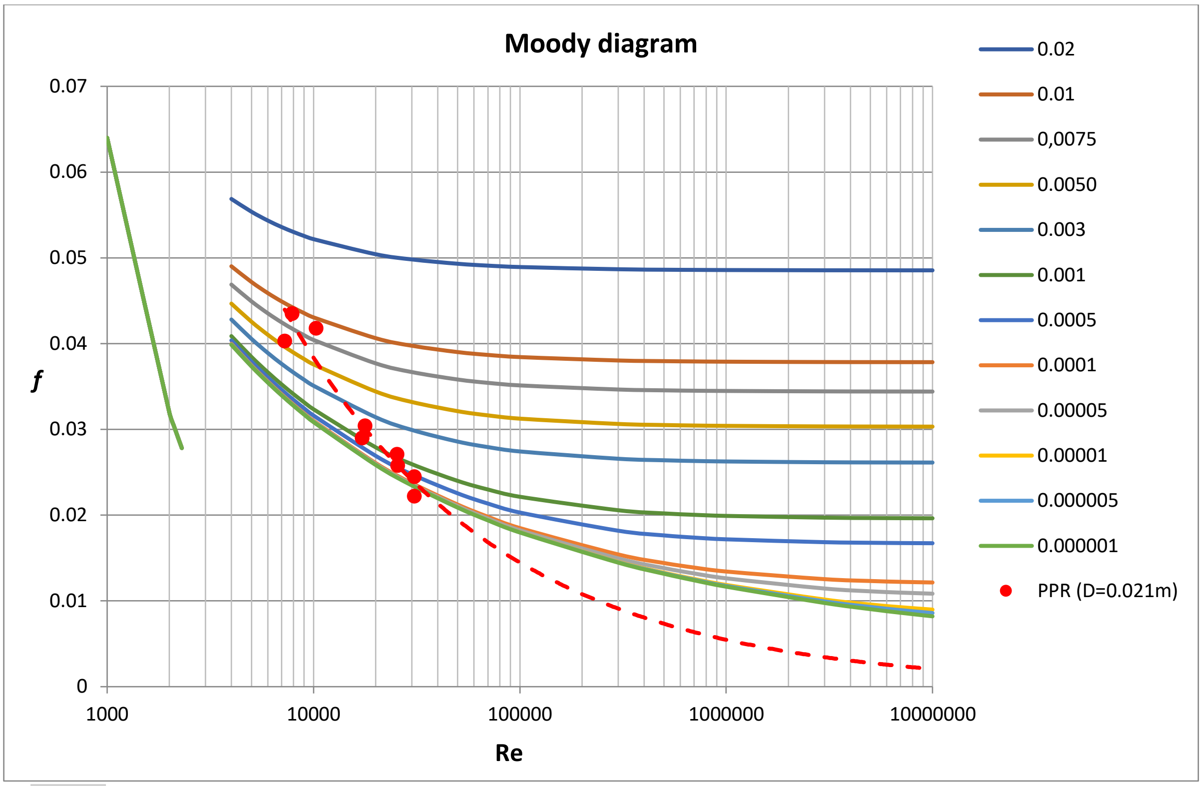

Fig. 9 Relationship of the Reynolds Number with the Average Friction Factor for the PPR Pipe of Diameter 0.021 m.

4.2.Results of the Relationship between the Influencing Factors and Friction Losses

The factors affecting the friction losses resulting from the flow of fluids inside the pipes are the flow velocity, length, and diameter of the pipe, in addition to the friction factor, which depends on the Reynolds number and the roughness of the pipe, according to the nature of the flow inside the pipe, whether it is laminar or turbulent. In the previous paragraph, the friction factor was calculated for all tested cases in this study, as shown in Table 2. The friction factor of flow inside PPR pipes increases with a decrease in flow velocity because the decrease in flow velocity leads to a reduction in the Reynolds number, which in turn leads to an increase in the friction factor. The results also showed that the internal roughness of PPR pipes was very low, as shown in Figs. 6, 7, and 8. To identify the other factors affecting the friction losses in PPR pipes, which are the flow velocity, length, and diameter of the pipe, Figs. 10, 11, and 12 illustrate the effect of each of these factors, respectively. Figure 10 shows the relationship between the flow velocity and head loss for a PPR pipe with a diameter of 0.0131m and four pipe lengths, i.e., 3, 10, 20, and 30m. As shown in this figure, friction losses increase with the flow velocity, exhibiting a nonlinear relationship. The exact context of this direct relationship was obtained for the diameters of the other pipes tested in this study. Figure 11 shows the effect of the pipe length on the friction losses inside a PPR pipe with a diameter of 0.0131m and for different flow velocities inside this pipe. The friction losses increased linearly with the pipe length, depending on the flow velocity inside the pipe. This result is consistent with the relationship between friction losses and pipe length, as predicted by the Darcy-Weisbach equation (Eq. (1)). Notably, the same relationship was also observed for pipes with diameters of 0.01675 and 0.021m. Additionally, it is worth noting that the test results for all models showed that friction losses increased almost in proportion to the increase in pipe length for any given pipe diameter. For example, the study showed that for a pipe with a diameter of 0.0131m, the rate of increase in friction losses was 9.75 times when the pipe length increased from 3 to 30m, i.e., the increase in friction losses is constant with the increase in pipe length. Figure 12 shows the effect of the pipe diameter on the friction losses of PPR pipes inside a pipe of length 30m and at different velocities. The friction losses decreased linearly as the pipe diameter increased, which is also consistent with the Darcy-Weisbach equation. The same relationship was obtained for pipes of other lengths used in this study. The study's results indicated that, at a pipe length of 30 m and a flow velocity of 1.53 m/s, friction losses decreased by 40% when the diameter increased from 0.0131 m to 0.01675 m. In comparison, the percentage of losses decreased by 55% when the diameter increased from 0.0131 m to 0.021

m. For low flow velocity (0.380 m/s), the decrease was very small compared to high velocities, as the percentage of decrease does not exceed 17% when the diameter increased from 0.0131m to 0.021m. These results reflect the importance of selecting the appropriate pipe diameter and adjusting the flow velocity in the design and operation of fluid flow systems to achieve optimal efficiency and minimize friction losses. Although the present study demonstrated that the PPR pipes have extremely low internal roughness, it was noted that using these pipes results in pressure or head losses due to the water flowing through them. To assess these pipes, the friction losses were compared to pipes of the same length and diameter, however, made from different materials, like galvanized iron, and flowed under identical conditions, see Fig. 13. Figure 13 compares the friction loss with flow velocity relationship for four PPR pipe lengths having an internal diameter of 0.01675 m to that of galvanized iron pipe lengths with an internal diameter of 0.01727 m. The results showed that the friction losses in PPR pipes were approximately 20% lower than those in galvanized iron pipes.

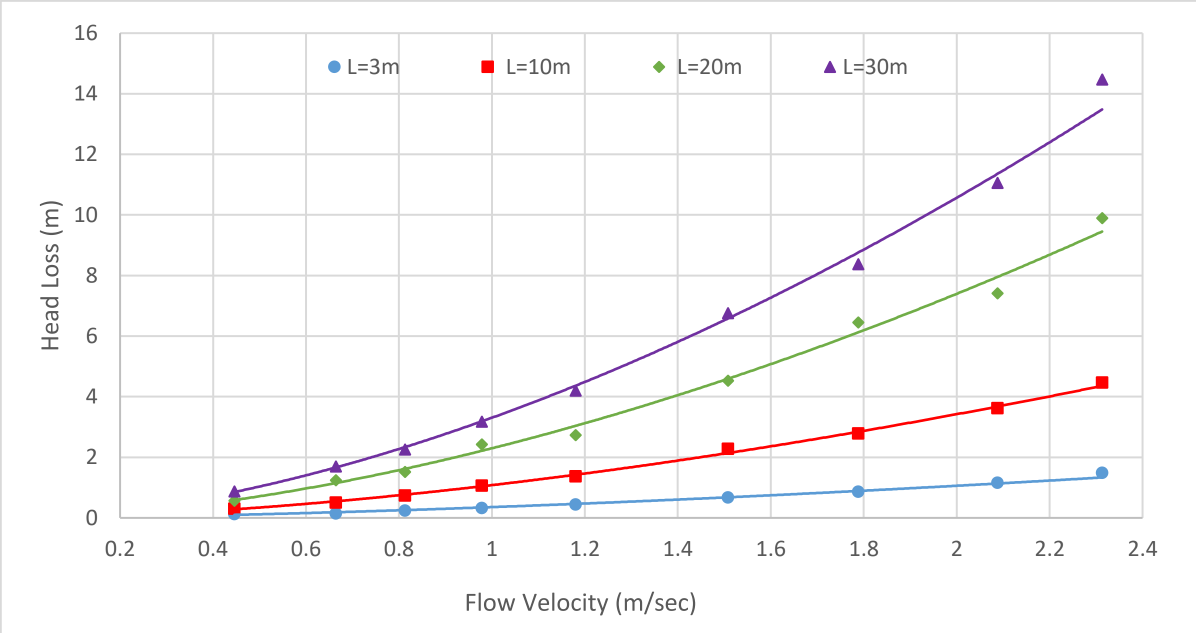

Fig. 10 Relationship between the Flow Velocity and Head Loss for a PPR Pipe with a Diameter of 0.0131 m.

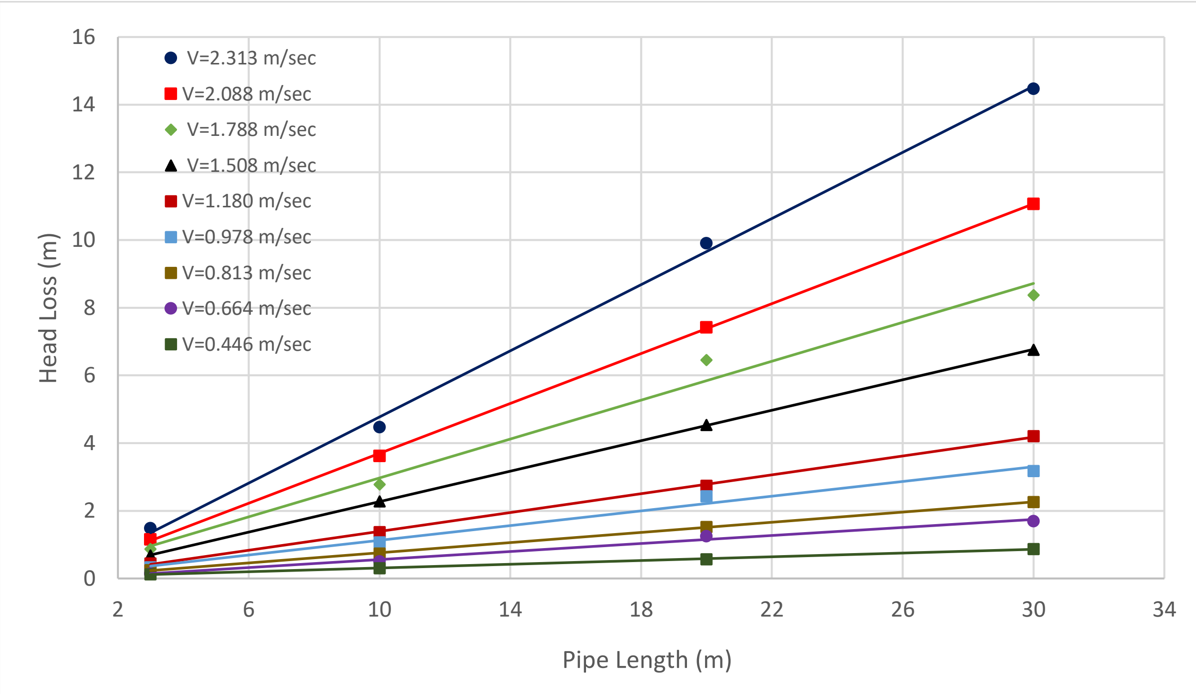

Fig. 11 Relationship between the Pipe Length and Head Loss for a PPR Pipe with a Diameter of 0.0131 m.

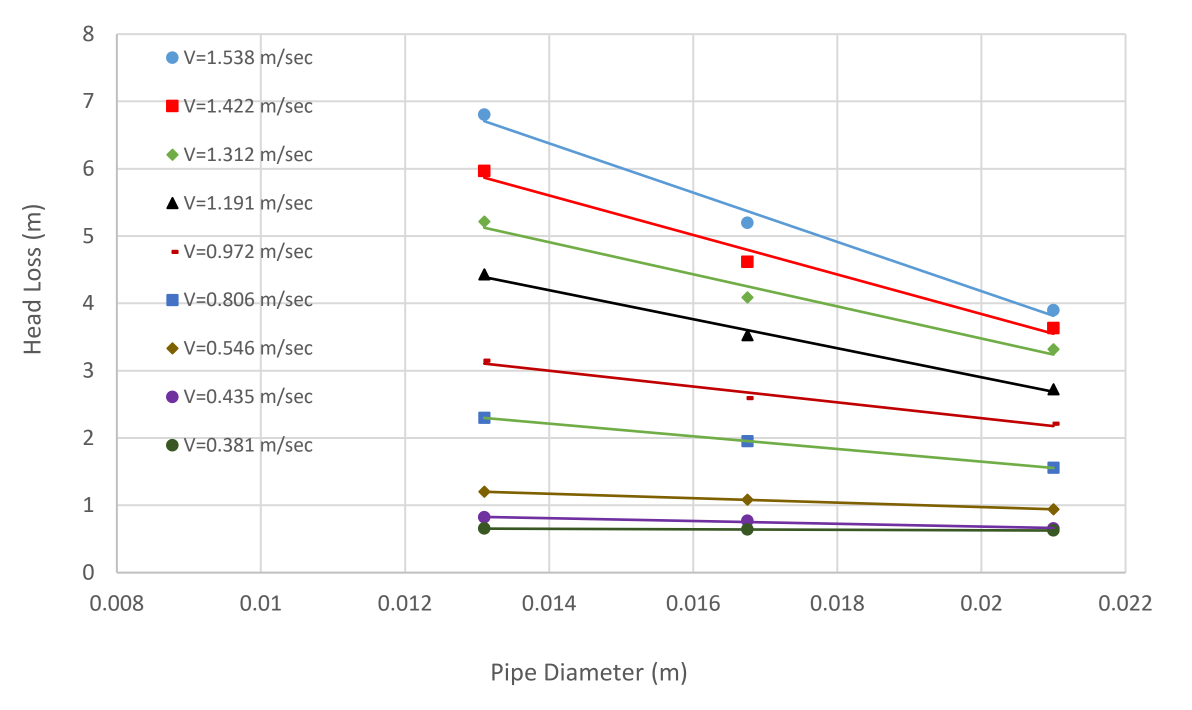

Fig. 12 Relationship between the Pipe Diameter and Head Loss for a PPR Pipe with a Length of 30 m.

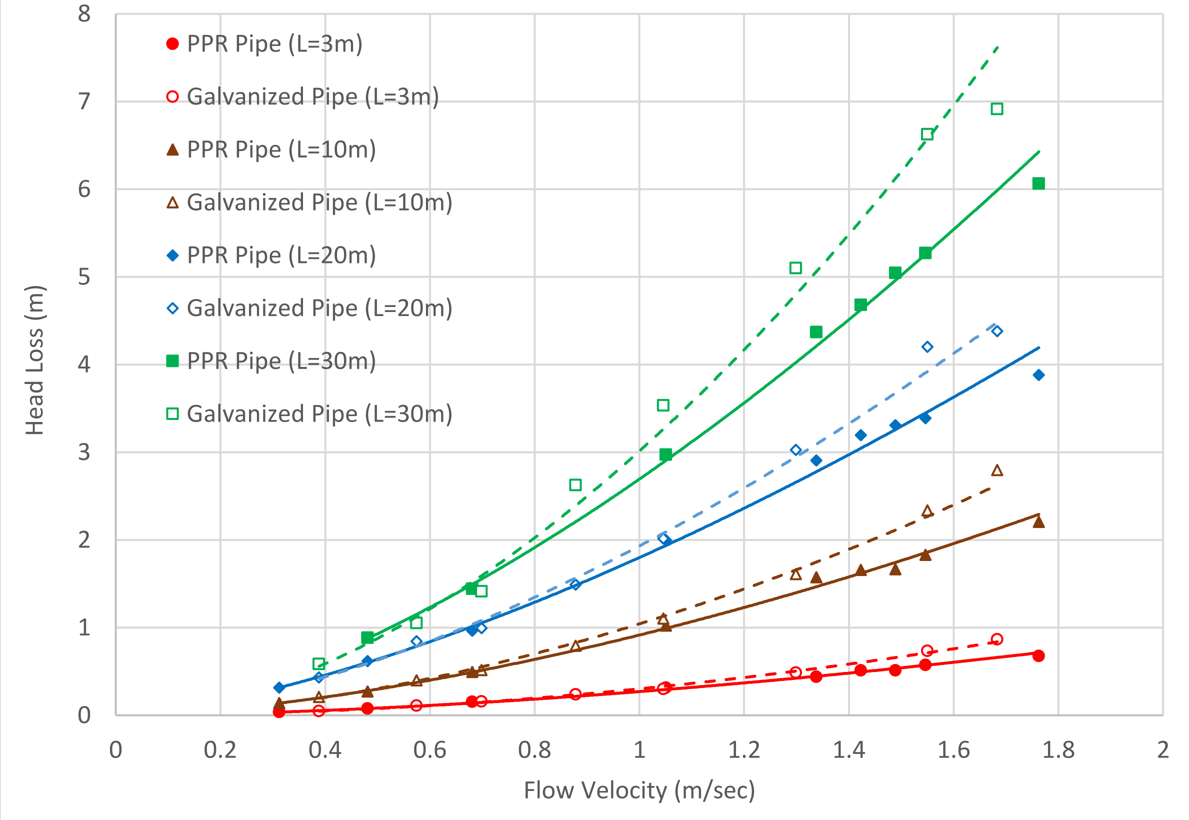

Fig. 13 Comparison between the Head Loss in PPR and Galvanized Pipes.

Based on the laboratory results shown in Tables 1 and 2, an empirical equation was derived to measure the friction losses in PPR pipes using the statistical program (SPSS-21). This equation relied on the length and diameter of the pipe, the amount of discharge through it, and Reynolds' number as follows:

$$H_L = 0.04\left(\frac{L^{0.995} * Q^{1.917}}{D^{4.768} * \mathrm{Re}^{0.264}}\right) \quad (5)$$

where H_L is the friction head loss (m), L is the length of pipe (m), D is the diameter of pipe (m), Q is the discharge of flow (m^3/sec), and Re is the Reynolds' number. The application of this equation is straightforward in determining friction losses in PPR pipes. To demonstrate the accuracy of this equation, the results of this equation were plotted with the results of the Darcy-Weisbach equation for all tested cases in this study, as shown in Fig. 14. From this figure, it is clear that the results of this equation are in excellent agreement with the experimental results, as the determination coefficient (R^2) and mean absolute error (MAE) are equal to 0.9946 and 0.11, respectively.

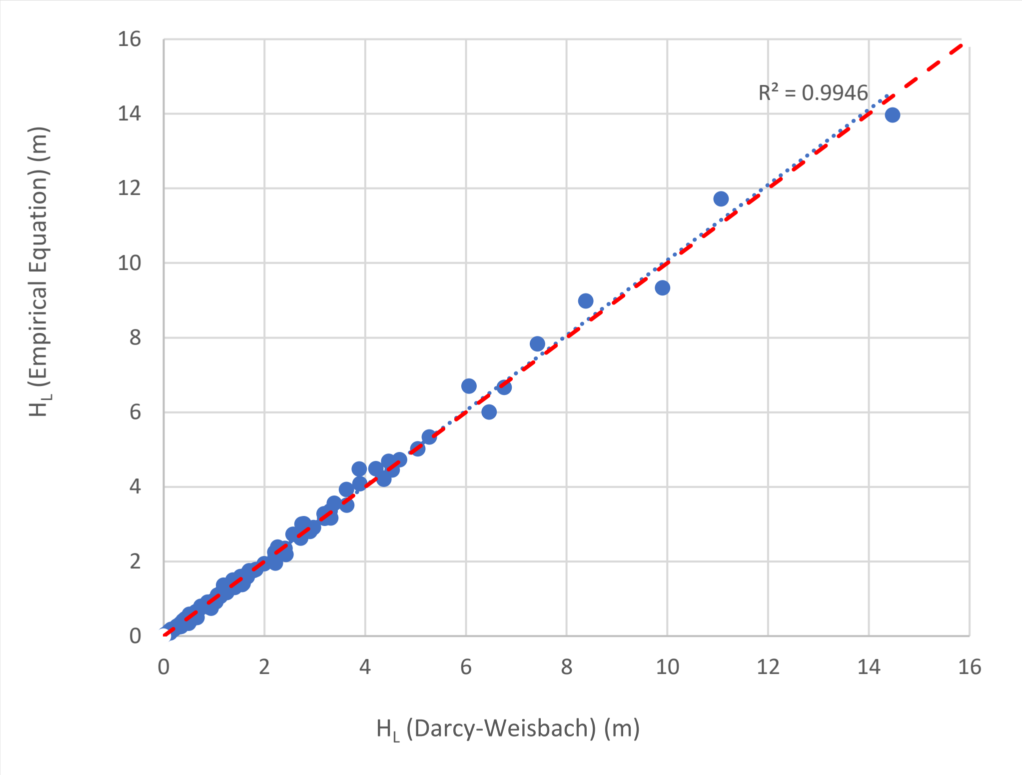

Fig. 14 Relationship between the Head Loss Results of the Empirical Equation and Darcy-Weisbach Equation.

5.CONCLUSIONS

Friction losses in PPR pipes have not been extensively studied, as previous research has primarily focused on the impact of environmental factors, such as heat, freezing, and pressure, on the material properties of these pipes. In light of the results of this study, the following conclusions can be summarized:

- The average height of the internal roughness of PPR pipes (e) was 0.00001 mm, indicating that these pipes are approximately smooth.
- The friction factor (*f*) of PPR pipes increased as the flow velocity decreased because a decrease in flow velocity resulted in a decrease in the Reynolds number, which in turn increased the friction factor. It was also noted that a nonlinear relationship existed between friction losses and flow velocity.
- The friction losses linearly increased with increasing pipe length. This result agrees with the Darcy-Weisbach equation. The results also showed that increasing the pipe length from 3 m to 30 m increased friction losses by a factor of 9.75.
- The friction losses decreased linearly as the pipe diameter increased, which is also consistent with the Darcy-Weisbach equation. In addition, the friction losses decreased by 40% when the diameter increased from 0.0131m to 0.01675m for a pipe length of 30 m and a flow velocity of 1.53 m/s. The losses decreased by 55% when the diameter increased from 0.0131m to 0.021m. For a low flow velocity of 0.38 m/s, the percentage decrease did not exceed 17% when the diameter increased from 0.0131m to 0.021m.
- The friction losses in PPR pipes were roughly 20% lower than those in galvanized iron pipes when the two types of pipes were under the same conditions and had the same length and diameter.
- An easy and reliable empirical equation was derived to measure friction losses in PPR pipes. The results of this equation showed excellent agreement with the experimental results, as indicated by the coefficient of determination (R^2) and mean absolute error (MAE), which were 0.9946 and 0.11, respectively.

Ultimately, considering the findings of this research, further economic analyses may be conducted to illustrate the benefits of employing PPR pipes in water conveyance systems for specific projects, such as factories, multi-story structures, or other similar projects.

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