

DOI: 10.7127/rbai.v1601254

SIMPLIFIED SCOBNEY FORMULA FOR DETERMINING HEAD LOSS IN PRESSURIZED PIPES**FÓRMULA SIMPLIFICADA DE SCOBNEY PARA A DETERMINAÇÃO DA PERDA DE CARGA EM TUBULAÇÕES PRESSURIZADAS****Juciano Gabriel da Silva¹, Marcia Xavier Peiter², Adroaldo Dias Robaina³, Jhosefe Bruning⁴, Miguel Chaiben Neto⁵, Laura Dias Ferreira⁶**¹Engenheiro Agrônomo, Mestrando em Engenharia Agrícola, Dept. Eng. Rural, UFSM, Santa Maria, RS, Brasil²Doutora em Engenharia Civil, professora associada da UFSM, Santa Maria, RS, Brasil³Doutor em Engenharia Civil, professor titular da UFSM, Santa Maria, RS, Brasil⁴Doutorando em Engenharia Agrícola, Dept. Eng. Rural, UFSM, Santa Maria, RS, Brasil⁵Doutorando em Engenharia Agrícola, Dept. Eng. Rural, UFSM, Santa Maria, RS, Brasil⁶Doutoranda em Engenharia Agrícola, Dept. Eng. Rural, UFSM, Santa Maria, RS, Brasil

ABSTRACT: Head loss in pressurized pipelines is one of the factors that must be considered in the hydraulic design. Therefore, the objective of this work was to simplify Scobey's empirical equation to calculate head loss in Polyvinyl Chloride pipes with nominal diameters from 32 to 200 millimeters and compare it with the Darcy-Weisbach equation. The performance of the simplified equation was statistically evaluated using the Willmott's index of agreement, correlation coefficient, performance index and percentage error. The simplified formula showed better correlation than the original equation, excellent performance index, and percentage errors smaller than 6% in most simulations compared to the results obtained by the Darcy-Weisbach equation.

Keywords: Darcy-Weisbach, empirical equation, plastic pipes.

RESUMO: A perda de carga em tubulações pressurizadas é um dos fatores que devem ser considerados no momento do dimensionamento hidráulico. Portanto, o objetivo do trabalho foi simplificar a equação empírica de Scobey, para o cálculo da perda de carga em tubos de Policloreto de Vinila com diâmetros nominais de 32 a 200 milímetros e comparar com a equação de Darcy-Weisbach. O desempenho da equação simplificada foi avaliado estatisticamente através do índice de concordância de Willmott, coeficiente de correlação, índice de desempenho e o erro percentual. A fórmula simplificada apresentou melhor correlação do que a equação original, excelente índice de desempenho, além de erros percentuais menores que 6% na maioria das simulações em comparação com os resultados obtidos pela equação de Darcy-Weisbach.

Palavras-chave: Darcy-Weisbach, equações empíricas, tubos plásticos.

INTRODUCTION

In the hydraulic design of irrigation systems, it is essential to know the energy losses, which occur from the motor-pump set to the end of the irrigation system. Head loss is one of the specific variables during the design process (ALVES et al., 2017), being directly related to the cost of pipes, choice of the motor-pump set and energy consumption (MIRANDA et al., 2019).

Continuous head loss in irrigation systems occurs due to friction between the particles of the fluid itself, kinematic viscosity, and also the friction of the liquid with the internal wall of the pipe (MIRANDA, 2016). It can be estimated through several equations (PIMENTA et al., 2018), allowing the designer to choose which head loss equation to use, provided that the situation meets the assumptions of use. Inadequate choice can lead to significant errors in the definition of pipe diameter and, consequently, throughout the hydraulic structure of the project (SOUSA, 2018).

Among the head loss equations applied to pressurized pipes, the Darcy-Weisbach equation can be applied under any condition of velocity, temperature, roughness and Reynolds number (ALLEN, 1999; LI et al., 2017), being considered the most complete and, because of this, the most recommended equation (LAPERUTA NETO et al., 2011; GEISENHOF, 2018; MELO et al., 2019; MINHONI et al., 2020). On the other hand, calculating continuous head loss with the Darcy-Weisbach equation is relatively difficult, since it involves separately the calculation of the friction factor, which is not

considered to be simple (VON BERNUTH, 1990; JAMIL et al., 2020).

For mathematical simplicity, many designers use empirical equations such as those of Hazen-Williams, Manning and Scobey to determine continuous head losses rather than the theoretical equation of Darcy-Weisbach (ALAZBA et al., 2012; RETTORE NETO et al., 2009). However, studies have found that the Scobey equation applied to diameters below 50 mm generates percentage errors greater than 20% in the head loss estimate (RETTORE NETO, 2016).

Therefore, the present study aims to develop a simplified formula from the modification of the Scobey equation, to determine head loss in PVC pipes with nominal diameters from 32 to 200 mm, comparing its performance with the results obtained by the Darcy-Weisbach equation.

MATERIAL AND METHODS

Head loss determination was simulated using Microsoft Excel® 2016 software, for a PVC (polyvinyl chloride) main line with 1000 meters length, for nominal diameters of 32, 40, 50, 75, 100, 125, 150 and 200 mm, with inner diameters of 28.81, 35.3, 48.1, 72.5, 97.6, 120, 144 and 200 mm, respectively, with flow velocity ranging from 0.5 m s⁻¹ to 3.5 m s⁻¹ at intervals of 0.1 m s⁻¹. For equivalent materials, the literature reports broad ranges representative of the values that can be assumed by the absolute roughness. Table 1 indicates some values and intervals of absolute roughness in PVC pipes found in the technical literature and used in the simulation.

Table 1: Reference values of absolute roughness for PVC pipes, according to different authors.

Absolute roughness - ϵ (mm)	Source
0.020	SOUZA et al., 2014
0.015	ALZBA, 2012
0.006	BEZZERA et al., 2017
0.00531	KELLNER et al., 2016

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0.003334	ROCHA et al., 2017
0.002	ALLEN, 1999
0.0015	URIBE et al., 2015

Continuous head loss was simulated by the Darcy-Weisbach equation (Equation 01), with friction factor (f) determined by the Colebrook-White formula (Equation 02), varying the roughness coefficient according to the values presented in Table 1. Subsequently, the continuous head loss determined by the Darcy-Weisbach equation was used to find a new “Ks” Scobey coefficient (Equation 03 and

04) for each diameter studied. Then, the new Ks values were correlated with the flow velocity, obtaining a new function (Equation 05) and later incorporated into the Scobey equation (Equations 06, 07 and 08). Table 2 shows the equations for determining head loss and the new value of the Ks coefficient used in the modification of the Scobey equation.

Table 2. Equations used to simplify Scobey’s empirical equation.

Eq. No.	Nomenclature	Equations
01	Darcy-Weisbach	$HF_{DW} = f \frac{L}{D} \frac{V^2}{2g}$
02	Colebrook-White	$\left(\frac{1}{\sqrt{f}} = -2 \log \left(\frac{\varepsilon}{3.7D} + \frac{2.51}{Re\sqrt{f}} \right)\right)$
03	Scobey	$HF_{(SCOBEY)} = \frac{K_S}{387} \frac{L}{D^{1.1}} V^{1.9}$
04	$K_{S(NEW)}$	$K_{S(NEW)} = \frac{HF_{(DARCY)}}{\frac{L}{D^{1.1}} V^{1.9}} 387$
05	$K_{S(NEW)}$	$K_{S(NEW)} = \alpha \cdot V^\beta$
06	Simplified formula	$HF_{(SF)} = \frac{\alpha V^\beta}{387} \frac{L}{D^{1.1}} V^{1.9}$
07	Simplified formula	$HF_{(SF)} = \frac{\alpha V^{\beta+1.9}}{387} \frac{L}{D^{1.1}}$
08	Simplified formula	$HF_{(SF)} = \frac{(\alpha D^{\beta+1.1}) (V^{\beta+1.9})}{387} L$

HF – head loss (m.w.c.); D – inner pipe diameter (m); f – friction factor of Darcy-Weisbach equation (dimensionless); L – pipe length (m); V – flow velocity (m s⁻¹); ε – roughness coefficient (m); Re – Reynolds number (dimensionless); g – gravity acceleration (m s⁻²); K_S – coefficient of the Scobey equation (dimensionless); HF_(SF) – head loss by the simplified Scobey formula (m.w.c.); a, b – calibration coefficients of the equation (dimensionless).

To verify the performance of the new equation, the head loss values calculated by the Darcy-Weisbach equation (reference head loss) were compared with the data obtained using the simplified Scobey equation (Equation 08). These results were statistically evaluated using 1:1 line, Willmott's index of agreement (d), correlation coefficient (r) and performance index (Id), according to

equations 09, 10 and 11, respectively, which are presented in Table 3.

Moreover, the percentage error (Equation 12) was adopted to evaluate head loss as a function of flow velocity (SOUZA, 2018).

The parameters used for classifying the agreement index, precision index and performance index are presented in Table 4.

Table 3. Statistical parameters used in the study.

Eq. No.	Abbreviation	Equation
9	d	$1 - \left[\frac{\sum_{i=1}^n (P_i - O_i)^2}{\sum_{i=1}^n (P_i - O_i + O_i - O)^2} \right]$
10	r	$\frac{\sum_{i=1}^n (P_i - P)(O_i - O)}{\sqrt{\sum_{i=1}^n (P_i - P)^2 \sum_{i=1}^n (O_i - O)^2}}$
11	Id	r . d
12	Error (%)	$\text{Error (\%)} = \frac{ TV - AV }{AV} 100$

P_i - estimated values, O_i - observed values, P - mean of estimated values; O - mean of observed values; N - number of observations; $h_{f_{est}}$ - Head loss estimated by the simplified formula; $h_{f_{ref}}$ - Reference head loss by Darcy-Weisbach equation; Error (%) - percentage error; TV - theoretical value (obtained by simplified equation), AV - actual value (obtained by Darcy-Weisbach equation).

Table 4. Criteria for interpretation of the Agreement Index, Correlation Coefficient and Performance Index and their respective classifications.

Agreement Index (d)	Correlation Coefficient (r)	Performance Index (Id)	Classification
0.95 – 1.00	0.95 – 1.00	0.90 – 1.00	Excellent
0.89 – 0.95	0.89 – 0.95	0.80 – 0.90	Great
0.84 – 0.89	0.84 – 0.89	0.70 – 0.80	Very Good
0.77 – 0.84	0.77 – 0.84	0.60 – 0.70	Good
0.71 – 0.77	0.71 – 0.77	0.50 – 0.60	Moderately Good
0.63 – 0.71	0.63 – 0.71	0.40 – 0.50	Moderate

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0.55 – 0.63	0.55 – 0.63	0.30 – 0.40	Moderately Poor
0.45 – 0.55	0.45 – 0.55	0.20 – 0.30	Poor
0.32 – 0.45	0.32 – 0.45	0.10 – 0.20	Very Poor
0.00 – 0.32	0.00 – 0.32	0.00 – 0.10	Terrible

Source: Pimenta et al. (2018)

RESULTS AND DISCUSSION

The head loss values obtained by Darcy-Weisbach equation (reference head loss) were compared with the data obtained by the original (Equation 03) and modified (Equation 14) Scobey equations with coefficient of the original Scobey equation (K_s) fixed at 0.32 (recommended for PVC pipes). The results of head loss estimated by the original and modified Scobey equations are shown in Figure 1. It can be noted that both equations showed good adherence to the 1:1 line,

because the values obtained by the Scobey equation are very close to the results estimated by the Darcy-Weisbach equation, using the same variables.

The simplified Scobey equation had coefficient of determination (R^2) equal to 0.996, which was higher than the coefficient obtained by the original Scobey equation, indicating an excellent proportion that the variation of the response variable is explained by the variation of the predictor variable (KENNEDY, 2008).

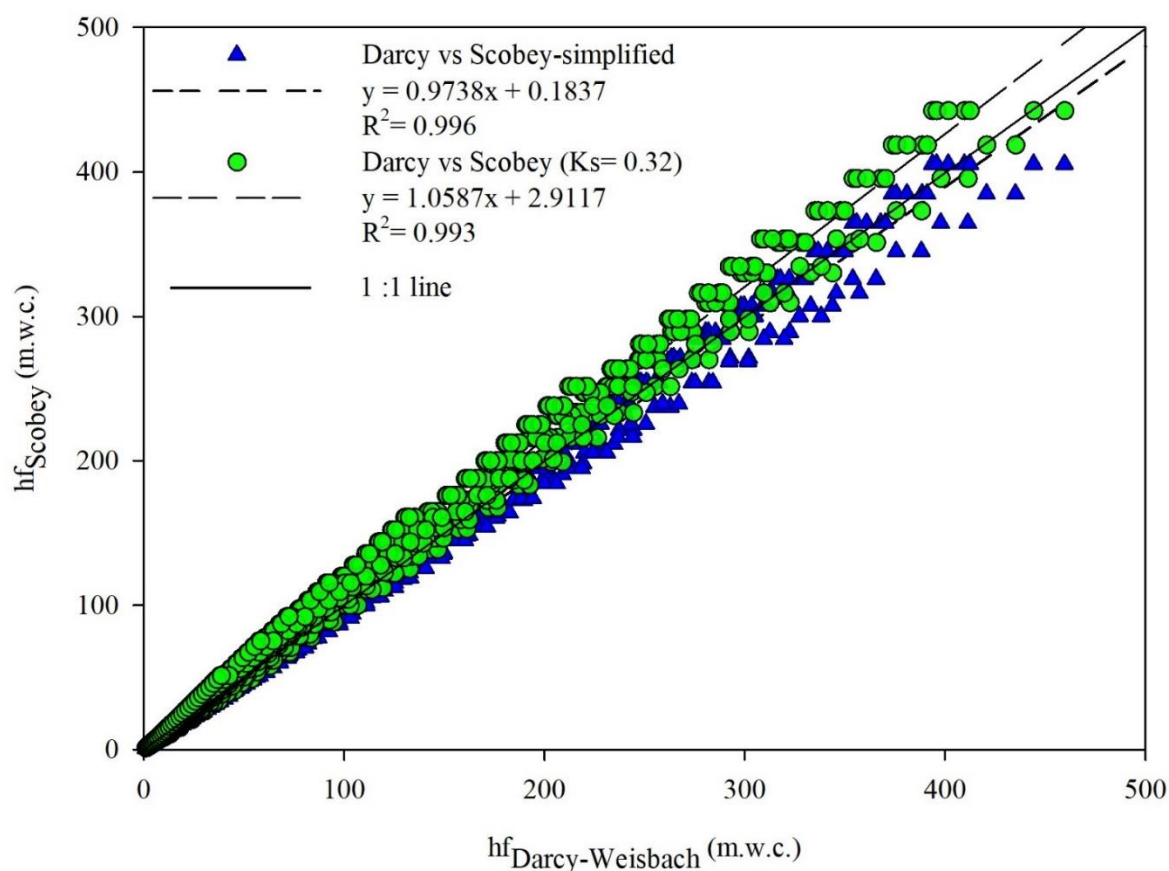


Figure 1. Comparison of continuous head loss (hf) estimated by the Scobey equation (original and simplified) and the Darcy-Weisbach equation, based on the simulations performed in a main line with 1000 meters length for the different values of roughness, inner diameter of the pipes and flow velocity.

Figure 1 shows that the highest values of energy loss estimated by the empirical Scobey equation were also the ones with the most dispersion compared to the results obtained by the Darcy-Weisbach equation (reference).

This distance of the data from the 1:1 line is due to the unsatisfactory performance of the empirical equation of Scobey in situations of pipes with nominal diameters

greater than 100 mm (SOUSA, 2018). Table 5 shows the Willmott's index of agreement (d), correlation coefficient (r) and performance index (P), to compare the results obtained by the Darcy-Weisbach equation (reference values) and by the simplified Scobey equation (estimated values), for different diameters and internal wall roughness of the pipes.

Table 5. Statistics of the data obtained by comparing the simplified Scobey equation and the Darcy-Weisbach formula.

Pipe (mm)	Roughness (mm)	Statistical indices		
		d	r	P
32	0.0015	0.998	0.991	0.988
	0.002	0.998	0.991	0.989
	0.003334	1.000	0.991	0.990
	0.00531	1.000	0.991	0.991
	0.006	1.000	0.991	0.990
	0.015	0.986	0.991	0.977
	0.02	0.975	0.991	0.966
40	0.0015	0.998	1.000	0.998
	0.002	0.998	1.000	0.998
	0.003334	1.000	1.000	1.000
	0.00531	1.000	1.000	1.000
	0.006	1.000	1.000	1.000
	0.015	0.977	1.000	0.977
	0.02	0.976	1.000	0.976
50	0.0015	0.998	1.000	0.998
	0.002	0.999	1.000	0.999
	0.003334	1.000	1.000	1.000
	0.00531	1.000	1.000	1.000
	0.006	0.999	1.000	0.999
	0.015	0.978	1.000	0.978
	0.02	0.975	1.000	0.974
75	0.0015	0.999	1.000	0.999
	0.002	1.000	1.000	1.000

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	0.003334	1.000	1.000	1.000
	0.00531	0.999	1.000	0.999
	0.006	0.999	1.000	0.999
	0.015	0.978	1.000	0.977
	0.02	0.977	1.000	0.977
	0.0015	1.000	1.000	1.000
	0.002	1.000	1.000	1.000
	0.003334	1.000	1.000	1.000
100	0.00531	0.998	1.000	0.998
	0.006	0.998	1.000	0.998
	0.015	0.985	1.000	0.985
	0.02	0.977	1.000	0.977
	0.0015	1.000	1.000	1.000
	0.002	1.000	1.000	1.000
	0.003334	0.999	1.000	0.999
125	0.00531	0.998	1.000	0.998
	0.006	0.997	1.000	0.997
	0.015	0.976	1.000	0.975
	0.02	0.975	1.000	0.975
	0.0015	1.000	1.000	1.000
	0.002	1.000	1.000	0.999
	0.003334	0.999	1.000	0.999
150	0.00531	0.997	1.000	0.997
	0.006	0.996	1.000	0.996
	0.015	0.974	1.000	0.974
	0.02	0.974	1.000	0.974
	0.0015	0.998	1.000	0.998
	0.002	0.998	1.000	0.998
	0.003334	0.997	1.000	0.997
200	0.00531	0.994	1.000	0.994
	0.006	0.993	1.000	0.993
	0.015	0.971	1.000	0.971
	0.02	0.971	1.000	0.971

The comparison between the values of head loss by the simplified equation and the Universal equation (Darcy-Weisbach), for pipes with the respective values of diameter and roughness (Table 5), showed high agreement, high degree of correlation and Performance Index considered as “Excellent” (PIMENTA et al., 2018).

For better interpretation of the simulations performed, the percentage error was used to demonstrate the values of head loss obtained with the simplified equation for the flow velocities ranging from 0 to 3.5 m s⁻¹, for each value of diameter and roughness under study (Figure 2).

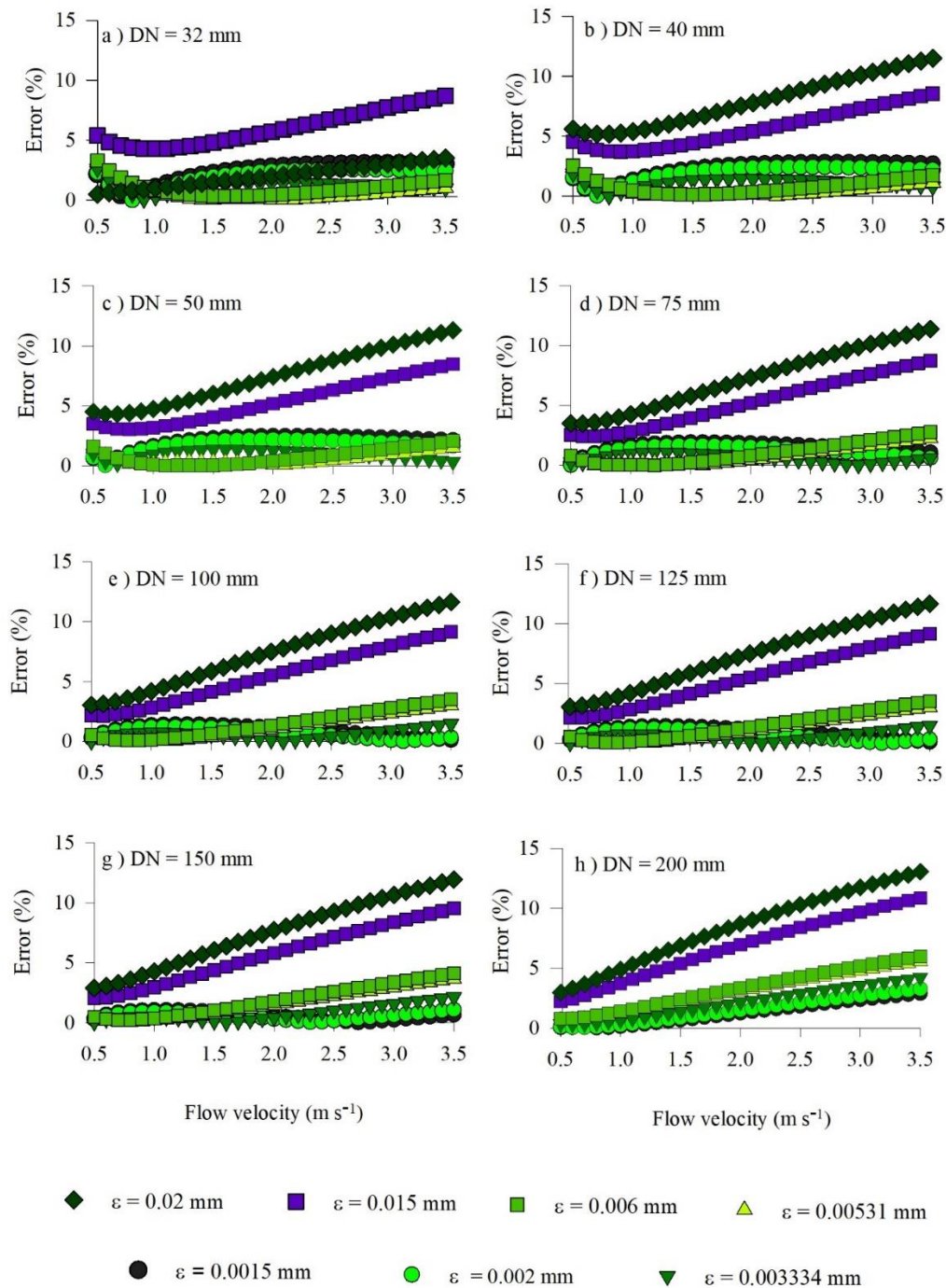


Figure 2. Percentage errors between the values of continuous head loss obtained by the Scobey equation and by the Darcy-Weisbach formula.

Figure 2 shows that the percentage errors decrease with the reduction in the internal roughness of the pipe. Since there is no perfectly smooth inner surface in pipes (MACDONALD et al., 2016), their internal walls usually have some degree of roughness. However, with the improvement of production processes, imperfections on these walls are minimized.

The calculation of head loss with the simplified equation led to lower percentage errors compared to the original Scobey equation. According to Sousa (2018), who evaluated the error in estimating continuous head loss in PVC and polyethylene pipes, the Scobey equation overestimated head loss in pipes of 100 and 200 mm in diameter by more than 30%, compared to the Universal formula.

Therefore, the proposed equation showed satisfactory results when compared to the results obtained with the Universal formula. In addition, empirical equations have specific coefficients that become useful almost exclusively for academic purposes and have little practicality. In this context, the use of equations with few variables and good results compared to complex equations is more useful in comparison with the other ones and the best option for the designer (YURDEM et al., 2010).

Equation

The equation below (Equation 14) was obtained from the simulations performed and shows application for calculating head loss in PVC pipes with nominal diameters of 35, 50, 75, 100, 125, 150 and 200 mm, simplifying the determination of head loss with excellent precision.

$$HF_{(\text{SIMPLIFIED SCOBEY})} = \frac{(0.2149 D^{-1.223}) (V^{1.8})}{387} L \quad (14)$$

CONCLUSIONS

It can be concluded that the simplification of Scobey showed good

performance for the calculation of head loss in polyvinyl chloride pipes with nominal diameters of 32, 40, 50, 75, 100, 125, 150 and 200 millimeters, with percentage errors below 6%, compared to the Darcy-Weisbach equation, for pipes with relative roughness between 0.006 and 0.0015 millimeters.

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