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BEHAVIOR OF WATER-FLOWED PIPES AT DIFFERENT TEMPERATURES

Comportamento da tubagem quando percorrida por água a diferentes temperaturas

GOMES, António Manuel Vilela Pereira[1]

Abstract

The implementation of water piping systems shows significant technological advances in the specialty of hydraulics. The pipes have great advantages, namely, in the reduction of fluid losses, as well as in the mitigation of problems resulting from water interruption and its preservation in relation to external harmful agents. In this numerical study will be tested pipes of various materials such as cast iron, stainless steel, galvanized steel, pex and fiberglass. The fluid that will circulate inside is water at different temperatures. Subsequently, several parameters will be evaluated, such as the friction factor, the head losses, the linear thermal expansion and the stress in the piping. Knowledge of these factors is paramount for the correct sizing of hydraulic networks, as well as for the correct choice of pumping systems.

Resumo

A implementação de sistemas de tubagem, de água, evidencia avanços tecnológicos significativos na especialidade de hidráulica. As tubulações, apresentam grandes vantagens, nomeadamente, na redução de perdas de fluido, bem como na amenização de problemas decorrentes da interrupção de água e na sua preservação, em relação a agentes nefastos exteriores. Neste estudo numérico vão ser testados tubos de vários materiais, tais como ferro fundido, aço inoxidável, aço galvanizado, pex e fibra de vidro. O fluido que circulará no seu interior é a água, a diferentes temperaturas. Posteriormente, serão avaliados vários parâmetros, tais como o fator de resistência, as perdas de carga, a dilatação térmica linear e a tensão axial, na tubagem. O conhecimento destes fatores é preponderante para o correto dimensionamento das redes hidráulicas, assim como para a correta escolha dos sistemas de bombagem.

Key-words: *Hydraulics; Piping; Head loss; Stress.*

Palavras-chave: *Hidráulica; Tubagem; Perda de carga; Tensão.*

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[1] ANTÓNIO MANUEL VILELA PEREIRA GOMES - Instituto Superior Politécnico Alvorecer da Juventude, ANGOLA. E-mail: vilelapgomes@gmail.com

INTRODUCTION

Water is an essential good for the perpetuation of human life on earth. Unfortunately, there are still many regions of the globe where people are deprived of the consumption of this liquid, with the minimum conditions of potability.

The transportation of water for human consumption through piping was carried out 3500 years ago on the island of Crete. Fluid flow through pipes serves a variety of applications. It can serve to transport water over long distances as well as the transport of solids through aqueous solutions. The design of piping systems is associated with a thorough understanding of various parameters such as materials, piping installation location, local regulations and inspection examinations and tests. Pipes not only include pipes but also flanges, bolts, gaskets, and valves (Swamee & Sharma, 2008).

The choice of piping material should be appropriate to the intended service. The material selected must be suitable for the fluid that will circulate inside it, the temperature variations and the pressure and safety conditions. The design life should also be considered as well as the mechanical strength of the material. The operating environment must also be taken care of to prevent material degradation and consequent loss of effectiveness (Nayyar, 2000).

In this numerical study, for the pipes, five different materials were used. Three pipes are metallic, one is thermoplastic and the other is fibrous. That is, they are cast iron, stainless steel, galvanized steel, pex and fiberglass pipes. The fluid that circulated inside them was water, at different temperatures, which ranged from 5 ºC to 50 ºC. The Reynolds number was determined to define the type of flow. Subsequently, the friction factor and the head loss were determined by varying the inside diameter of the tube as well as the fluid velocity. Further, the linear thermal expansion and the stress of the pipe, caused by the temperature variation, were calculated. Knowledge of these parameters is of utmost importance as disregarding them can lead to serious pipe problems. The pipes are made of different materials, so their behavior will also differ between them. On the other hand, piping systems are usually coupled with pumping or pressurizing equipment, so it is essential to reduce friction and losses as much as possible to reduce the power of these machines.

1. MATERIALS

There are several types of pipes on the market to be used for water transport, having the capacity to withstand the most varied temperatures and pressures. In this article, several piping materials were discussed, as shown below.

1.1. Cast iron

Cast iron is an iron alloy with carbon content ranging from 2 to 4% and silicon from 1 to 3%. It has a low melting point and is very fluid when melted. It should not be hot worked and is generally brittle (ICE, 2009).

Figure 1 – Cast iron pipe

Source: Ferpac

1.2. Stainless steel

Stainless steel is a steel made up of at least 12% chromium. This type of steel has good tensile strength and enables reduction of pipe thickness under the same pressure conditions (Llewellyn & Hudd, 2000).

Figure 2 – Stainless steel pipe

Source: Toni Clark

1.3. Galvanized steel

Galvanized steel is a steel that has a thin layer of zinc to prevent corrosion. Zinc is applied by electroplating or by a hot-dip bath (Kuklík & Kudlâĉek, 2016).

Figure 3 – Galvanized steel pipe

Source: Pipeline Dubai

1.4. PEX

Cross-linked polyethylene (PEX) pipes are normally used in hot and cold water distribution networks and can withstand temperatures up to 95 °C. Due to the high coefficient of thermal expansion, the pipes must be installed in thermally stabilized polyethylene protective sleeves or bends or expansion arms should be introduced (Pedroso, 2014).

Figure 4 – Pex pipe

Source: Zurn

1.5. Fiberglass

Fiberglass is a material composed of the agglomeration of flexible and very thin filaments of glass. The filaments are joined by resin. It is a lightweight, durable material with low thermal conductivity (Wallenberger & Bingham, 2010).

Figure 5 – Fiberglass pipe

Source: Alario Bros

2. EVALUATED PARAMETERS

2.1. Reynolds number

The magnitude of the Reynolds number, *Re*, will determine the flow regime, which may be laminar flow, unpredictable or turbulent (Elger, Williams, Crowe, & Roberson, 2012).

The expression that allows to calculate is as follows:

$$R_e = \frac{\rho \cdot v \cdot D}{\mu} = \frac{v \cdot D}{\nu} \qquad \text{[unitless]} \tag{1}$$

where:

ρ – density, [kg/m^3]
v – flow velocity, [m/s]
D – inner diameter, [m]
μ – dynamic viscosity, [Pa·s]
ν – kinetic viscosity, [m^2/s]

The classification regarding the flow regime is not always consensual among the various technical books. However, in this article we will take the following values as a reference:

Reynolds Number: Up to 2,000 → Laminar flow
From 2,000 to 3,000 → Transient flow
Greater than 3,000 → Turbulent flow

2.2. Kinematic viscosity

Kinematic viscosity, ν, is the quotient between dynamic viscosity and density, μ, and it is known that:

$$\nu = \frac{\mu}{\rho} \qquad [m^2/s] \qquad (2)$$

where:

μ – dynamic viscosity, [Pa·s]
ρ – density, [kg/m^3]

The following table shows the kinematic viscosity for various temperatures:

Table 1 – Kinematic viscosity of water

Temperature, *T* [ºC]	Kinematic viscosity, *ν* [m^2/s]	Temperature, *T* [ºC]	Kinematic viscosity, *ν* [m^2/s]
5.00	1.52×10^{-6}	**30.00**	0.81×10^{-6}
10.00	1.31×10^{-6}	**40.00**	0.66×10^{-6}
15.00	1.14×10^{-6}	**50.00**	0.55×10^{-6}
20.00	1.01×10^{-6}	**60.00**	0.48×10^{-6}
25.00	0.90×10^{-6}	**80.00**	0.37×10^{-6}

Source: Andrés, L.

2.3. Friction factor

The friction factor, *f*, depends on the Reynolds number, material roughness and pipe diameter.

According to Quintela (2014), Colebrook in 1939, after extensive experiments with White, proposed the following Colebrook-White expression, which allows quantifying this parameter in commercial circular tubes:

$$\frac{1}{\sqrt{f}} = -2 \cdot \log\left(\frac{k}{3{,}7 \cdot D} + \frac{2{,}51}{R_e \cdot \sqrt{f}}\right) \qquad [\text{unitless}] \qquad (3)$$

where:

k – absolute roughness coefficient, [mm]
D – inner diameter, [mm]
R_e – Reynolds number, [unitless]

For the determination of the friction factor, the Colebrook-White formula could be used, but we chose to use the expression given by S.E. Haaland to avoid successive iteration:

$$\frac{1}{\sqrt{f}} = -1.8 \cdot \log\left[\frac{6.9}{R_e} + \left(\frac{k/D}{3.7}\right)^{1.11}\right] \qquad [\text{unitless}] \qquad (4)$$

The absolute roughness coefficients are as follows:

Table 2 – Absolute Roughness Coefficient

Surface Material	**Absolute Roughness Coefficient, *k* [mm]**
Cast iron	0.5250
Stainless steel	0.0150
Galvanized steel	0.1500
PEX	0.0070
Fiberglass	0.0050

Source: Enggcyclopedia & Ditasa

2.4. Head loss

Head loss, h_L, occurs due to fluid viscosity and obstructions to fluid passage inside the tubing. Head loss is expressed by Darcy-Weisbach equation:

$$h_L = f \cdot \frac{L}{D} \cdot \frac{v^2}{2 \cdot g} \qquad [\text{m}] \qquad (5)$$

where,

f – friction factor, [unitless]
L – length of pipe work, [m]
D – inner diameter of pipe work, [m]
v – flow velocity, [m/s]
g – acceleration due to gravity, [m/s^2]

2.5. Linear thermal expansion

The linear thermal expansion will be calculated for the five piping materials. The axial length variation will be evaluated. The mathematical expression for calculating change in object length, ΔL, is as follows:

$$\Delta L = \alpha \cdot L_0 \cdot \Delta T \qquad [\mathrm{m}] \tag{6}$$

where:

α – linear expansion coefficient, [ºC^{-1}]
L_0 – initial length of object, [m]
ΔT – temperature differential, [ºC]

Table 3 – Linear expansion coefficient

Surface Material	**Linear expansion coefficient, α [ºC^{-1}]**
Cast iron	12.1×10^{-6}
Stainless steel	17.3×10^{-6}
Galvanized steel	6.5×10^{-6}
PEX	1.4×10^{-4}
Fiberglass	5.7×10^{-6}

Source: Perry & Uponor

2.6. *Stress in axial direction*

Stress in axial direction is very important because, if the pipe is restricted to axial deformations, stress will arise and will cause deformations or even pipe rupture. Therefore, there should always be an empty space for material deformation. For the calculation of stress in axial direction, σ, we use the following expression:

$$\sigma = E \cdot \alpha \cdot \Delta T \qquad [\mathrm{kPa}] \tag{7}$$

where,

E – modulus of elasticity, [kPa]
α – linear expansion coefficient, [ºC^{-1}]
ΔT – temperature differential, [ºC]

Table 4 – Modulus of elasticity

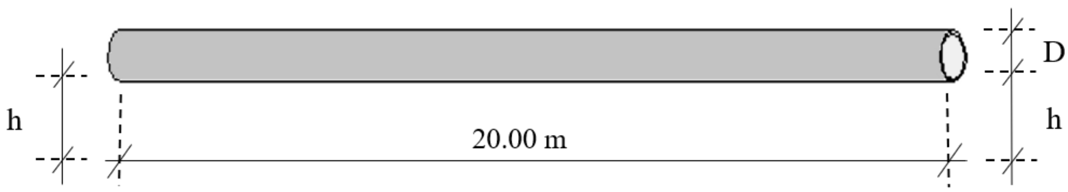
Surface Material	Modulus of elasticity, *E* [GPa]
Cast iron	92.39
Stainless steel	195.12
Galvanized steel	200.00
PEX	0.85
Fiberglass	72.30

Source: Stewart, Wallenberger & Bingham

3. NUMERICAL STUDY METHOD

In the numerical study, the Reynolds number will be determined to classify the flow. Subsequently, the friction factor and head loss will be calculated for the various pipelines by varying the temperature and fluid velocity as well as the inner diameter of the tube. Calculations will be made for the pipe with an inner diameter of 16.0 mm and speeds of 1.0 m/s and 1.5 m/s. Then, the same calculations will be made, but for the pipe with an inner diameter of 20.0 mm and velocities of 1.0 m/s and 1.5 m/s. The adopted gravitational acceleration value is 9.80665 m/s^2. The temperature will range from 5.0 °C to 50.0 °C and it is assumed that the temperature along the tube is constant and equal to the fluid temperature. The pipe length is 20.0 linear meters and is parallel to the horizontal plane as shown in the following figure:

Figure 6 – Experimental tube



Source: Prepared by the author

Further, the values of linear thermal expansion and Stress in axial direction will be determined for the various studied materials.

Finally, the results obtained will be evaluated and discussed.

4. RESULTS AND DISCUSSION

5.1. Head loss

→ $D_{int.}$ = 16.0 mm ; v = 1.0 m/s

Table 5 – Cast iron pipe with 16.0 mm inner diameter and 1.0 m/s fluid velocity

Temperature, ºC	Reynolds number	Friction factor	Head loss, m
5.00	10526.32	0.0622311	3.96613
10.00	12213.74	0.0618592	3.94243
15.00	14035.09	0.0615564	3.92313
20.00	15841.58	0.0613236	3.90830
25.00	17777.78	0.0611261	3.89570
30.00	19753.09	0.0609638	3.88536
40.00	24242.42	0.0606924	3.86807
50.00	29090.91	0.0604926	3.85533

Source: Prepared by the author

Table 6 – Stainless steel pipe with 16.0 mm inner diameter and 1.0 m/s fluid velocity

Temperature, ºC	Reynolds number	Friction factor	Head loss, m
5.00	10526.32	0.0316926	2.01984
10.00	12213.74	0.0305985	1.95011
15.00	14035.09	0.0296467	1.88945
20.00	15841.58	0.0288704	1.83997
25.00	17777.78	0.0281745	1.79563
30.00	19753.09	0.0275742	1.75737
40.00	24242.42	0.0264989	1.68884
50.00	29090.91	0.0256375	1.63393

Source: Prepared by the author

Table 7 – Galvanized steel pipe with 16.0 mm inner diameter and 1.0 m/s fluid velocity

Temperature. ºC	Reynolds number	Friction factor	Head loss. m
5.00	10526.32	0.0421527	2.68649
10.00	12213.74	0.0415225	2.64632
15.00	14035.09	0.0410006	2.61306
20.00	15841.58	0.0405940	2.58715
25.00	17777.78	0.0402445	2.56487
30.00	19753.09	0.0399547	2.54641
40.00	24242.42	0.0394636	2.51511
50.00	29090.91	0.0390967	2.49172

Source: Prepared by the author

Table 8 – PEX pipe with 16.0 mm inner diameter and 1.0 m/s fluid velocity

Temperature. ºC	Reynolds number	Friction factor	Head loss. m
5.00	10526.32	0.0309993	1.97565
10.00	12213.74	0.0298487	1.90233
15.00	14035.09	0.0288402	1.83805
20.00	15841.58	0.0280114	1.78523
25.00	17777.78	0.0272629	1.73753
30.00	19753.09	0.0266120	1.69604
40.00	24242.42	0.0254322	1.62085
50.00	29090.91	0.0244709	1.55959

Source: Prepared by the author

Table 9 – Fiberglass pipe with 16.0 mm inner diameter and 1.0 m/s fluid velocity

Temperature. ºC	Reynolds number	Friction factor	Head loss. m
5.00	10526.32	0.0308320	1.96499
10.00	12213.74	0.0296670	1.89074
15.00	14035.09	0.0286438	1.82553
20.00	15841.58	0.0278012	1.77183
25.00	17777.78	0.0270386	1.72323
30.00	19753.09	0.0263741	1.68088
40.00	24242.42	0.0251655	1.60386
50.00	29090.91	0.0241760	1.54080

Source: Prepared by the author

→ $D_{int.}$ = 16.0 mm ; v = 1.5 m/s

Table 10 – Cast iron pipe with 16.0 mm inner diameter and 1.5 m/s fluid velocity

Temperature. ºC	Reynolds number	Friction factor	Head loss. m
5.00	15789.47	0.0613297	8.79453
10.00	18320.61	0.0610780	8.75844
15.00	21052.63	0.0608735	8.72912
20.00	23762.38	0.0607166	8.70662
25.00	26666.67	0.0605835	8.68753
30.00	29629.63	0.0604744	8.67188
40.00	36363.64	0.0602919	8.64572
50.00	43636.36	0.0601578	8.62648

Source: Prepared by the author

Table 11 – Stainless steel pipe with 16.0 mm inner diameter and 1.5 m/s fluid velocity

Temperature. ºC	Reynolds number	Friction factor	Head loss. m
5.00	15789.47	0.0288909	4.14288
10.00	18320.61	0.0279998	4.01510
15.00	21052.63	0.0272269	3.90428
20.00	23762.38	0.0265988	3.81420
25.00	26666.67	0.0260377	3.73375
30.00	29629.63	0.0255555	3.66460
40.00	36363.64	0.0246969	3.54148
50.00	43636.36	0.0240149	3.44368

Source: Prepared by the author

Table 12 – Galvanized steel pipe with 16.0 mm inner diameter and 1.5 m/s fluid velocity

Temperature. ºC	Reynolds number	Friction factor	Head loss. m
5.00	15789.47	0.0406045	5.82259
10.00	18320.61	0.0401590	5.75871
15.00	21052.63	0.0397922	5.70610
20.00	23762.38	0.0395077	5.66531
25.00	26666.67	0.0392642	5.63039
30.00	29629.63	0.0390630	5.60155
40.00	36363.64	0.0387237	5.55288
50.00	43636.36	0.0384715	5.51672

Source: Prepared by the author

Table 13 – PEX pipe with 16.0 mm inner diameter and 1.5 m/s fluid velocity

Temperature. ºC	Reynolds number	Friction factor	Head loss. m
5.00	15789.47	0.0280334	4.01993
10.00	18320.61	0.0270739	3.88234
15.00	21052.63	0.0262332	3.76177
20.00	23762.38	0.0255427	3.66276
25.00	26666.67	0.0249196	3.57342
30.00	29629.63	0.0243786	3.49583
40.00	36363.64	0.0234004	3.35556
50.00	43636.36	0.0226066	3.24173

Source: Prepared by the author

Table 14 – Fiberglass pipe with 16.0 mm inner diameter and 1.5 m/s fluid velocity

Temperature. ºC	Reynolds number	Friction factor	Head loss. m
5.00	15789.47	0.0278236	3.98983
10.00	18320.61	0.0268458	3.84963
15.00	21052.63	0.0259866	3.72642
20.00	23762.38	0.0252789	3.62493
25.00	26666.67	0.0246385	3.53310
30.00	29629.63	0.0240807	3.45311
40.00	36363.64	0.0230674	3.30781
50.00	43636.36	0.0222396	3.18911

Source: Prepared by the author

→ $D_{int.}$ = 20.0 mm ; v = 1.0 m/s

Table 15 – Cast iron pipe with 20.0 mm inner diameter and 1.0 m/s fluid velocity

Temperature. ºC	Reynolds number	Friction factor	Head loss. m
5.00	13157.89	0.0566863	2.89020
10.00	15267.18	0.0563557	2.87334
15.00	17543.86	0.0560864	2.85961
20.00	19801.98	0.0558794	2.84906
25.00	22222.22	0.0557036	2.84009
30.00	24691.36	0.0555592	2.83273
40.00	30303.03	0.0553175	2.82041
50.00	36363.64	0.0551395	2.81133

Source: Prepared by the author

Table 16 – Stainless steel pipe with 20.0 mm inner diameter and 1.0 m/s fluid velocity

Temperature. ºC	Reynolds number	Friction factor	Head loss. m
5.00	13157.89	0.0297860	1.51866
10.00	15267.18	0.0287849	1.46762
15.00	17543.86	0.0279125	1.42314
20.00	19801.98	0.0271998	1.38681
25.00	22222.22	0.0265601	1.35419
30.00	24691.36	0.0260075	1.32601
40.00	30303.03	0.0250160	1.27546
50.00	36363.64	0.0242200	1.23488

Source: Prepared by the author

Table 17 – Galvanized steel pipe with 20.0 mm inner diameter and 1.0 m/s fluid velocity

Temperature. ºC	Reynolds number	Friction factor	Head loss. m
5.00	13157.89	0.0390904	1.99306
10.00	15267.18	0.0385180	1.96387
15.00	17543.86	0.0380435	1.93968
20.00	19801.98	0.0376733	1.92081
25.00	22222.22	0.0373550	1.90457
30.00	24691.36	0.0370908	1.89110
40.00	30303.03	0.0366427	1.86826
50.00	36363.64	0.0363076	1.85117

Source: Prepared by the author

Table 18 – PEX pipe with 20.0 mm inner diameter and 1.0 m/s fluid velocity

Temperature. ºC	Reynolds number	Friction factor	Head loss. m
5.00	13157.89	0.0291676	1.48713
10.00	15267.18	0.0281149	1.43346
15.00	17543.86	0.0271907	1.38634
20.00	19801.98	0.0264299	1.34755
25.00	22222.22	0.0257419	1.31247
30.00	24691.36	0.0251429	1.28193
40.00	30303.03	0.0240553	1.22648
50.00	36363.64	0.0231673	1.18120

Source: Prepared by the author

Table 19 – Fiberglass pipe with 20.0 mm inner diameter and 1.0 m/s fluid velocity

Temperature. ºC	Reynolds number	Friction factor	Head loss. m
5.00	13157.89	0.0290184	1.47953
10.00	15267.18	0.0279525	1.42518
15.00	17543.86	0.0270148	1.37737
20.00	19801.98	0.0262415	1.33794
25.00	22222.22	0.0255406	1.30221
30.00	24691.36	0.0249291	1.27103
40.00	30303.03	0.0238152	1.21423
50.00	36363.64	0.0229012	1.16764

Source: Prepared by the author

→ $D_{int.}$ = 20.0 mm ; v = 1.5 m/s

Table 20 – Cast iron pipe with 20.0 mm inner diameter and 1.5 m/s fluid velocity

Temperature. ºC	Reynolds number	Friction factor	Head loss. m
5.00	19736.84	0.0558848	6.41099
10.00	22900.76	0.0556608	6.38530
15.00	26315.79	0.0554788	6.36442
20.00	29702.97	0.0553390	6.34839
25.00	33333.33	0.0552205	6.33479
30.00	37037.04	0.0551232	6.32363
40.00	45454.55	0.0549607	6.30499
50.00	54545.45	0.0548411	6.29127

Source: Prepared by the author

Table 21 – Stainless steel pipe with 20.0 mm inner diameter and 1.5 m/s fluid velocity

Temperature. ºC	Reynolds number	Friction factor	Head loss. m
5.00	19736.84	0.0272187	3.12247
10.00	22900.76	0.0263993	3.02848
15.00	26315.79	0.0256876	2.94683
20.00	29702.97	0.0251082	2.88037
25.00	33333.33	0.0245901	2.82093
30.00	37037.04	0.0241442	2.76978
40.00	45454.55	0.0233491	2.67856
50.00	54545.45	0.0227162	2.60596

Source: Prepared by the author

Table 22 – Galvanized steel pipe with 20.0 mm inner diameter and 1.5 m/s fluid velocity

Temperature. ºC	Reynolds number	Friction factor	Head loss. m
5.00	19736.84	0.0376829	4.32291
10.00	22900.76	0.0372770	4.27635
15.00	26315.79	0.0369425	4.23798
20.00	29702.97	0.0366829	4.20820
25.00	33333.33	0.0364606	4.18269
30.00	37037.04	0.0362768	4.16161
40.00	45454.55	0.0359666	4.12602
50.00	54545.45	0.0357359	4.09956

Source: Prepared by the author

Table 23 – PEX pipe with 20.0 mm inner diameter and 1.5 m/s fluid velocity

Temperature. ºC	Reynolds number	Friction factor	Head loss. m
5.00	19736.84	0.0264501	3.03431
10.00	22900.76	0.0255681	2.93312
15.00	26315.79	0.0247939	2.84431
20.00	29702.97	0.0241572	2.77127
25.00	33333.33	0.0235820	2.70528
30.00	37037.04	0.0230819	2.64791
40.00	45454.55	0.0221763	2.54402
50.00	54545.45	0.0214400	2.45955

Source: Prepared by the author

Table 24 – Fiberglass pipe with 20.0 mm inner diameter and 1.5 m/s fluid velocity

Temperature. ºC	Reynolds number	Friction factor	Head loss. *m*
5.00	19736.84	0.0262620	3.01273
10.00	22900.76	0.0253633	2.90963
15.00	26315.79	0.0245722	2.81888
20.00	29702.97	0.0239198	2.74403
25.00	33333.33	0.0233286	2.67621
30.00	37037.04	0.0228131	2.61707
40.00	45454.55	0.0218752	2.50948
50.00	54545.45	0.0211076	2.42142

Source: Prepared by the author

5.2. Linear thermal expansion

In this subchapter we will analyze the change in object length:

Table 25 – Change in object length

Material	**Change in object length, *ΔL* [m]**
	5ºC to 50ºC Temperature variation
Cast iron	0.01089
Stainless steel	0.01557
Galvanized steel	0.00585
PEX	0.12600
Fiberglass	0.00513

Source: Prepared by the author

5.3. Stress in axial direction

The following table shows the stress in axial direction as a function of temperature variation:

Table 26 – Stress in axial direction

Material	**Stress in axial direction, *σ* [kPa]**
	5ºC to 50ºC Temperature variation
Cast iron	50306.355
Stainless steel	151900.92
Galvanized steel	58500.00
PEX	5355.00
Fiberglass	18544.95

Source: Prepared by the author

5.4. Results analysis

Once we have determined all the results, we will analyze and discuss all the values found. Then a summary table was made to more easily see under what circumstances minor head losses arose:

Table 27 – Minor head loss

Material	**Minor head loss, h_L [m]**			
	D = 16.0 mm v = 1.0 m/s	D = 16.0 mm v = 1.5 m/s	D = 20.0 mm v = 1.0 m/s	D = 20.0 mm v = 1.5 m/s
Cast iron	3.85533	8.62648	2.81133	6.29127
Stainless steel	1.63393	3.44368	1.23488	2.60596
Galvanized steel	2.49172	5.51672	1.85117	4.09956
PEX	1.55959	3.24173	1.18120	2.45955
Fiberglass	1.54080	3.18911	1.16764	2.42142

Source: Prepared by the author

Analyzing the table shows that the lowest head loss values emerged for the higher fluid temperature values. That is, for the temperature of 50 ºC, the head losses are smaller because the viscosity of the water is also lower. In this table you can see that cast iron is the material with the highest head loss and fiberglass the lowest values.

Next, a summary table was elaborated to verify which materials had the highest head loss:

Table 28 – Major head loss

Material	**Major head loss, h_L [m]**			
	D = 16.0 mm v = 1.0 m/s	D = 16.0 mm v = 1.5 m/s	D = 20.0 mm v = 1.0 m/s	D = 20.0 mm v = 1.5 m/s
Cast iron	3.96613	8.79453	2.89020	6.41099
Stainless steel	2.01984	4.14288	1.51866	3.12247
Galvanized steel	2.68649	5.82259	1.99306	4.32291
PEX	1.97565	4.01993	1.48713	3.03431
Fiberglass	1.96499	3.98983	1.47953	3.01273

Source: Prepared by the author

It is found that the major head loss is reached at the lowest temperature of the fluid, that is, at the temperature of 5 ºC, where the viscosity has higher values. We can see that the results of this table follow the same trend as the previous table, that is, cast iron is the material with the highest head loss and fiberglass has the lowest values for all pipe diameters and velocity of the fluid.

Then, from the results obtained above, a table was made to evaluate the head loss variations for the liquid temperature differential from 5 °C to 50 °C:

Table 29 – Variation of head loss

Material	**Variation of head loss, Δh_L [m]**			
	D = 16.0 mm v = 1.0 m/s	D = 16.0 mm v = 1.5 m/s	D = 20.0 mm v = 1.0 m/s	D = 20.0 mm v = 1.5 m/s
Cast iron	0.11080	0.16805	0.07887	0.11972
Stainless steel	0.38591	0.69920	0.28378	0.51651
Galvanized steel	0.19477	0.30587	0.14189	0.22335
PEX	0.41606	0.77820	0.30593	0.57476
Fiberglass	0.42419	0.80072	0.31189	0.59131

Source: Prepared by the author

In this case, cast iron is the material with the lowest head loss variations and fiberglass has the highest values. Therefore, cast iron is the material that shows more regular behavior.

Regarding linear thermal expansion, change in object length is greater in pex, a thermoplastic material, while fiberglass is the material with the smallest length variation, for temperatures ranging from 5 °C to 50 °C.

With regard to stress in axial direction, cast iron is the one with the highest values. In pex and fiberglass, the tension applied to them is lower.

5. CONCLUSIONS

At the end of this article, and after determining all the values related to the characteristics of the materials used, it is possible to draw some conclusions regarding the behavior of the piping when crossed by a fluid, in this case, water.

The Reynolds number is found to be independent of the piping material as it depends only on kinematic viscosity, inner tube diameter and fluid velocity. The value of this parameter is high for low kinematic viscosities. As the velocity and/or inner diameter of the pipe increases, the value of this parameter is lower. In this study, the flow observed in all cases was turbulent.

The friction factor follows the inverse trend of the Reynolds number, i.e. it decreases whenever the temperature increases. This is because this parameter depends on the Reynolds number and the roughness of the material.

Head loss has in all cases the same behavior as the friction factor as it depends on each other. Therefore, if the friction is low, the head loss is also low. On the other hand, it was also found that increasing the velocity while maintaining the tube diameter caused the increase in head loss. It was also found that increasing the diameter at the same speed caused a decrease in head loss.

Regarding the linear thermal expansion, it can be concluded that the thermoplastic material (PEX) presents unreasonably high values when compared to the values of the other materials. The temperature variation imposed on this type of material can cause serious problems because, almost always, the tube is restricted to movements in the axial direction, which will cause tensile and compressive forces in that same direction. To solve this problem, it is strongly recommended that 90° bends or loops be imposed along the pipe layout.

Stress in axial direction is higher in metal pipes. The emergence of these stresses is also related to the restriction conditions imposed on piping movement, when subjected to thermal load variations. Failure to generate voltages that are too high may result in piping performance problems as well as damage to the tubing and support structure. However, plastic materials are more flexible than metallic materials due to their low elastic modulus, which may provide less stress transmission to structural and fastening elements.

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