Jordanian Journal of Engineering and Chemical Industries

Print ISSN: 2616 - 9584 Online ISSN: 2617 - 720X

Analysis of the Effect of Piping Geometrical Shape on Major Head Losses in Pipes

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Abstract

This simulation study has been designed to study and scale the head losses (h_f) through internal flow passages with different five cross-section areas: these are circular, elliptical, rectangular, square and triangular cross-sectional passages. Those equivalent hydraulic diameters (D_h) were modelled for each shape to be used in head loss calculations and analysis using the Darcy-Weisbach equation. These equations formed the main structure of the mathematical model of this study to enable the building of the subsequent computerized model using MATLAB® software. Five major parameters were considered for head losses investigation and scaling for each pipe shape, these are the pipe length (L), the hydraulic diameters (D_h), friction coefficient (f), volumetric flow rate or discharge (Q) and mass flow rate (dm/dt). The results showed that head losses of non-circular pipes have relatively higher head losses than that of circular pipes, also the scaling head losses were strongly affected by the pipe geometry and shape, the flow characteristics and fluid properties. Furthermore, the head losses have been severely inversely affected by low pipe hydraulic diameter (D_h<0.10 m) and then be likely to be the same at higher pipe diameter ($D_h \geq 0.25$ m) for all pipe shapes. Also, the most recommended pipe shapes for lower head losses next to the circular pipe are elliptical and square, while the less recommended are triangular and rectangular shapes respectively.

Paper type: Research paper
Keywords: pipes, head losses, geometrical shapes, flow characteristics, fluid characteristics.
Citation: Alshorman A., L., Al-Samrraie, and K. Alrawashdeh "Analysis of Effect of Piping Geometrical Shape on Major Head Losses in Pipe", Jordanian Journal of Engineering and Chemical Industries, Vol. 5, No.3, pp: 82-90 (2022).

Introduction

Pipes and piping systems have had a very wide range of applications in different industrial, domestic, and engineering fields over many decades. This is interrelated to many parameters of technical applications and the piping system like pipe geometry, shape, roughness, material and head losses across the pipes. Geometry and dimensions of pipe-like shape, diameter, hydraulic diameter, thickness and length are very significant effective parameters that affect the rate of head losses across the pipe and then the design and selection of the pump in addition to its capacity and characteristics. Normally pipes have a circular cross-section as this is preferred by users over years for internal flow due to ease of use, durability, standard fabrications, well-established formulation and modelling characteristics for flow and operation and relatively reasonable head losses. Normally, the flow through pipes is motivated by the hydrodynamic driving force of fluid and opposed by the friction resistance force which is naturally generated due to fluid viscosity and roughness of the internal surface of the pipe (Abraham and Maki, 2018; Abdelrazek *et al*., 2020; Aguirre and Camacho, 2014; Kim *et al*., 2018; Alawee *et al*., 2020). Most previous studies were concentrated on modelling, simulation and calculation of head losses through pipes and piping systems networks based on the circular cross-section shape using pipe diameter as the fundamental characteristics length. Mainly, most of these studies were conducted using mathematical modelling and CFD simulation, and a limited part of them have been performed experimentally using piping or piping networks but not in any non-circular cross-section (Ntengwe *et. al.*, 2015; Sanchez *et al.*, 2008, Arbat *et al.*, 2011; Annan and Gooda, 2018; Chakraborty et al., 2016; Celik et al., 2015; Clark, 2010; Crowe, 2001; Miranda and López, 2011).

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Received on August 15, 2022. Accepted on October 24, 2022.
Jordanian Journal of Engineering and Chemical Industries (JJECI), Vol.5, No.3, 2022, pp. 82-90. Revised: November 21, 2022.

However, it is not common to use non-circular shapes for pipes in any industrial and engineering applications, but there were some investigations for the head losses in pipes with different shapes and geometry of fitting and obstacles (da Silva and de Moura, 2014; Demir *et al*., 2009; Mahood *et. al.*, 2009, Mansourpour and Shayamehr, 2009), and for piping systems of different types of bifurcations or branching (Divyesh, 2019; Gao *et al*., 2018; Ghani, 2017). Also, other important parameters were considered in the analysis of head losses in pipes like working fluid's hydrodynamic and thermal properties (Falconi, 2018), flow types if it is laminar or turbulent based on Reynolds number (Fox, 2004), pipe flexibility (Jamil and Mujeebu, 2019) and pipe materials, orientation and thermal load of the pipe (Jamil, 2019; Senzi *et al*.,2016). These studies concentrated on the effect of piping system design, pipe geometry, piping layout, piping fittings, flow type and working fluids, but none of them considered the effect of pipe shape on the operational head losses, which highlights the uniqueness of this study in its main theme. Mainly, there is a lack of head losses investigations for non-circular cross-section pipes and pathways, also there is a very limited study for comparative analysis of head losses analysis for non-circular pipes or ducts to scale the order of magnitude of head losses for non-circular pipes in comparison to that of a circular one. So the current investigation study has come to bridge this gap and to elucidate the details of head losses in the non-circular pipe, then to scale the order of magnitude of all of them against that of circular pipe. In this simulation study, a comparison analysis between five different pipe shapes has been performed to study the effect of pipe shape on head losses through pipes. These cross-sectional pipe shapes are elliptical, rectangular, square and triangular shapes in addition to circular ones. The main motivations of this study were to study and scale the head losses of non-circular pipes, to analyze the joint effects of pipe and flow characteristics on head losses and finally to suggest the best noncircular pipes for relative truncated head losses for different working fluids.

1 Materials and Methods

1.1 Mathematical modelling and logic of simulation

In this simulation study, a geometrical and head losses analysis was prepared for the circular and four non-circular shapes (elliptical, rectangular, square and triangular shapes) to establish a standard formulation of the mathematical model for this analysis based on shapes geometry and Darcy-Weisbach equation as explained in the following sections

1.2 Head losses Through Pipes

The Darcy-Weisbach equation was used to calculate the head loss h_f through the pipe for fully developed flow, as explained below (Crowe, 2001; Fox and McDonald, 2004):

$$h_f = \frac{f\,l}{D_h}\frac{V^2}{2g} \tag{1}$$

Where f is the friction coefficient (dimensionless), l is the pipe length in (m), V is the flow velocity in (m/s), D_h is the hydraulic diameter of the pipe in (m) for non-circular pipe shapes, such that

$$D_h = \frac{4A}{P} \tag{2}$$

Where A is the cross-section of the pipe in (m^2), and P is the perimeter of the pipe in (m)

1.3 Dimensional and equivalent cross-sectional area analysis

For dimensional analysis and to scale the head losses for non-circular shapes to that of circular shapes, it is needed to model an equivalent area A^* for all four shapes regardless of the shape such that the area A in the calculation will be equal to the equivalent area A^* or $A = A^*$ such that $A^*_{cir} = \frac{\pi}{4}D^2$ where D is the pipe diameter in (m). Moreover, the following effective parameters were modelled for the five pipe shapes investigated, these are the cross-sectional area A in (m), the perimeter P in (m), the hydraulic diameter D_h in (m), the flow velocity V in (m/s) and the head losses h_f in (m), in addition to volumetric flow rate Q in (m^3) and mass flow rate *dm/dt* in (kg/s). Based on this demonstration, there are listed explained formulas for each shape as follows:

1.3.1 Modelling of circular cross-section pipe

$$A = \frac{\pi}{4}D^2 \tag{3}$$

$$P = \pi D \tag{4}$$

$$D_h = \frac{4\left(\frac{\pi}{4}D^2\right)}{\pi D} = D \tag{5}$$

$$V = \frac{Q}{A} = \frac{Q}{\frac{\pi}{4}D^2} \tag{6}$$

Where Q is the volumetric flow rate of fluid in (m^3/s). Here $D_h = D$, then head loss will be according to equation (7) is defined:

$$h_f = \frac{8f\,l}{g\pi^2}\,\frac{Q^2}{{D_h}^5} \tag{7}$$

1.3.2 Modelling of square cross-section pipe

$$A = a^2 \tag{8}$$

$$P = 4a \tag{9}$$

$$D_h = \frac{4a^2}{4a} \tag{10}$$

$$V = \frac{Q}{A} = \frac{Q}{a^2} \tag{11}$$

Here $D_h = a$, then head loss will be

$$h_f = \frac{f\,l}{2g}\,\frac{Q^2}{{D_h}^5} \tag{12}$$

But $A^* = A_{sq}$ so $D_h = \frac{\sqrt{\pi}}{2}\,D$ then the equation of head loss will be:

$$h_f = \frac{f\,l}{2g}\,\frac{Q^2}{(\frac{\sqrt{\pi}}{2}D)^5} \tag{12-a}$$

1.3.3 Modelling of rectangular cross-section

$$A = a\,b \tag{13}$$

$$P = 2(a+b) \tag{14}$$

Where a and b are the length and width of the rectangular.

$$D_h = \frac{4ab}{2(a+b)} \tag{15}$$

$$V = \frac{Q}{A} = \frac{Q}{ab} \tag{16}$$

$$h_f = \frac{f\,l\,(a+b)}{4g}\,\frac{Q^2}{(ab)^3} \tag{17}$$

Here $A^* = A_{rec}$, whereas, $a = \frac{\pi}{4\,b}\,D^2$, the value of b could be assumed first then head loss can be calculated using variable D using equation (17-a)

$$h_f = \frac{f\,l\,(\frac{\pi}{4\,b}D^2+b)}{4g}\,\frac{Q^2}{(\frac{\pi}{4})^3\,D^6} \tag{17-a}$$

1.3.4 Modelling of elliptical cross-section pipe

$$A = \pi\,R_1\,R_2 \tag{18}$$

$$P = 2\pi\sqrt{\frac{{R_1}^2+{R_2}^2}{2}} \tag{19}$$

$$D_h = \frac{4\;R_1\,R_2}{2\pi\sqrt{\frac{{R_1}^2+{R_2}^2}{2}}} \tag{20}$$

$$V = \frac{Q}{A} = \frac{Q}{\pi\,R_1\,R_2} \tag{21}$$

$$h_f = \frac{f\,l\sqrt{\frac{{R_1}^2+{R_2}^2}{2}}}{4\,\pi^2 g}\,\frac{Q^2}{(R_1\,R_2)^3} \tag{22}$$

Where $A^* = A_{elli}$, then $R_2 = \frac{D^2}{4\,R_1}$, so to calculate head loss the value of R_1 must be assumed and hence the equation of head loss will be as shown in equation (22-a)

$$h_f = \frac{4f\,l\sqrt{\frac{16R_1{}^4 + D^2}{2}}}{\sqrt{2}\pi^2 g}\,\frac{Q^2}{R_1\,D^6} \tag{22-a}$$

1.3.5 Modelling of triangular cross-section pipe

The area of the triangular cross-section with equal side lengths is

$$A = \frac{1}{2}bh \tag{23}$$

$$P = b + 2\sqrt{h^2 + \frac{b^2}{2}} \tag{24}$$

$$D_h = \frac{2\,b\,h}{b+2\sqrt{h^2+\frac{b^2}{2}}} \tag{25}$$

$$V = \frac{Q}{A} = \frac{2Q}{ah} \tag{26}$$

$$h_f = \frac{f\,l\,[\,b+2\sqrt{h^2+\frac{b^2}{2}}\,\,]}{g}\,\frac{Q^2}{(\,bh)^3} \tag{27}$$

Where $A^* = A_{tri}$ whereas $b = \frac{\pi D^2}{2\,h}$, then the value of b is substituted in equation 27, so the head loss equation for triangular pipe will be as follows

$$h_f = \frac{4f\,l\,[\,\frac{\pi D^2}{2\,h}+2\sqrt{h^2+\frac{(\frac{\pi D^2}{2\,h})^2}{2}}\,\,]}{g\,\,\pi^3}\,\frac{Q^2}{D^6} \tag{27-a}$$

1.4 Computerized simulation model

In order to perform a full simulation analysis, the above mathematical model is subsequently used to establish a computerized simulation model using MATLAB® software to perform consequent investigations of scaling head losses for all pipe shapes at different operating conditions and variable parameters for different working fluids. In particular, the effects of pipe material roughness, the effects of hydraulic diameter and length of the pipe in addition to the effects of pipe shape were studied deeply to reveal their quantifiable roles in head losses through the pipe for different flow conditions. Table 1 shows the numerical range of input parameters for head losses analysis such that the values of head losses are determined for each pipe shape, and then it is compared to that of other values of different pipe shapes to determine the order of magnitude of head losses and then to make values scaling and technical assessment of the hydraulic situation.

2 Results and Discussion

2.1 Effects of pipe dimension and geometry on head losses

Figures 1 and **2** show the effects of changes in pipe hydraulic diameter D_h and pipe length L on head losses for the five pipe shapes, respectively. The hydraulic diameter has an inversely parabolic critical effect on head losses, especially at low values of hydraulic diameter (*i.e.*, D_h<0.10m) as shown in Fig. 1. Also, the results show that the best pipe shape for minimum head losses is the circular shape, then the square and rectangular while the higher head losses are related to the triangular and elliptical shapes respectively. The head losses for circular, square and rectangular shapes are the same at moderate and high hydraulic diameter i.e., D_h≥0.15 m, while all shapes have closer-overlapped head losses at high hydraulic diameter (i.e., D_h≥0.25m). This could be explained based on the Darcy-

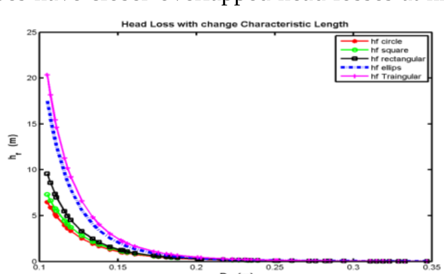

Fig. 1 The effect of hydraulic diameter (D_h) on head losses (h_f) for different pipe shapes–effect of pipe shape and geometry.

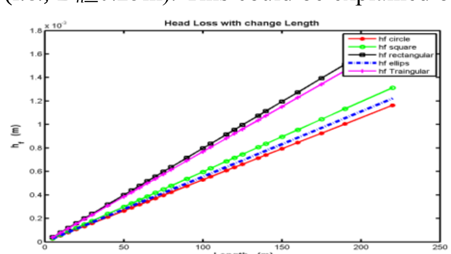

Fig. 2 The effect of pipe length (L) on head losses (h_f) for different pipe shapes.

Weisbach equation, which indicates that hydraulic diameter has a crucial effect on head losses at its low values, then it is gradually reduced to its minimum contribution at high values regardless of the shape of the pipe.

Table 1 Numerical values of input parameters for simulation analysis (operating range).

Parameter	SI Units	Numerical Range or value
D_h:	m	0.0-0.5
f	Dimensionless	0.01-0.05
L	m	0.0-500
Q	m^3/s	0.0-0.05
ρ	kg/m^3	1000
ρ (oil)	kg/m^3	880
(g)	m/s^2	9.81

On the other hand, the pipe length has a linear-direct increasing effect on head losses as explained in Fig. 2. Under normal conditions, the head loss increases with pipe length as a result of the effects of pipe material roughness and geometry of the pipe. As shown in Fig. 2, the minimum head loss ($h_{f\text{-}min}$) under variation of pipe length (L) occurs in the circular pipe and then the in elliptical pipe preceded by square pipe to form the geometrical group of lower head losses, while the geometrical group of higher head losses are the triangular and rectangular pipe, respectively. However, it could be noted that at low pipe lengths, the head loss tends to be relatively close to each other within both higher (triangular and rectangular pipes) and lower (circular, elliptical and square) head losses in geometrical groups. The increase in pipe length means a higher surface area of the pipe and hence more opposing effect of wall shear stress due to friction between the working fluid and the surrounding pipe and this causes higher head losses through the pipe. Principally, this factor is considered one of the principal factors of major head losses of pipe flow according to the Darcy-Weisbach equations as explained above. Specifically, the results revealed that the best-recommended pipe shapes for lower head losses after circular shape are the elliptical and square shapes respectively under the effect of pipe length variation for different working fluids.

2.2 Effects of pipe material roughness on head losses

One of the principal factors that motivate pipe head losses is the friction coefficient f due to the roughness of the inside surface of the pipe, which depends on the pipe materials and the inside surface of the pipe. This was considered and inspected in the course of this study and the results are represented in **Figure 3**. The pipe head loss h_f is directly increasing in the direction of the friction coefficient f in linear relation for all types of pipe shapes, and it has the same order effect as that of pipe length L but in a higher order of magnitude. Similarly, the minimum head loss is associated with circular shapes then elliptical and square shapes respectively, while the higher head loss is related to the rectangular and triangular shapes respectively, as shown in Fig. 3. Also, it can be noted that the pipe shape group of minimum head losses under the effect of friction coefficient variation is the same as that of pipe length (i.e., circular, elliptical and square shapes, respectively). This could be explained based on equations (7, 12, 17, 22 and 29) where the power of each parameter makes a dominant role in controlling its contribution to head losses through the pipe for different pipe shapes. Here the hydraulic diameter has a power value of more than one for all pipe shapes, while the power of exactly one for both pipe length and friction coefficient and this elucidates the scale of the influential rate for each parameter as illustrated in Figs. 1, 2 and 3.

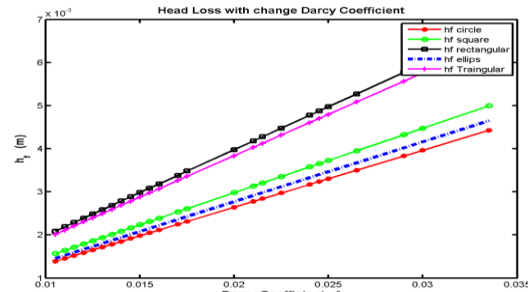

Fig. 3 The effect of Darcy friction coefficient (f) on head losses (h_f) for different pipe shapes- effect of pipe material roughness.

2.3 Effects of flow characteristics on head losses

The other parameter group that is strongly affecting the head losses includes the hydrodynamic parameters like volumetric flow rate or discharge Q, mass flow rate dm/dt, flow velocity V and fluid density ρ. The first two parameters Q and dm/dt are considered in the current investigation as they covered the other later parameters V, and ρ water and oils as working fluids, as shown in F**igures 4** to **6**. Fig. 4 shows the effect of volumetric discharge Q on pipe head losses h_f for different pipe shapes. It could be noted that Q has a parabolic effect on h_f under the variable scale of pipe shapes, but the minimum head losses have been gained using the circular pipe and then the elliptical and square in the sequence arrangement. While, the higher head losses are related to rectangular and triangular pipes, respectively. However, the head losses are nearly very low and asymptotic at low discharge (i.e., $Q \leq 0.01 m^3/s$) for all pipe shapes as shown in Fig. 4. This could be explained based on the amount of hydraulic momentum of working fluid which depends on volumetric flow rate, flow velocity (Demir *et al*., 2009; Clark *et al*., 2010; Arbat *et al*., 2014; Celik *et al*., 2015) and the amount of interaction between the moving fluid and the inside surface of the pipe that enhances the friction rate and henceforward the rate head losses (Annan and Gooda, 2018; Divyesh *et al*., 2019; Jamil and Mujeebu, 2019).

The effect of mass flow rate *dm/dt* has the same behaviour as that of volumetric flowrate Q on head losses as explained in Fig. 5 for oil and Fig. 6 for water. This is expected since the mass flow rate is directly related to the volumetric flowrate by the fluid density ρ as $dm/dt=\rho Q$. Once again the circular, elliptical and square shapes enable the minimum head losses more than that of rectangular and triangular shapes for both working fluids. The order of magnitude of head losses for both volumetric and mass flow rates is higher than that of other parameters like pipe length, pipe diameter and friction coefficient and this coincides with the head losses equations (7,12,17, 22 and 29) and to the physical characteristics of internal flow which is controlled by pipe geometry, flow velocity, fluid properties and roughness of pipe material (Sukhapure *et al*., 2017; Williams *et al*., 2020).

The investigations of discharge and mass flow rates pointed out that the recommended arrangement of pipe shapes for minimum head losses is circular, elliptical, square, triangular and rectangular shapes, respectively.

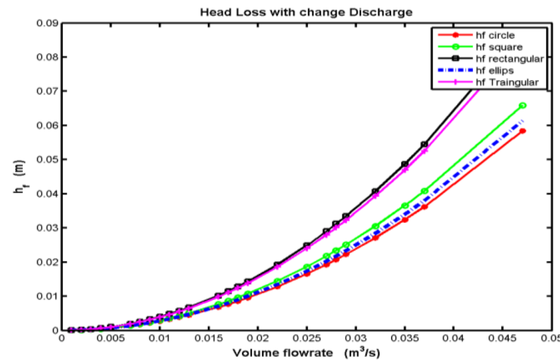

Fig. 4 The effect of the volumetric flow rate of fluid (discharge) (Q) on head losses (h_f) for different pipe shapes-effect flow characteristics.

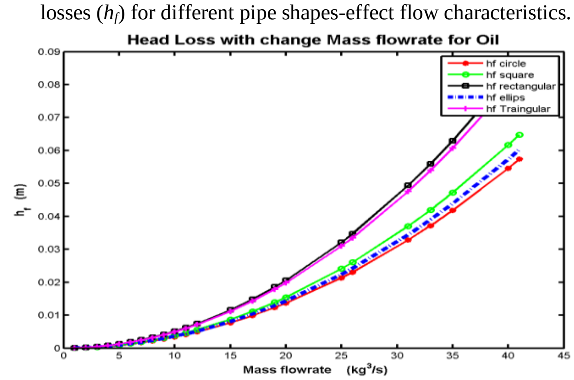

Fig. 5 The effect of mass flow rate of fluid (oil) on head losses (h_f) for different pipe shapes- effect flow characteristics

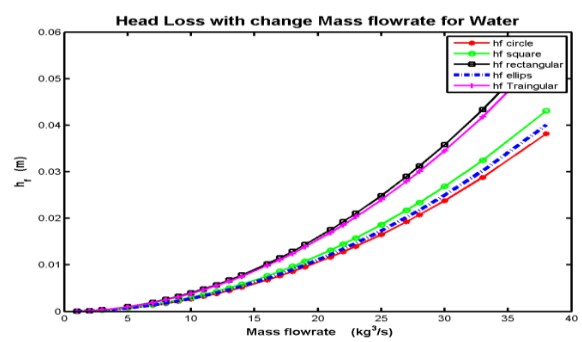

Fig. 6 The effect of mass flow rate of fluid (water) on head losses (h_f) for different pipe shapes- effect flow characteristics.

2.4 Numerical ranges of head loss scaling for different pipe shapes

To show the scaling ranges of head losses for different pipe shapes, a set of controlled investigations were performed using the input data of **Table 2**. The results are presented in the histograms in **Figures 7** to **10**.

Fig. 7 shows the scaling values of head losses under the effect of hydraulic diameter and the scaling arrangement is circular, square, rectangular, elliptical and triangular shapes. Likewise, the scaling arrangement under the effect of pipe length change is the same with distinct orders of magnitude of head losses, as explained in Fig. 8.

The scaling amount of head losses get higher under the effective friction coefficient change with different order of magnitude as explained in Fig. 9. However, the analysis of this parameter effect revealed a different scaling arrangement of head losses, these are circular, square, elliptical, triangular and rectangular shapes.

This scaling arrangement is achieved under the effect of volumetric flow rate at the same sequence, as shown in Fig. 10.

Table 2 Numerical values of effective parameters for scaling simulation analysis (controlled range).

Parameter	SI Units	Controlled Numerical Range
D_h	m	0.10-0.4
f	Dimensionless	0.01-0.03
L	m	5.0-300
Q	m^3/s	0.001-0.045
ρ	kg/m^3	1000
ρ oil	kg/m^3	880
g	m/s^2	9.81

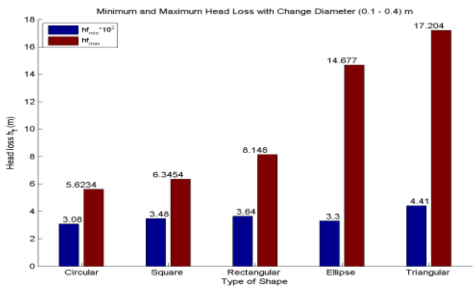

Fig. 7 Ranges of head losses for different pipe shapes under the effect of hydraulic diameters D_h.

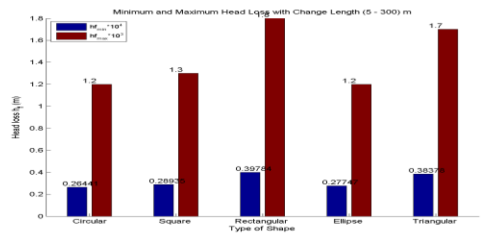

Fig. 8 Ranges of head losses for different pipe shapes under the effect of pipe length L.

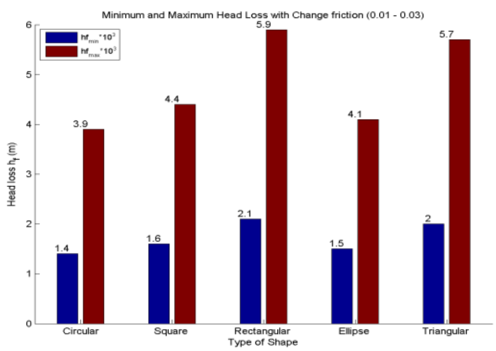

Fig. 9 Ranges of head losses for different pipe shapes under the effect of friction coefficient f.

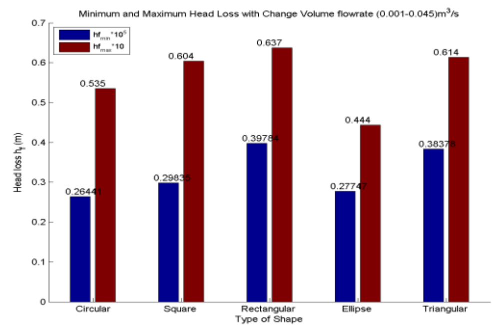

Fig. 10 Ranges of head losses for different pipe shapes under the effect of volumetric flowrate Q.

As a result of the full investigations of all pipe shapes for all parameter changes, the scaling arrangements are summarized in **Table 3** for one parameter change and **Table 4** for the interrelated change of three parameters.

The final results for all investigations indicated that the best pipe shape for minimum head losses is the circular shape under the effect of all influential parameters and all working fluids, while the non-recommended pipe shape for low head losses is the triangular shape for all conditions. Moreover, the square and elliptical shapes are the second recommended choice for minimum head losses. Nevertheless, the circular, elliptical and square shapes gave relatively closer head losses to form a group of low head losses, while the opposite behaviour has been noted for triangular and rectangular shapes where the higher head losses are related to them. Comparatively, all pipe shapes had closer relative scaling of head losses at low values of investigated parameters like pipe length L, friction coefficient f and discharge Q, while the opposite manner was observed at low hydraulic diameters D_h where maximum head losses normally occurred. These findings act following the equations of head losses of all pipe shapes, as explained in the above mathematical model of the current study.

Table 3 The best arrangement for minimum head loss ($h_{f\text{-}min}$) for different pipe shapes under the effect of one parameter change

No	D_h	f	L	Q	$(dm/dt)_{oil}$	$(dm/dt)_{water}$
1	Circular	Circular	Circular	Circular	Circular	Circular
2	Square	Ellipse	Ellipse	Ellipse	Ellipse	Ellipse
3	Rectangular	Square	Square	Square	Square	Square
4	Ellipse	Triangular	Triangular	Triangular	Triangular	Triangular
5	Triangular	Rectangular	Rectangular	Rectangular	Rectangular	Rectangular

Table 4 The best arrangement for minimum head loss ($h_{f\text{-}min}$) for different pipe shapes under the effect of three parameter changes.

No	Change of (L &f &Q)	Change of (L& f & D_h)	Change of (D_h &f &Q)	Change of (D_h & L &Q)
1	Circular	Circular	Circular	Circular
2	Ellipse	Square	Square	Square
3	Square	Rectangular	Rectangular	Rectangular
4	Rectangular	Ellipse	Ellipse	Ellipse
5	Triangular	Triangular	Triangular	Triangular

2.5 Model validation

The results of this simulation study are demonstrated through Figs. 1 to 6 above, where the results of head losses according to the Darcy-Weisbach equation are represented in a red colour circle while the results of the simulation model are shown in other symbols and colours as explained in Figs. 1 to 6. The simulation results for non-circular pipe shapes have the same coincide behaviour as that for circular shapes according to the Darcy-Weisbach equation but in different values due to the effect of the cross-section of the pipe shape. Moreover, **Figure** 11 shows a comparison of the simulation results of head losses for the non-circular pipe to that of the circular pipe according to the Darcy-Weisbach equation, this comparison indicates good manners agreement of model results to that of standard results, which designates the effectiveness of the current simulation model and emphasize its creditable validation.

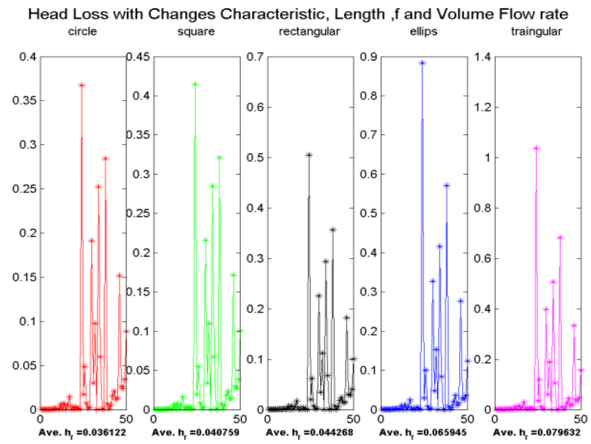

Fig. 11 Simulation results of the current model for circular pipe and non-circular pipes with similar behaviour but with different values of high coincidence.

Conclusions

Numerical simulation investigations were executed to study the effect of pipe shape on head losses under the effects of different operative parameters and working fluids. In specific, five pipe shapes were studied under the effects of five controlled parameters to determine and scale the amount of head loss of the considered pipe shapes based on minimum head loss limits. The results of this study have revealed several significant conclusions regarding the scaling amount of head losses due to the effects of pipe materials and geometry, flow characteristics, and working fluids. In particular, the most effective parameters in scaling head losses are the pipe hydraulic diameter, the fluid mass flow rate and the inside surface roughness of the pipe (friction coefficient). Furthermore, the best-recommended pipe shapes for minimum head losses are the circular, elliptical and square shapes respectively, while rectangular and triangular shapes are associated with higher head losses under the effect of different parameters and working fluids. The outcomes of the current investigations have shown that the pipe head loss was higher at low pipe hydraulic diameter, high volumetric flow rate, high friction coefficient and extended pipe length for all considered pipe shapes. Finally, the scaling head losses were impressed by the pipe geometry and shape, the flow characteristics and fluid properties, respectively. Also, the most recommended pipe shapes for lower head losses next to the circular pipe are elliptical and square, while the less recommended are triangular and rectangular shapes.

Nomenclature

A	=Cross section area of the pipe	[m^2]
A^*	=Equivalent area	[m^2]
a	=Shape length	[m]
b	=Shape width	[m]
D	=Pipe diameter	[m]
D_h	=Hydraulic Diameter	[m]
dm/dt	=mass flow rate	[kg/s]
f	=Friction coefficient	[-]
g	=Gravity constant [	m/s$^{2]}$
h	=height	[m]
h_f	=Head losses	[m]
l, L	=Pipe length	[m]
P	=Perimeter of the pipe	[m]
Q	=Volumetric flow rate	[m^3/s]
R	=Shape radius	[m]
R_1, R_2	=Ellipse radii	[m]
V	=Flow velocity	[m/s]
w	=Width	[m]
ρ	=Fluid density	[kg/m^3]

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