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Energy Loss Investigation in Submarine Pipelines: Case Study of Cyprus Water Supply Project

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ABSTRACT

Submarine pipelines have become one of the popular ways of transboundary water supply. The hydraulic design of these pipelines is of significant technical challenges for engineers as it requires a comprehensive energy loss analysis. The major portion of energy loss in a submarine pipeline is created by friction losses. Besides, many fittings and connections in the pipeline cause significant minor losses. In this study, energy loss in the submarine Cyprus water supply pipeline, the longest offshore water supply pipeline in the world, was investigated. To this end, a MATLAB script was developed to calculate both friction and minor losses. The well-known total energy loss formulae, namely, Darcy-Weisbach, Hazen-Williams, Manning, and Chezy were used and the results were compared. Our calculations showed that the highest deviation is observed for the Hazen-Williams equation comparing to the Darcy-Weisbach equation. The energy loss values obtained by Manning and Chezy equations gave similar results with the Darcy-Weisbach equation. Moreover, it was found that the friction and minor losses are approximately 95% and 5% of the total energy loss, respectively.

Keywords:

Energy Loss, Head Loss, Friction Coefficients, Offshore Pipeline, Darcy-Weisbach, Cyprus Water Supply Project.

1. Introduction

The first offshore pipeline was born in the Summerland, an idyllic-sounding spot just southeast of Santa Barbara. Since then the offshore pipeline has become the unique means of efficiently transporting offshore fluid, i.e., oil, gas, and water [1]. These pipelines can be made of commercial materials such as steel, iron and concrete or can be made of plastic materials such as poly vinyl chloride and high-density polyethylene (HDPE). Tas et. al [2] reported that the HDPE pipes have grown to become one of the most extensive usage plastic material on water supply systems. The design of an offshore HDPE pipeline requires a comprehensive energy loss analysis. Energy loss resulting from in a pipeline is commonly termed friction head loss. This is the loss of head caused by pipe wall friction and the viscous dissipation in flowing water. Friction loss is also referred to as “major loss” because of its magnitude, and all other loss losses are referred to as “minor losses” [3]. There are several methods to calculate friction head loss. One of the leading methods is well known theoretical Darcy-Weisbach equation [4,5]. It can be used only if Darcy friction factor is known. Colebrook -White (C-W) equation [6] is the best predictor of Darcy friction factor for turbulent regime as well as smooth pipe. Moreover, many engineers use empirical equations such as Hazen-Williams [7], Manning [8], and Chezy to calculate friction head loss. The friction coefficients must be determined to use these empirical equations. On the other hand, fittings, valves, and geometrical changes in pipeline can be caused minor losses. Minor loss can be calculated by multiplying the velocity head with minor loss coefficient. However, calculation of minor loss coefficients is a challenging engineering problem. Several methods to calculate minor loss coefficients presented in various books and manuals. For example, Pipe Friction Manuel [9] suggests equations and charts to calculate minor loss coefficient in pipeline. For long pipelines, the value of the minor losses is usually considered to be insignificant especially when compared to the value of the major losses. However, for long pipelines the number of installed fittings on a pipeline is usually high which means the value of minor losses can be high also [10].

Several studies have been presented for energy loss calculation methods and their corresponding coefficients by researchers in literature. For example, Kamand [11] revealed the variation of the friction factors of Darcy-Weisbach, Manning and Hazen-Williams equations. Bombardelli and Garcia [12] analyzed the limitations of Hazen-Williams equation for the friction head loss calculation of large diameter pipe systems. A case study was used to show the misuse of the Hazen-Williams equation. Yoo and Singh [13] proposed two methods to calculate friction factors for commercial pipes based on the modification of C-W equation. Wang et. al [14] presented the design basics of longitudinal section of a long water supply pipeline in China. Tas and Agiralioglu [15] compared the accuracy of the several theoretical and empirical friction head loss methods for long polyethylene (PE) pipeline system. Authors reported that the Darcy-Weisbach equation with using C-W equation to calculate friction factor is the most accurate methods. Tian et. al [16] reviewed the minor loss coefficient calculation methods for pipe fittings. A computational fluid dynamics model was used to calculate minor loss coefficients of an elbow and globe valves. Annan and Gooda [10] presented the effect of minor losses in water transmission pipelines with using three different case studies. The results showed that minor losses can significantly affect the hydraulic design of long pipelines.

In this paper, a general methodology was presented to calculate energy losses including friction losses and minor losses used in the hydraulic design of offshore pipeline system. The determination technique of friction coefficients was introduced. Presented methodology was applied to suspended sea crossing pipeline system of the CWSP, which is the first in the world. The total energy loss values were calculated by using different equations and a statistical comparison was performed. In addition, a MATLAB code was presented that has the ability of automatically calculate friction and minor losses (see Appendix A).

2. Cyprus Water Supply Project

2.1. Overview of the Project

The CWSP has also known as the Cyprus Peace Water Project, the Cyprus Life Water Project, and the Project of the Century from time to time in Northern Cyprus [17]. It transports 75 million m^3 fresh water from Turkey to Turkish Republic of North Cyprus (TRNC) per year. The overall project includes three sides, namely, Turkey side, sea crossing side and TRNC side. Turkish side comprises the Alaköprü Dam with storage capacity of 130.5 million m^3, onshore transmission line of 23-km length, Anamuryum Balancing tank, and sea entrance valve rooms. The sea crossing side includes an 80 km sea crossing pipeline. It is the first in the World with its HDPE pipeline that crossing the Mediterranean Sea in a suspended position under 280 m below the sea level. TRNC side comprises Güzelyalı pumping station at the shoreline, force main line of 3-km length and the Geçitköy Dam with storage capacity of 26.5 million m^3. The top view of the CWSP can be seen in Figure 1.

Figure 1. Top View of CWSP [17].

This study considers only sea crossing part of the CWSP. For more information about the project overall, please see the paper presented by Agiralioglu et. al. [17].

2.2. Overview of Sea Crossing Pipeline

The existing sea crossing pipeline can be divided in two as, shore section and offshore section. Shore section is where the water depth is up to 280-m. Offshore section is where the water depth higher than 280 meters. Offshore section of the CWSP is the longest suspended HDPE pipeline system in the World. The side view of the sea crossing pipeline route can be seen in Figure 2 with connection elements.

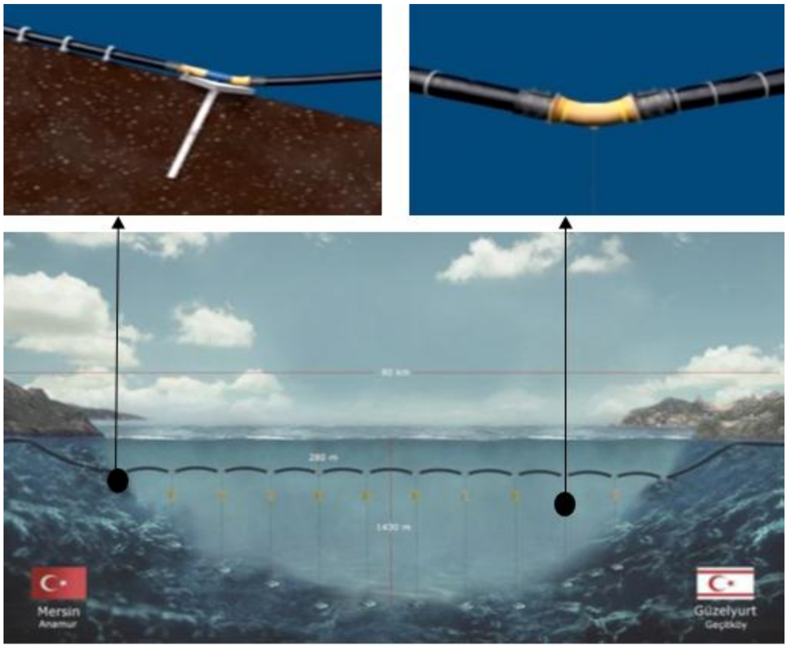

Figure 2. Side View of Sea Crossing Pipeline with Connection Elements.

On the both shores of Turkey and TRNC, the pipeline is buried under seabed until 20-m water depth is reached. The pipeline is laid on the seabed between 20-m and 280-m water depth. After reaching 280 meter of water depth, a 90-degree bend S-shaped spool piece connects the onshore section to suspended offshore section. From this point, offshore section begins. 500 meters long single-piece HDPE pipes are connected mechanically to each other by Y-piece connections. Total of 134 Y-piece connections, each of which 16000 kg, were located 280-meter below the sea level. These are connected to buoyancy modules and, in turn, anchor blocks that provide stable suspended pipeline system [17]. Sea crossing pipeline system ends at a receiving basin in TRNC side.

2.3. Hydraulics of the Project

CWSP pipeline system has a nominal capacity of 2.38 m3/s (75 million m^3/year) and it is operated by gravity flow without using any pump. The outer diameter and inner diameter of each HDPE pipes are 1600-mm and 1474-mm, respectively. Each pipe has a wall thickness of 63-mm. The pipeline has a true length of 80-km. Maximum design pressure of the sea crossing pipeline is 0.5 m. The main energy loss on the sea crossing pipeline of CWSP is governed by wall friction. The main cause of the wall friction is the pipe roughness. Pipe roughness is an important factor for magnitude of energy loss. The higher pipe roughness value causes higher energy loss on the pipeline system. However, HDPE pipes are smooth with comparing commercial pipes. Other elements such as Y-pieces and spool pieces generate minor energy losses on the pipeline system. The sea crossing pipeline of the CWSP includes 134 Y-piece connections (see Figure 2). The internal diameter of these Y-pieces is equal to outer diameter of HDPE pipes. Firstly, flow is subjected to a sudden expansion then flow direction changes due to miter bend with an angle of 23-degree and finally a sudden contraction occurs in Y-pieces. Spool pieces are 90-degree bends that used to connects shore section to offshore section (see Figure 2). Also, outlet at TRNC side is another minor energy loss element.

3. Theoretical Energy Loss Calculation Method

Energy loss is also referred to as “pressure head loss”. It can be classified into two as, friction head loss and minor head loss on a pipeline system. The total energy loss can be expressed as following:

$$\Sigma h_L = \Sigma\left(h_f + h_m\right) \tag{1}$$

Where, h_L is total energy loss in m, h_f is friction head loss in m and h_m is minor head loss in m.

3.1. Friction Head Loss

Several equations were reported by the researchers to calculate friction loss. Four well-known equations; namely, Darcy-Weisbach, Hazen-Williams, Manning, and Chezy were presented in this section. Design of pipeline systems generally involve calculation of the friction loss in a pipeline in terms of discharge. Therefore, all equations were presented in terms of discharge. In 1845, Henri Darcy [4] and Julius Weisbach [5] proposed a theoretical based Darcy-Weisbach equation. It is given as following form:

$$hf_{DW} = fL\frac{0.0826Q^2}{D_i^5} \tag{2}$$

Where f is Darcy friction factor, L is length in m, D_i is inner diameter in m, and Q is discharge in m^3/s. The calculation of Darcy friction factor is related with the flow regime in pipeline. Reynolds Number is used to classify flow regime. When Reynolds Number higher than 4000, the flow regime is called as “turbulence flow”. It is given as following form:

$$\mathrm{Re} = \frac{4Q}{\pi D_i \nu} \tag{3}$$

Where υ is kinematic viscosity of water in m^2/s. When Reynolds Number is between 4000 - 10^5, Blasius equation is the predictor of Darcy friction factor. It is given as following form:

$$f = \frac{0.3164}{\mathrm{Re}^{0.25}} \tag{4}$$

In 1939, C.F. Colebrook [5] proposed implicit C-W equation to calculate Darcy friction factor. The C-W equation is a very powerful tool to calculate Darcy friction factor and it covers the whole turbulent flow regime (Re= 4000-10^8). It is given as following form:

$$\frac{1}{\sqrt{f}} = -2\log(\frac{e}{3.7D_i} + \frac{2.51}{\mathrm{Re}\sqrt{f}}) \quad (5)$$

Where *e* is pipe roughness in mm. Pipe roughness is an important friction coefficient to calculate Darcy friction factor. It can take different values for different pipe materials. In 1933, Williams and Hazens [7] presented an empirical Hazen-Williams equation. It is given as following form:

$$hf_{HW} = \frac{kL}{C_{HW}^{1.852} D_i^{4.871}} Q^{1.852} \quad (6)$$

Where C_{HW} is Hazen-Williams friction coefficient, *k* is unit conversion factors. The factor *k* is 10.69 when *Q* is in m^3/s and D_i is in m. The Hazen-Williams coefficient C_{HW}, is not a function of flow conditions (i.e., Reynolds number). Another popular empirical equation is Manning equation. The Manning equation [8] has been used extensively for open-channel designs. However, it is also quite commonly used for pipe flows as well as for PE pipes. It is given as following form:

$$hf_{Mn} = \frac{10.29n^2L}{D_i^{16/3}} Q^2 \quad (7)$$

Where *n* is Manning friction coefficient. Its value depends on the pipe or channel material. The earliest known standardized friction head loss equation was developed by Chezy in approximately 1775 [15]. It is given as following form:

$$hf_{Ch} = \frac{6.48L}{C^2 D_i^5} Q^2 \quad (8)$$

Where *C* is Chezy friction coefficient. The relation between the Manning friction coefficient and Chezy friction coefficient can be expressed as following:

$$C = \frac{1}{n} R_h^{1/6} \quad (9)$$

Where R_h is the hydraulic radius which is the ratio between the wetted area and wetted perimeter of the pipe.

3.2. Minor Loss Calculation

Most of the pipeline systems includes some elements such as fittings, connectors, and bends. These elements are frequently used throughout the pipeline to overcome geographic obstacles and diverse the pipe flow. However, these elements cause minor loss on the pipeline system. Minor loss can be calculated by multiplying a coefficient with velocity head. It is given as following form:

$$h_m = K_m \frac{V^2}{2g} \quad (10)$$

Where K_m is the minor loss coefficient. Equation 10 can be expressed as following in terms of discharge:

$$h_m = K_m \frac{0.0826Q^2}{D_i^4} \quad (11)$$

Five well known causes of minor loss in a pipeline; namely, sudden expansion, sudden contraction, miter bend, 90-degree bend, and outlet loss were considered in this study. To calculate minor loss on a pipeline, the minor loss coefficients must be first determined. Hydraulic Institute [9] published the Pipe Friction Manual in 1961. This manual suggests various equations and charts to determine minor loss coefficients based on the experimental results. In this study the given equations and chart for determination of minor loss coefficients were taken from this manual. Sudden expansion and sudden contraction coefficients for pipe flow can be determined as following equations:

$$K_e = \left(1 - \frac{D_i^2}{D_o^2}\right)^2 \tag{12}$$

$$K_C = 0.5\left(1 - \frac{D_i^2}{\left(D_o + 2t\right)^2}\right)^{0.75} \tag{13}$$

Where K_e and K_c are the minor loss coefficients for sudden expansion and sudden contraction. D_o is the outer diameter of pipe in m. A chart was presented in Figure 3 to determine minor loss coefficients due to 90-degree bend and miter bend in a pipeline system. Y-axis of the chart represents the minor loss coefficient and the x-axis represents the angle of the bend (α).

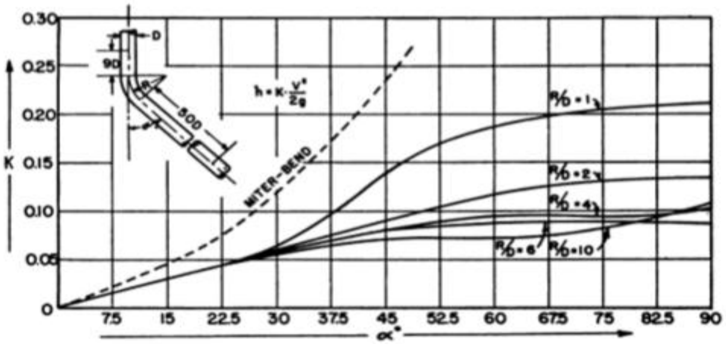

Figure 3. Minor Loss Coefficient for Bends of Uniform Diameter and Smooth Surface [9].

Whereas the minor head loss produced by a 90-degree bend depends on the ratio between the radius of curvature of the bend (R) and the outer diameter of the pipe (D_o), the minor head loss produced by a miter bend is just depend on the angle of the bend (α).

4. Determination of Friction Coefficients

The hydraulic design of an offshore HDPE pipeline requires comprehensive energy loss calculations. The most challenging part of the energy loss calculations is the determination of friction coefficients. Pipe roughness and other friction coefficients such as C_{HW}, n, C can be determined by experimental investigations. For this, energy losses must be first determined. A typical experimental setup for measuring friction loss on a pipeline includes some equipment such as water tank, electric pump, pressure gauges, flow meter and control valves. This equipment is installed on a horizontal metal bench. The water that stored in the water tank is delivered into the pipeline by the pump. A flow meter is used to measure flow rate. Control valves regulates the flow.

Water in a pipeline flows with the effect of gravity and pressure force. However, gravity force has no effect on a horizontal pipeline. In such a case, water flow occurs along the pipeline due to pressure differences. Pressure differences are measured along the pipeline by pressure gauges. When pressure differences are measured for the pipeline segment between the two pressure gauges, the friction loss can be expressed as follows:

$$h_f = \frac{\Delta p}{L} \tag{14}$$

Where Δp is pressure differences along a length of pipeline. When the friction loss on the system is known, the friction coefficients can be determined. Several experimental studies were performed to determine friction loss and friction coefficients of plastic pipes including PE pipes by researchers [18-21]. The friction coefficients values that reported by Houghtalen [3] were used in this study. For PE pipes, Houghtalen [3] suggested the values of 0.0015, 150, and 0.010 for e, C_{HW}, and n. Also, the Chezy coefficient, C can be determined by using the equation 9.

5. Results and Discussion

In this study, a MATLAB code was developed to calculate the total energy loss for 80 km long sea crossing HDPE pipeline of CWSP. After entering the necessary friction and minor loss coefficients, MATLAB code automatically calculates the both friction loss and minor loss on the system (see Appendix A). During the calculation, friction loss and minor loss were assumed to be linearly distributed. Also, HDPE pipes were assumed as perfectly horizontal and arches were not considered.

5.1. Friction Head Loss

Friction coefficient values were determined as 150, 0.01, and 84.67 for Hazen-Williams, Manning, and Chezy, respectively. The pipe roughness value of 0.0015 mm was selected for HDPE pipes. Using the equation 3, Reynolds Number was found as 1.5×10^6. It shows that the flow regime is fully developed turbulence where the value of Darcy friction factor, f can be calculated by C-W equation. However, implicit nature of the C-W equation, makes it difficult to solve. Therefore, an iterative algorithm was used in MATLAB code with the error tolerance of 0.01. The effective Darcy friction factor was found as 0.0109 by using equation 5. Then, total friction loss values were calculated by Darcy-Weisbach, Hazen-Williams, Manning and Chezy equations, using equations 2,6,7, and 8, respectively. Table 1 presented the calculated friction head loss values along the 80 km sea crossing pipeline system.

Table 1. Calculated Friction Loss along the 80-km Pipeline.

Length (m)	Friction Head Loss (m)			
	Darcy-Weisbach	Hazen-Williams	Manning	Chezy
0	0	0	0.00	0.00
10000	7.31	7.51	7.36	7.36
20000	14.62	15.02	14.72	14.72
30000	21.93	22.52	22.08	22.07
40000	29.24	30.03	29.44	29.43
50000	36.55	37.54	36.80	36.79
60000	43.86	45.05	44.16	43.15
70000	51.17	52.56	51.52	51.51
80000	58.48	60.06	58.89	58.86

According to Table 1, the total friction loss on the pipeline was found as 58.48, 60.06, 58.89, and 58.41-m for Darcy-Weisbach, Hazen-Williams, Manning, and Chezy equations, respectively.

5.2. Minor Loss Calculation

Elements such as Y-pieces and spool pieces generate minor head losses on the sea crossing pipeline system. In addition, minor head loss is generated by due to outlet at TRNC side. In order to calculate total minor loss on the pipeline system, firstly minor loss coefficients were determined for each element and presented in Table 2.

Table 2. Calculated Minor Loss Coefficients for the Elements of Pipeline.

Elements	Type of Minor Loss Coefficient	Value
Y-piece	Sudden Expansion	0.023
	Miter Bend	0.060
	Sudden Contraction	0.161
Spool piece	90-degree bend	0.140
Outlet TRNC	Outlet	1.000

In Table 2, sudden expansion loss coefficient and sudden contraction loss coefficient were calculated by using equation 12, and 13, respectively. Miter bend loss coefficient was calculated by using angle of 23-degree and chart presented in Figure 3. 90-degree bend minor loss coefficient was calculated by using a R/D ratio of 2 and chart presented in Figure 3. Finally, minor losses for each element were calculated considering the sea crossing pipeline includes 134 Y-pieces and 2 spool pieces by using equation 11. The results were presented in Table 3.

Table 3. Calculated Minor Loss.

Elements	Total Minor Head Loss (m)
Y-pieces	3.26
Spool pieces	0.03
Outlet at TRNC	0.10

Based on the results in the Table 3, the total minor loss on the pipeline system was found as 3.39-m.

5.3. Total Energy Head Loss

Summation of total friction head loss along the 80 km pipeline and total minor head loss including all elements gives the total energy head loss on the pipeline system. The total energy losses on the pipeline system were presented in Table 4 by using four different friction head loss equations.

Table 4. Calculated Total Energy Loss Using Four Different Formula.

Used Equation	Total Energy Loss (m)
Darcy-Weisbach	61.87
Hazen-Williams	63.45
Manning	62.28
Chezy	62.25

5.4. Comparison and Discussion

Total energy loss results found by Hazen-Williams, Manning and Chezy equations were compared with the results of Darcy-Weisbach equation. Statistical comparison was performed by using the two criteria. These criteria are absolute error and relative error and given as following:

$$AE = \lfloor h_{L-DW} - h_{L-CALC} \rfloor \tag{14}$$

$$RE = \frac{\left(h_{L-DW} - h_{L-CALC}\right)}{h_{L-DW}} x100 \tag{15}$$

Where, h_{L-DW} is the total energy loss calculated with the Darcy-Weisbach equation, h_{L-CALC} is the total energy loss calculated by the individual equations. In table 5, the calculated results of statistical criteria were presented. The highest error was observed for Hazen-Williams equation comparing with Darcy-Weisbach equation. As expected, the similar absolute and relative error values were found for Manning and Chezy equations comparing with Darcy-Weisbach equation. The similar results were obtained due to fact that the Manning equation is the modified version of Chezy equation. It should be noted that various friction coefficient values for PE pipes were reported in literature. All these values were determined based on the experimental investigations. However, Tas et. al [2], indicated that these experimental investigations were done by only small diameter pipes. Therefore, the reported values by researchers may not be always true for large diameter pipeline projects such as CWSP. The different values of these coefficients may alter the total friction loss values and, accordingly, total energy loss values.

Table 5. Statistical Comparison for Equations.

Equation Comparing with Darcy-Weisbach	AE	RE (%)
Hazen-Williams	1.58	2.55
Manning	0.41	0.66
Chezy	0.38	0.61

On the other hand, the minor losses were accounted for about approximately 5% of the total energy loss. This indicates that the minor losses have a significant magnitude which can not be ignored in the sea crossing pipeline of CWSP. The main reason for minor loss of this significant magnitude is the large number of Y-piece connections in the pipeline system.

6. Results and Discussion

Offshore water supply pipelines crossing long distances under a sea require a huge investment. Therefore, the hydraulic design of offshore pipelines has paramount importance. Energy loss calculation is the major part of the hydraulic design of the pipelines. In this study, a general methodology to calculate energy loss was presented for a real engineering pipeline project. The friction loss on the pipeline was calculated as 58.48, 60.06, 58.89, and 58.41-m for Darcy-Weisbach, Hazen-Williams, Manning, and Chezy equations, respectively. The elements that cause the minor loss on the pipeline were determined. Then, the total minor loss on the pipeline was calculated as 3.39-m. Thus, total energy losses were calculated. The friction loss and minor losses were accounted for about 95% and 5% of the total energy loss on the pipeline system, respectively. In addition, a statistical comparison of the total energy losses found by Hazen-Williams, Manning, and Chezy with respect to Darcy-Weisbach was performed. The highest difference was observed for the Hazen-Williams equation. The energy loss values found by Manning and Chezy equations gave similar results with the Darcy-Weisbach equation. Energy loss calculations should be done with utmost precision. For example, a small error that can be made during the calculation of the Darcy friction factor can lead to several meter differences in total energy loss. This can be directly affecting the project's cost. The MATLAB code presented in this paper (Appendix A) can be applied to overcome the potential miscalculations. It can be used to calculate friction and minor losses on any water supply pipeline with small modifications. For future studies, investigation of the change in pipe diameter due to the radial strain of the pipeline and its effect on the total energy loss would be informative.

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APPENDIX A: MATLAB Script

```
%Hydraulic Parameters
Q=2.38;        % discharge in m3/s
Do=1.6;        % outer diameter in m
Di=1.474;      % inner diameter in m
Dimm=1474;     % inner diameter in mm
v=1.33*10^-6;  % kinematic viscosity in m2/s
L=80000;       % total length of pipeline in m
Rh=Di/4;       % hydraulic diameter
t=0.035;       % thickness of Y-piece
```

```
%Friction Coefficients for HDPE Pipes

e=0.0015;     % Roughness height in mm
CHW=150;      % Hazen-Williams coefficient
n=0.01;       % Manning coefficient

% Calculation of Chezy Coefficient

C=(1/n)*Rh^(1/6);

% Calculation of Reynolds Number

Re=(4*Q)/(pi*Di*v);

%Iterative method to Calculate Darcy Friction Factor

f=linspace(0.001,0.20,10000);% the interval for assuming darcy friction factor
for i=1:10000
    A=1/sqrt(f(i));
    B=-2*log10((2.51/(Re*sqrt(f(i))))+((e/Dimm)/3.70));
    if abs(A-B)<=0.01; % error tolerance of iteration
    friction(i)=f(i)
    end
end
Darcyf=max(friction) %highest value of Darcy friction factor

% Calculation of total friction head loss for individual equations

hfDW=(Darcyf*L*0.0826*Q^2)/(Di^5);            % Darcy-Weisbach

hfHW=(10.69*L*Q^1.852)/(CHW^1.852*Di^4.871); % Hazen-Williams

hfMn= (10.29*n^2*L*Q^2)/(Di^(16/3));          % Manning

hfCh= (6.48*L*Q^2)/(C^2*Di^5);                % Chezy

%Calculation of friction head loss along 80000-m pipeline

Length=[0 10000 20000 30000 40000 50000 60000 70000 80000];
for i=1:9
    hfDW(i)=(Darcyf*Length(i)*0.0826*Q^2)/(Di^5); % Darcy-Weisbach

    hfHW(i)=(10.69*Length(i)*Q^1.852)/(CHW^1.852*Di^4.871); % Hazen-
                                                       Williams
    hfMn(i)= (10.29*n^2*Length(i)*Q^2)/(Di^(16/3));          % Manning

    hfCh(i)= (6.48*Length(i)*Q^2)/(C^2*Di^5);                % Chezy

end

% Minor Loss Coefficents for HDPE Pipeline
```

```
Ke=(1-(Di^2/Do^2))^2;              % sudden expansion coefficient

Kc=0.5*(1-Di^2/(Do+2*t)^2)^0.75;   % sudden contraction coefficient

Kmiter=0.060;                          % 23-degree miter bend coefficient(using
                              Figure 3)
Ksp=0.140;                             % 90-degree bend coefficient(using a R/D
                              ratio of 2 and Figure 3)
Kout=1;                                % outlet coefficient at TRNC side

% Calculation of Minor Loss for each Elements

hmypiece=135*(Ke+Kc+Kmiter)*(0.0826*Q^2/Di^4); % total minor loss for Y-
                                          pieces

hmspoolpiece= 2*(Ksp)*(0.0826*Q^2/Di^4);       % total minor loss forSpool
                                          pieces

hmout=(Kout)*(0.0826*Q^2/Di^4);                % total minor loss for
                                          outlet at TRNC side

hmtotal=hmypiece+hmspoolpiece+hmout            % total minor loss
```