COBEM-2017-1537
PRESSURE, FLOW RATE AND HEAD LOSS ANALYSIS ON MULTIPLE PARALLEL FLOW SYSTEMS BY COMPUTATIONAL APPROACH

João Lucas Lobato Soares
George Stephane Queiroz de Oliveira
Marcelo Lucas Souza Silva
Samuel de Castro Silva
Gianfranco de Mello Stieven
Federal University of Pará, Augusto Corrêa St., 1 - Guamá, Belém - PA, 66075-110
soaresjoao974@gmail.com
georgeoliveira.ufpa@gmail.com
marcelolucas_souza@yahoo.com
samuelcastro.ufpa@gmail.com
gianfrancostieven@yahoo.com.br

Abstract. The analysis of multiple parallel flow in engineering has the objective of enabling a satisfactory distribution of fluid in a given environment, where is possible to fight fire in residential and laboratory buildings using water supply systems, for example. Therefore, is indubitable the relevance of the evaluation of flow and pressure resulting in a circular section pipes branched of a main duct, also considering the study of head loss and turbulence by the Reynolds number. However, the calculations applied by the conjugate equations in fluid mechanics tend to become unfeasible when considering a significant number of branches. Furthermore, systems found in the literature only estimate flows with a low and constant number of pipes. Based on the exposed, this paper proposes to generate an iterative code that reproduces the behavior of the displacement of a fluid, considering located head loss in multiple channels and, thus, showing the variation of flow rate and pressure distributed in a general system of infinite pipes coupled into a main connection.

Keywords: Algorithm, MATLAB, parallel flow, multiple branches.

1. INTRODUCTION

Multiple Parallel flows are found in design of canal systems, design of pumps, compressors, pipes and circular section ducts used in the water and air conditioning systems of houses and buildings (Fox and McDonald, 2014). Following this premise, it is indispensable to determine the flow rate and pressure values of the multiple pipes, based on lack to evaluate the individual characteristics and properties of all the possible branches.

Considering the hydrodynamic parameters, the multiple parallel flows are based as internal flow. In addition, the Reynolds number indicates the flow behavior in terms of the ordering of the moving fluid slides, relative to the solid surface at their contact. The three possible stages are defined as laminar, transient and turbulent, being directly proportional to the increase of Reynolds Number with the respective transition of each stage (White, 2011). This dimensionless number previously explained, implicitly determines the fluid friction factor in contact with the solid, which is dependent on Reynolds Number's value.

Another important topic in the analysis of multiple parallel flows are head losses, which are influenced by the duct walls, dissipating energy by friction (White, 2011). This dissipation of energy causes a reduction of the total pressure of the system, characterizing a head loss on the fluid, (Fox and McDonald, 2014). However, for some fluids the localized head loss are particular and, consequently, the flow variables are different in each branch, providing difficult by unfeasible calculations for flow and pressure if stipulated a great variety of dendritic ducts. Therefore, the solution of the problems of fluid flow found in practice could be done using of algorithmic methods, which employs computational iterations in fluid mechanics' equations.

2. COMPUTATIONAL PROCEDURE

An iterative method was created to enable the calculation of the output values, which was related in a loop with friction factor and Reynolds number, represented by Equations (1) and (2), respectively. Consequently, the final outflows were estimated by Equation (3).

$$\mathrm{Re} = \frac{\rho v D}{\mu} \tag{1}$$

$$\frac{1}{\sqrt{f}} = -2\log\left(\frac{e}{3,7D} + \frac{2,51}{\mathrm{Re}\sqrt{f}}\right) \tag{2}$$

$$Q_P = A_P \sqrt{\frac{2P_A}{\rho}} \left[\frac{1}{\left(\frac{D_P}{D_n}\right)^4 + f\left(\frac{L}{D} + \frac{L_e}{D}\right)}\right]^{\frac{1}{2}} \tag{3}$$

The Colebrook-White equation, exposed on Eq. (2), has been considered the most accurate equation developed for the friction factor calculation. Even so, its manipulation depends of iterative methods, to consider being an implicit equation. This parameter is of extreme importance to enable the creation of a data structure in programming languages, as illustrated by Figure 1.
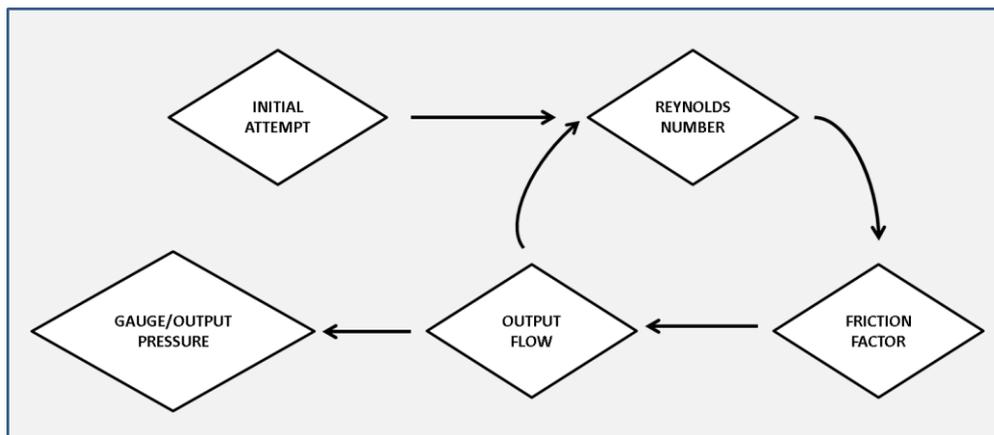

Figure 1. Iterative calculation loop.

Subsequently, the flows are duly adjusted in relation to their respective head losses due to the tubes described geometric configurations and the values are applied to the equations of gauge pressure and output pressure in each branch, represented by Equations (4) and (5), respectively.

$$P_A = \frac{\rho}{2}\left(\frac{Q_P}{A_P}\right)^2 \left[\left(\frac{D_P}{D_n}\right)^4 + f\left(\frac{L}{D} + \frac{L_e}{D}\right)\right] \tag{4}$$

$$P_i = P_A + \frac{\rho}{2}\left[\left(\frac{Q_A}{A_P}\right)^2 - \left(f\frac{L}{D} + f\frac{L_e}{D} + 1\right)\left(\frac{Q_P}{A_A}\right)^2\right] \tag{5}$$

Therefore, the iterative code developed by the algorithm generated in the software MATLAB R2013b® was expressed in Figure 2 below.

```
clear, clc

K1 = {'Which flow rate unit will be used?'};
K2 = {'m³/s'; 'in³/s'; 'L/min'; 'gpm'};
K3 = listdlg ('PromptString', K1,'ListSize', [300 70], 'ListString',K2, 'SelectionMode', 'single');  % Flow Rate Unit box
```

```
J1 = {'Which lenght unit will be used?'};
J2 = {'m'; 'in'; 'ft'; '"ft" for the length and "in" for the diameters'};
J3 = listdlg ('PromptString', J1,'ListSize', [300 70], 'ListString',J2, 'SelectionMode', 'single');  % Lenght Unit box

im1 = imread ('Insert the Roughness Table Location');
imshow (im1);  % Roughness Table

Tb=(str2double (inputdlg ({'Number of Extensions:','Input Flow:','Main Tube Diameter:','Tube Roughness:'},'Main
tube', [1 24;1 24;1 24;1 24])))';  % Main Tube's Input Values box

n = Tb(1);
a = zeros (4,n);

for n = 1:n
im2 = imread ('Insert the Roughness Table Location ');
imshow (im2);  % Minor Losses Table

a(:,n)=(str2double (inputdlg ({'Extension Length', 'Input Diameter', 'Output Diameter', 'Head Loss'}, (sprintf('Ramal
%d', n)), [1 24;1 24;1 24;1 24])))';   % Individual Ramal's Input Values box
end

% ITERATIVE PROCESS

if K3 == 1
   Tb(2) = Tb(2)*61023.74409;
elseif K3 == 2
   Tb(2) = Tb(2);
elseif K3 == 3
   Tb(2) = Tb(2)*1.01706;
elseif K3 == 4
   Tb(2) = Tb(2)*3.85;
end

if J3 == 1
   Tb(3) = Tb(3)*39.37008;
   a(1:3,:) = (39.37008).*a(1:3,:);
elseif J3 == 2
   Tb(3) = Tb(3);
   a(1:3,:) = a(1:3,:);
elseif J3 == 3
   Tb(3) = Tb(2)*12;
   a(1:3,:) = 12*a(1:3,:);
elseif J3 == 4
   Tb(3) = Tb(3);
   a(1,:) = 12*a(1,:);
   a(2:3,:) = a(2:3,:);
end

A = (pi*Tb(3)^2)/4;
p = 9.355709876543210e-05;
v = 0.00173;

b = zeros(5,n);
b(2,:) = Tb(2)/n;
b(4,:) = 0.1;

for Z = 1:100000

   for n = 1:n
```

```
    b(1,n) = ((pi*((a(2,n))^2))/4);
    b(3,n) = ((4*b(2,n))/(pi*v*a(2,n)));

     while (abs((inv(sqrt(b(4,n))))-(-2*log10((((Tb(4))/(a(2,n)))/3.7 + (2.51/((b(3,n))*sqrt(b(4,n))))))))) > 0.000001
            b(4,n) = (inv(-2*log10((((Tb(4))/(a(2,n)))/3.7) + (2.51/((b(3,n))*sqrt(b(4,n)))))))^2;
      end

    b(2,n) = sqrt(1/(((a(2,n)/a(3,n))^4)+(b(4,n)*((a(1,n)/a(2,n))+a(4,n)))));
  end

  c = b(2,:);
  S = sum(c);

  for  n = 1:n
     b(2,n) = (b(2,n)/S)*Tb(2);
  end
end

Pa = (p/2)*((b(2,1)/b(1,1))^2)*(((a(2,1)/a(3,1))^4)+b(4,1)*((a(1,1)/a(2,1))+a(4,1)));

for n = 1:n
b(5,n) = Pa + (p/2)*((Tb(2)/A)^2)*(1-((b(4,n)*((a(1,n)/a(2,n))+a(4,n)))+1)*((b(2,n)/Tb(2))^2)*((A/b(1,n))^2));
end

if K3 == 1
  b(2,:) = b(2,:)/61023.74409;
elseif K3 == 2
  b(2,:) = b(2,:);
elseif K3 == 3
  b(2,:) = b(2,:)/1.01706;
elseif K3 == 4
  b(2,:) = b(2,:)/3.85;
end


M1 = {'Which pressure unit will be used?'};
M2 = {'Psi'; 'MPa'};
M3 = listdlg ('PromptString', M1,'ListSize', [300 70], 'ListString',M2, 'SelectionMode', 'single');  %Pressure Unit box

%RESULTS

if M3==2
  for n = 1:n

     disp ('---------------------------------------------')
     fprintf ('Flow at the branch %.f \b:',n)
     disp (b(2,n))
     fprintf ('Exit pressure at branch %.f \b:',n)
     disp (b(5,n)*0.00689)
  end

Pa = Pa*0.00689;

Disp ('---------------------------------------------')
fprintf ('Manometric Pressure MPa: %.4f \b:', Pa)

else
 for n = 1:n

     disp ('---------------------------------------------')
```

```
        fprintf ('Flow at the branch %.f \b:',n)
        disp (b(2,n))
        fprintf ('Exit pressure at branch %.f \b:',n)
        disp (b(5,n))
end

disp ('--------------------------------------------')
fprintf ('Manometric Pressure Psi: %.4f \b:', Pa)
end

msgbox ('Calculation Finished. Observe the values inbox.')
```

Figure 2. Algorithm Code Lines.

3. RESULTS AND DISCUSSION

3.1 User Interface

The computational approach obtains the flows in each branch, as well as their respective output pressures and the input pressure, as was corroborated below in the isolated areas analysis to the profiles and the main tube, illustrated by Figure 3. In this way, the results are a wide range of possibilities with respect to the applications that obtain results and behaviors of single-phase parallel flows.
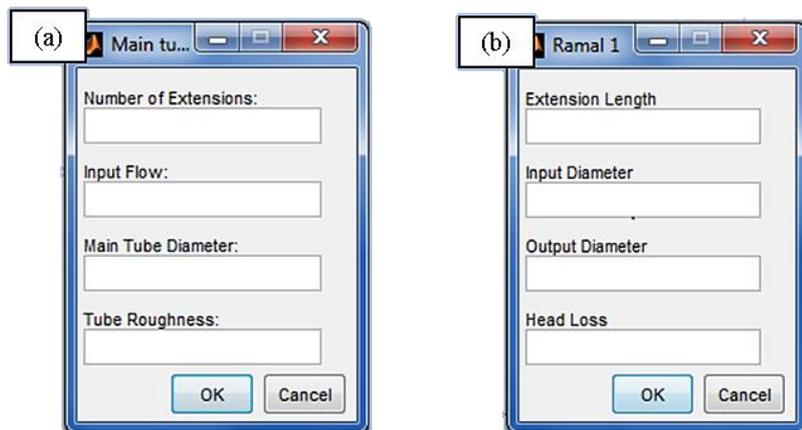

Figure 3. Input values (a) Main Tube (b) Individual Ramal.

In addition, a graphical interface was created to make it possible for the user to use the program to perform his work more easily, thus preventing user's access and modification on the base algorithm. In these windows, it is possible to make conversion of units to display flow rate, length and pressure values according to the International System and the English System, demonstrated by Figures 4.
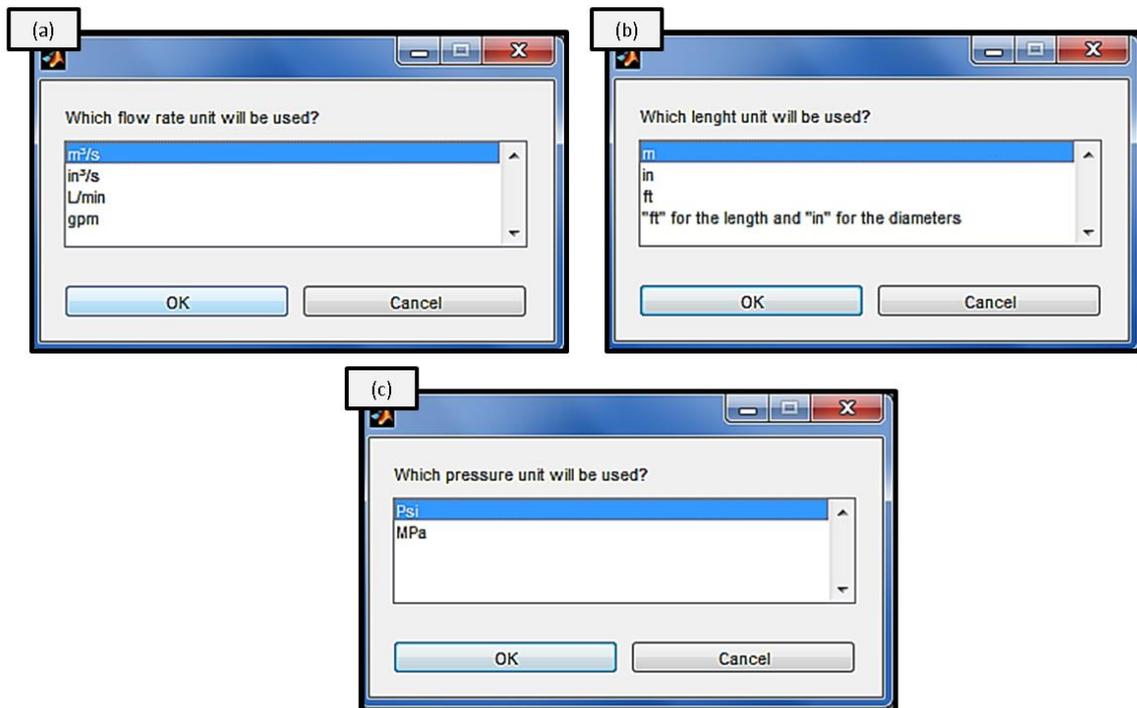
Figure 4. Units (a) Flow Rate (b) Length (c) Pressure.

Beyond, as illustrated by the Tab. 1 and 2, auxiliary information with number roughness of some common engineering materials and equivalent length of minor losses are shown to help the operator at data input moment.

Table 1. Roughness Number contents.

ROUGHNESS TABLE					
Material kind	**Roughness**		**Material kind**	**Roughness**	
-	**[mm]**	**[in]**	**-**	**[mm]**	**[in]**
New laminated steel	0,0015	0,00006	**Cast iron with incrustation**	1,5-3	0,05906-0,11811
Used laminated steel	0,046	0,001811	**Rust cast iron**	1-1,5	0,03937-0,05906
Galvanized steel	0,15	0,005906	**New cast iron**	0,26-1	0,01024-0,03937
Flat welded steel	0,1	0,003937	**Cast iron coated with asphalt**	0,12-0,26	0,00472-0,01024
Fine stone masonry	1-2,5	0,03937-0,09843	**Planed timber**	0,2-0,9	0,0079-0,03543
Rough stone masonry	8-15	0,31496-0,59055	**Rough timber**	1-2,5	0,03937-0,09843
Brick masonry	5	0,19685	**Polyethylene**	0,001	0,00004
Copper	0,0015	0,00006	**Rigid PVC**	0,005	0,00020
Smoothed concrete	0,3-0,8	0,0118-0,03150	**Glass**	0,0015	0,00006
Centrifugal concrete	0,07	0,00276	**-**	-	-

Table 2. Minor losses contents.

FITTING IDENTIFICATION			L/D FACTORS						
ColRo	Description	Name	Water	Glycol	Brine	Diesel	Petrol	Steam	Gas
A8	90 deg Elbow: Regular Screwed	EL90-RG-SC	45	53	61	45	36	30	35
A9	90 deg Elbow: Long Radius Screwed	EL90-LR-SC	25	29	34	25	20	15	20
A10	90 deg Elbow: Regular Flanged	EL90-RG-FI	45	53	61	45	36	30	35
A11	90 deg Elbow: Long Radius Flanged	EL90-LR-FL	25	29	34	25	20	15	20
A12	45 deg Elbow: Regular Screwed	EL45-RG-SC	25	29	34	25	20	20	25
A13	45 deg Elbow: Regular Flanged	EL45-RG-FL	15	18	20	15	12	15	20

A14	Return U-Bend: Regular Screwed	BEND-RG-SC	90	105	123	90	72	70	75
A15	Return U-Bend: Regular Flanged	BEND-RG-FL	90	105	123	90	72	70	75
A16	Return U-Bend: Long Radius	BEND-LR-SC	50	59	68	50	40	45	45
A17	Tee: Line Flow Screwed	TEE-LF-SC	20	24	27	20	16	20	25
A18	Tee: Branch Flow Screwed	TEE-BF-SC	65	76	89	65	52	65	70
A19	Tee: Line Flow Flanged	TEE-LF-LF	20	24	27	20	16	20	25
A20	Tee: Branch Flow Flanged	TEE-BF-FL	65	76	89	65	52	65	70
A21	Strainer: Basket	STRAINER	90	105	123	90	72	70	75
A22	Union / Coupling	UNION	45	53	61	45	36	30	35
A23	Inlet: Bell-Mouthed	INLET-BM	20	24	27	20	16	20	25
A24	Inlet: Square-Edged	INLET-SE	45	53	61	45	36	30	35
A25	Outlet: All Types	OUTLET	65	76	89	65	52	65	70

Finally, 10E5 iterations are used as a fixed parameter, in addition to the implicit function of friction factor, which reaches the value with an error smaller than 10E-6, so it is possible that through such methods the algorithm can reach optimal approximations results. It's relevant to emphasize that the algorithm is value to many fluids, as shown in table 2.

3.2 Iterative Computation

In addition, to approve the algorithm, it was tested its output of pressure and flow rate with a literature example of a multiple parallel system. So, the results were calculated on a branched flow in three extensions, exemplified in an adapted problem found in a relevant publication (Fox and McDonald's, 2014) illustrated by Figure 5.
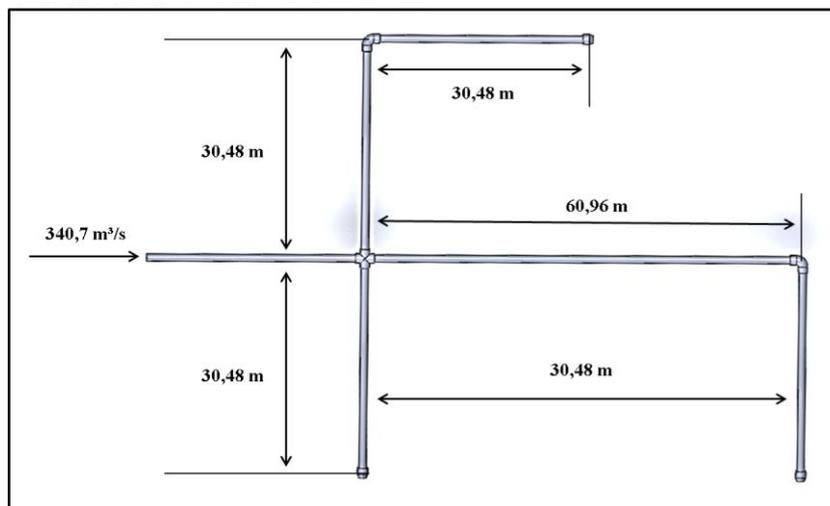

Figure 5. Illustrative Branch System Way

Considering "Water" as fluid flow and "New Laminated Steel" as tube material, should be estimated the Minor Losses by the individual components (1 Double Tee, 2 Elbows and 3 Nozzles) in the Figure 6. Also, the Main Tube and Ramal input values was organized in the Table 3.
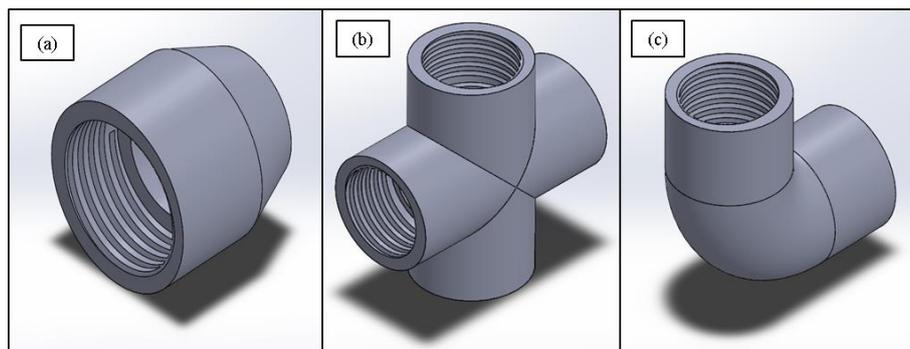
Figure 6. Minor Losses Components (a) Nozzle (b) Double Tee (c) Screwed Elbow.

Table 3. Computational approach input values.

PROFILE SYSTEM							
Number of Extensions		**Input Flow (m³/s)**		**Main Tube Diameter (m)**		**Tube Roughness**	
3		**0.09463529**		**0.0762**		**0,00006**	
TUBE 1		**TUBE 2**			**TUBE 3**		
Length Extensions (m)	60.96	**Length Extensions (m)**	30.48		**Length Extensions (m)**		91.44
Input Diameter (m)	0.0762	**Input Diameter (m)**	0.0762		**Input Diameter (m)**		0.0762
Output Diameter (m)	0.0381	**Output Diameter (m)**	0.0381		**Output Diameter (m)**		0.0381
Head Losses	90	**Head Losses**	45		**Head Losses**		90

The final pressure and flow rate on each branch and the main tube's gauge pressure was expressed in the Software Command Window in Figure 7. The numerical results obtained had an acceptable accuracy degree compared with the adapted example according SI (m³/s and MPa).

```
------------------------------------------------
Flow at the branch 1:    0.0311

Exit pressure at branch 1:    0.5635

------------------------------------------------
Flow at the branch 2:    0.0352

Exit pressure at branch 2:    0.6616

------------------------------------------------
Flow at the branch 3:    0.0283

Exit pressure at branch 3:    0.5046

------------------------------------------------
Manometric Pressure MPa: 0.6527:>>
```

Figure 7. Command Windows Results.

4. CONCLUSIONS

Based on the formulated program, the paper presents an easy way to enable the user to analyze and identify the variation of flow rate, pressure and head loss in infinite braches of a main duct, not mattering the flow or fluid, based on the analysis of the fluid mechanics equations. The user is free to choose the input values such as main tube flow, diameter and length of the extensions, as well as many pipefittings to consider located head loss in the duct.

The algorithm considers an error of 10E-6 for the implicit equation of friction factor and 10E5 iterations to analyze the flow rate and pressure, ensuring the minimum error in the study. Through a graphical interface generated by MATLAB R2013b® in an accessible and practical way, the program could be available to download to promote the interest of mechanical engineering students to use it in order to confirm their calculus and compare their experimental data from their researches, as permitting other professions use the algorithm on a relevant application for them.

5. REFERENCES

Çengel, Yunus A., Cibala, John M., *Fluid Mechanic: Fundaments and Aplications*. 1st edition. Porto Alegre, Brazil: AMGH, 2007.
Energy models. 'Pipe Sizing Charts Tables'. 12 Apr. 2017 <http://energy-models.com/pipe-sizing-charts-tables>.

Fox, Robert W., McDonald, Alan T., *Introduction to Fluid Mechanics*. 8th edition. LTC – Livros Técnicos e Científicos Editora S.A., 2014.

L.B, R. Raoni; Biscaia, A. R. Secchi E E. C., 2014. " Nova metodologia para o cálculo de redes de tubulação com anéis". *20th Brazilian Congress Brasileiro of Chemical Engineering - COBEQ2014*, Florianópolis, Brazil.

Martins, M. A. F. et al., 2015. "Avaliação da incerteza em estimativas de medição de vazão: um caso implícito, não linear e multivariável". *18th Brazilian Congress of Metrology*, Bento Gonçalves, Brazil.

Raoni, Rafael; Secchi, Argimiro R.; Jr, Evaristo C. Biscaia., 2016. "Novel method for looped pipeline network resolution". *Elsevier*, Rio de janeiro, Brazil.

White, Frank M. *Fluid Mechanics*. 6th edition. Porto Alegre, Brazil: AMGH, 2011.

6. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.