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FLUID FLOW ASPECTS WITHIN CIRCULAR DUCTS WITH SECTION CHANGE

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Abstract: *Aspects of the fluids flow within circular ducts have been presented along the time being established the main flow regimes represented by the laminar and the turbulent regime. It should be emphasized that the fluids movement in circular ducts is always accompanied by energy losses, due to both the pipe walls roughness and the change of the flow section, leaving aside the viscosity properties of the fluid. Summarized these energy losses are constituted as hydraulic resistances in the fluid flow path-lines. In this paper are presented the types of resistors that can influence the fluid flow through circular pipes when changing the flow section in the direction of widening or narrowing of the pipe flow section. Theoretical aspects of flow resistances as well as numerical analyzes on fluid flow on the virtual model are presented in order to highlight the flow parameters in the respective section.*

Keywords*: Fluid flow, circular duct, section change, three-dimensional model, numerical analysis*

1. Introduction

The liquids and mainly water flow has been studied over time, with experiments describing the main laminar and turbulent flow regimes. For the liquids flow inside the circular ducts, it can be argued that there are efforts acting in order to slow the fluid flow, called hydraulic resistors, which are actually fluid friction forces with the pipe walls, stresses due to the viscosity forces inside the fluid, forces due to terrestrial gravity, hydrostatic pressure forces, forces due to turbulent flow, but also compressibility forces. All these summed forces determine the hydraulic resistance when advancing the respective fluid through the circular duct, being taken into account when writing the fluid flow motion equations.
If we only refer to the pipe properties, it is mainly considered the roughness of the pipe walls that can oppose to the fluid motion through the circular pipe as well as the sudden changes in the flow section.
The main types of changes in the flow section of the circular pipeline are presented, showing both theoretical calculation and numerical flow analyzes performed on the virtual model of the pipeline in order to highlight the main flow parameters involved as well as their value modifications as result of pipe flow section change. [1][4]

2. Hydraulic resistances to fluid flow in circular ducts

In order to study aspects regarding hydraulic resistances in the fluids flow, we must refer to the flow regimes inside circular pipes represented by the laminar and turbulent regime.
The laminar regime is characterized by a steady flow, the fluid layers are arranged in parallel layers and the regime is considered to be as moderate energy consumer during the flow.
The turbulent regime is characterized by a very high energy consumption compared to the laminar regime due to the fluid swirls that are born during the transport of the fluid particles inside the pipe. [3][5]
Hydraulic resistors are considered both locally within the pipeline and linear along the whole length, being summed up with the following relationship: [2]

$$H_r = \sum H_d + \sum H_l \quad (1)$$

where:

H_r - total hydraulic resistances;

H_d - hydraulic resistances linearly distributed along the length of the fluid flow;

H_l - hydraulic resistances at the local level due to changes in the fluid flow geometry.

Hydraulic resistances as well as velocity distribution in the fluid flow section can vary depending on the flow pattern (laminar or turbulent).

The formula Darcy-Weissbach establishes the linearly distributed hydraulic resistances along the length of the fluid flow for the laminar and turbulent modes: [2]

$$H_d = \lambda \frac{l}{d} \frac{v_{med}^2}{2g} \tag{2}$$

where:

λ - flow resistance coefficient for distributed loads;

l, d - length and diameter of the pipeline;

v_{med} - average flow velocity;

g - gravitational acceleration.

$$\lambda = \frac{64}{\mathrm{Re}} \tag{3}$$

The distribution of the velocity values in the pipe section for the turbulent flow regime is described by the following relation: [2]

$$\frac{1}{u_{\max}} u = 1 - 2\lg \frac{\frac{r_0}{y}}{\frac{0.975}{\sqrt{\lambda}} + 1.35} \tag{4}$$

where:

u - the average value recorded for the local velocity at the distance y from the pipe wall;

$u_{\max}$ - the velocity value at the pipe axis;

r_0 - radius of the flow pipe;

Between the average flow velocity through the circular duct (v_{med}) and the maximum velocity values at the pipe axis $(u_{\max})$ there is Prandtl's relationship: [2]

$$\frac{u_{\max}}{v_{med}} = 1 + D\sqrt{\frac{\lambda}{8}} \tag{5}$$

where:

D - velocity deficit;

While A. D Altschul's relationship defines the ratio of the two velocity values as being: [2]

$$\frac{u_{\max}}{v_{med}} = 1 + 1.35\sqrt{\lambda} \tag{6}$$

For circular pipelines in which the flow regime is turbulent, we can define the Coriolis coefficient described with relation: [2]

$$\alpha = 1 + 2.65\lambda \tag{7}$$

For the laminar flow regime inside a circular pipeline it can be considered that the velocity is of the parabolic type according to the Stokes formula: [2]

$$u = \frac{\gamma J}{4\mu}\left(r_0^2 - r^2\right) = \frac{\gamma H_d}{4\mu l}\left(r_0^2 - r^2\right) \tag{8}$$

where:

u - the local velocity recorded at the distance *r* from the pipe axis;

r_0 - pipe radius;

J - hydraulic slope;

γ - fluid specific gravity weight;

μ - dynamic viscosity coefficient.

Changing the flow section in the case of circular pipes leads to the formation of local resistances in the flow path-lines so that the fluid velocity values are changed, which implies additional load losses in the fluid flow.

Two cases are presented, namely the case of pipe diameter increase (sudden passage at a larger diameter), as well as the case of a decrease in the diameter value for the pipeline (abrupt pipe narrowing).

2.1 The case of sudden drop in pipe diameter

In the event of a sharp drop in the diameter value of the flow pipe, a contraction of the fluid stream flow occurs.

The value of the local flow resistance coefficients is influenced by the flow path geometry as well as by the Reynolds number of the fluid flow and can be calculated with the relationship: [2]

$$\xi_l = \left(\frac{1}{\zeta} - 1\right)^2 \tag{9}$$

$$\zeta = \frac{A_c}{A_2} \tag{10}$$

where:

ζ - contraction coefficient of the fluid stream;

A_c - the fluid flow area due to the changing diameter of the contracted flow;

A_2 - the area of the reduced diameter pipe.

The area ratio or change in diameter determines the value of the contraction coefficient whose value depends on the input and output area.

$$n = \frac{A_2}{A_1} \tag{11}$$

Figure 1 shows a diagram for a sudden narrowing of the pipe section.

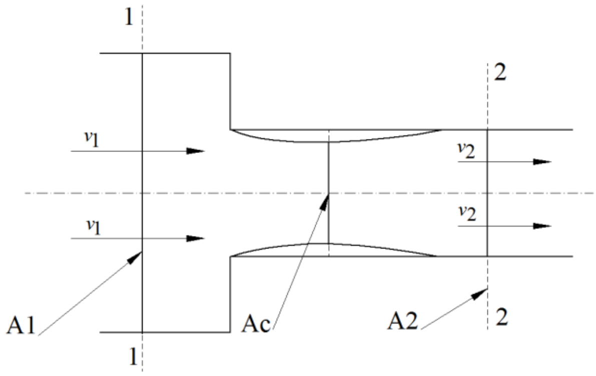


Fig. 1. The case of sudden drop in the pipe flow diameter

For the values of the ratio of the input and output areas in the interval (0; 1), the values of the contraction coefficient of the fluid flow are within the interval (0,6; 1); and the values of the local resistance to fluid flow are within the range of values (0.4; 0.1). [2]

2.2 The case of a sudden rise in the pipe diameter

In case of a sudden increase in the pipe diameter and the flow section, a load loss is recorded due to the flowing regime that becomes strongly turbulent in respective fluid region.

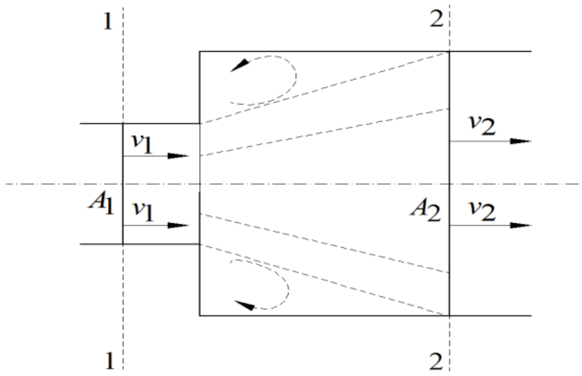


Fig. 2. The case of the sudden increase in the pipe flow diameter

For the calculation of the load loss at the sudden increase in the pipe diameter, Borda's relationship is used: [2]

$$H_l = \frac{(v_1 - v_2)^2}{2g} = \xi_l \frac{v_2^2}{2g} \tag{12}$$

The coefficients of the local resistance to fluid flow are within the range of values (80; 0) for the values of the section area ratios comprised in the range (10; 1). [2]

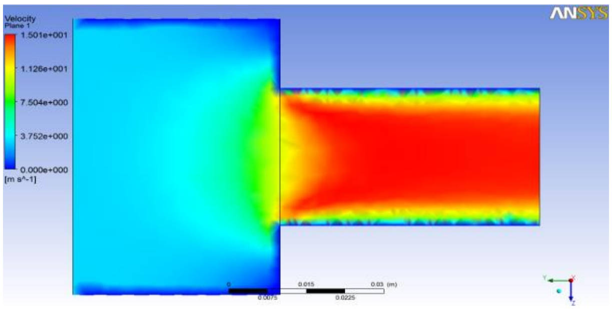
3. Numerical flow analysis on virtual model

The flow analysis is performed on the virtual model for the two considered cases as the sudden narrowing of the flow section as well as for the sudden increase of the pipe diameter and consequently the increase of the flow section.
On the virtual model of the circular pipe is defined the fluid region with the reference pressure of 1 atm, having the input velocity value declared at 3 m/s.

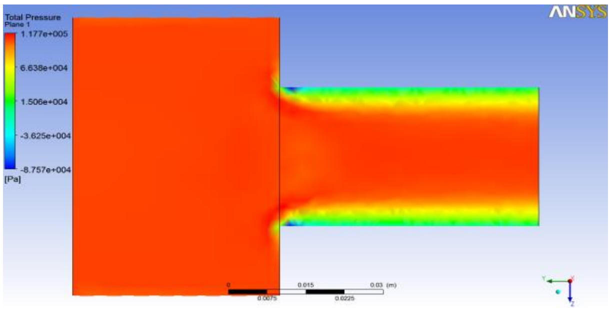
The obtained results for the two analyzed cases, referring to the narrowing of the flow section and the sudden enlargement of the section, are presented below.

3.1 Fluid flow analysis for the sudden drop in pipe diameter

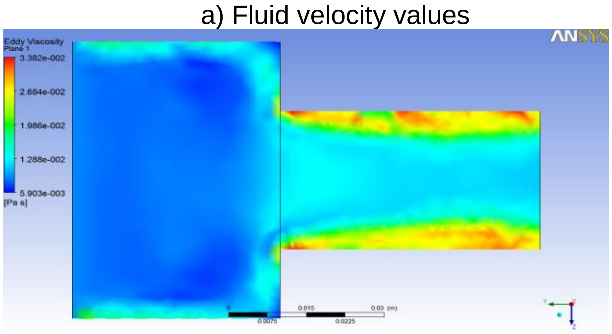
It is considered the case where occurs a sudden narrowing of the flow section as a result of a lower passage diameter through the pipe. The inlet is declared for the large pipe diameter (60 mm) and the fluid velocity value of 3 m/s. The outlet diameter is of 30 mm. The working fluid is represented by water at 25 °C, the turbulence model being of medium intensity k-Epsilon type.
The meshing network is made with tetrahedral shaped elements having a number of 9033 nodes and 45106 elements.
The result values are shown in Figure 3, where the values for the given working total pressure and for the fluid velocity can be seen on the cutting plane YZ.
Also, are presented values for turbulence due to fluid viscosity and kinetic energy.



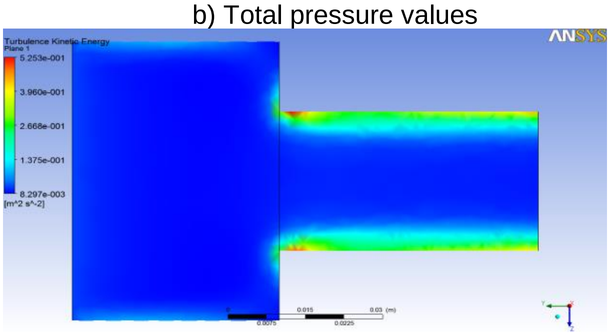
a) Fluid velocity values



b) Total pressure values



c) Eddy viscosity values



d) Turbulence kinetic energy

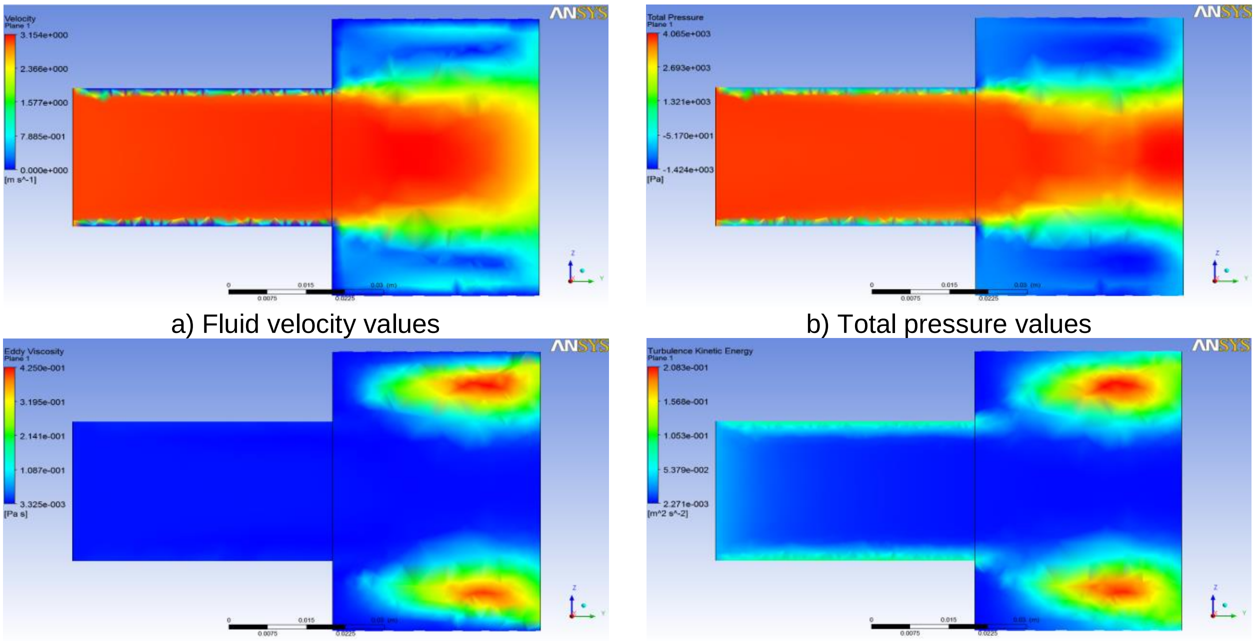
Fig. 3. Values obtained from the numerical analysis for the sudden decrease of the pipe diameter

By analyzing the fluid circulation velocity values in the range 3.7 - 15 m/s, it can be stated that there is an exponential increase in velocity values at the passage area from the large diameter region to the fluid region of reduced diameter where maximum values are recorded for pipeline axis and smaller near the pipeline wall due to friction dissipation in this area.
The total pressure values are larger on the inlet area, with a jump at the entrance to the reduced diameter pipe, where the fluid flow is strongly contracted.
Maximum turbulence values due to fluid viscosity are present within the shrinkage area of the fluid stream, near the pipeline walls.

3.2 Fluid flow analysis for the sudden increase of pipe diameter

For the second analysed case where the flow pipe has a connection with a larger diameter pipe, the numerical analysis being made on a virtual model whose inlet opening has a diameter of 30 mm and the outlet diameter is 60 mm. The working fluid is water at 25 ° C, the turbulence model is established as medium intensity k-Epsilon type.

The same value of 3 m/s is declared for the fluid velocity at the inlet, being expected a uniform fluid circulation around the reduced diameter pipe region and for the larger pipe diameter region a relaxation in the fluid flow stream mainly due to the larger space available for the fluid.
The obtained results for this case are shown in Figure 4 for the YZ coordinate section plane.
The velocity values recorded at the fluid region level within the range of (0.8-3.15 m/s) are higher on the reduced diameter pipe area, the path-lines being continued in the large diameter region only for the central pipe axis region, up to the outlet region where flow energy dissipation is accomplished.
The velocity values for the larger diameter pipe region near the walls are reduced.
For total pressure values, it can be noted that there is an increase in the small diameter pipe area, while at the passage into the larger diameter pipe there is an initial relaxation followed by higher values at the outlet region near the pipe axis.
The pressure values for larger diameter pipe region close to the wall are reduced.
The turbulence values due to the internal friction of the working fluid and the kinetic energy are higher in the region near the large diameter pipe wall.



a) Fluid velocity values
b) Total pressure values
c) Eddy viscosity values
d) Turbulence kinetic energy values

Fig. 4. Values obtained from the numerical analysis for the sudden increase of the pipe diameter

4. Conclusions

Aspects about flow through circular pipes with sudden change in diameter have been presented in this paper.
Specific resistances of fluid flow occurring in the situations described by the reduction and sudden increase of the flow section are shown.
Also, the numerical flow analysis on the virtual model of the pipeline was performed in order to highlight the specific values at the analyzed fluid region level relative to the flow velocity, total pressure and turbulence obtained.
There have been considered two specific cases: first case in which the diameter of the pipe has a sudden drop and in the second case there is a sudden increase in pipe diameter, altering in this way the fluid stream section.

The obtained results for both analysed cases highlight the turbulent fluid flow model with large values near the axis of the pipeline for the flow velocity and total pressure and along and in the vicinity of the walls for the turbulence values.
The numerical flow analysis on the virtual model of the pipeline was performed for water at 25 °C but can be performed for different types of fluids at different values related to the circulation velocity, pressure or working temperature, corresponding to the hydrostatic drive systems that work with high ranges of velocity and pressure values.

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