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CFD ANALYSIS OF FLOWS IN A HIGH-PRESSURE NATURAL GAS PIPELINES WITH DIFFERENT SHAPES OF ORIFICE PLATES

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Abstract: *This work aims to present the numerical analysis of the natural gas which flows through the high-pressure pipelines and the orifice plate by using CFD methods. The paper contains CFD calculations of the flowing natural gas in the pipe with different geometry of used orifice plates. One of them has a standard geometry and a shape without any deformation and the others are deformed by the action of the pressure differential. It shows behaviour of the natural gas in the pipeline by the pressure fields of the gas in all models and their differences. This research is based on the fact, that small deformation of the orifice plate can cause differences in the measured pressure differentials from what is mass flow calculated.*

Keywords: Orifice plate, High-pressure pipeline, Natural gas, CFD analysis, Pressure fields.

1. Introduction

Worldwide raising requirements for the heat and the energy have huge influence on decreasing amounts of the mineral resources and on increasing tendency of their prices. It is necessary to deal with them responsibly. One of these cases is using natural gas as an energy and heat source. Nowadays there are billions of normalized cubic meters of natural gas transferred and used every day all around the world. The most common flow measurement type, used in high-pressure pipelines, is measuring by pressure differential, which mainly uses orifice plates inserted in the pipelines. This paper tries to focus on behaviour of the natural gas flowing in the high pressure pipeline with installed orifice plate used as a flow meter. This type of measuring is still most common for the flow measurements in the transit gas lines in Slovakia and the other European countries (Malcho, 2006).

This paper shows differences in pressure differentials, pressure fields and velocity streams between undeformed and deformed orifice plates. For those analyses were prepared 3 models. The undeformed model is not loaded by the action of any tensions. The geometry of the deformed models is affected by the action of pressure differential, which causes shift and deformation of the orifice plate. In this comparison analysis was chosen pressure differential of 30 kPa and 50 kPa and a thickness of the plate was 10 millimeters. Maximum shifts caused by the deformation were 0.75 mm for 30 kPa and 1.23 mm for 50 kPa (Fig. 1) (Kiš, 2013).

Fig. 1: Cut through undeformed and deformed model of the orifice plate (Δp = 50 kPa, t = 10 mm).

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2. Model Preparation

The model analysis is calculated in ANSYS Workbench. All models consist of three parts, two straight pipes and the orifice plate in the middle of them. In one model is the orifice plate modelled as undeformed one and in the other is the orifice plate deformed by the action of the pressure differential. In the analysis there is used only the inverted solid volume, what is the fluid flowing through the pipes and the orifice plate. In this case the natural gas is the fluid medium. The model is axisymmetric to reduce a number of the cells and to simplify the calculation. Because of the axial symmetry the geometry contains only one half of the section. The height of the pipe is 365 millimetres, the inlet length is 2000 millimetres and the outlet length is 10000 millimetres long (Fig. 2). Thickness of the orifice plate is 10 millimetres.

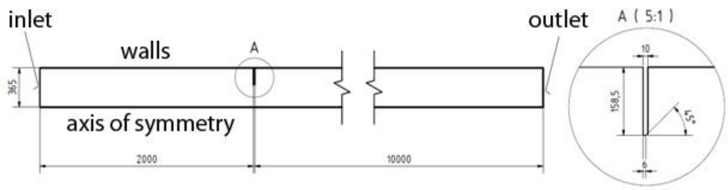

Fig. 2: Geometry of the model.

3. Mesh

The mesh of all three models consists of 527740 quadrilateral cells and it has 530078 nodes. The surface of the model is split into the ten blocks. Two blocks are for the orifice plate's part and four blocks are for each pipe (Fig. 3a). This splitting is necessary to make the mesh thicker in the areas around the orifice plate (areas no.: 1, 2, 3, 4, 7, 8) and the pipe walls (areas no.: 4, 5, 8, 9). In the areas 6 and 10 it is not important to have too many cells and that is the reason why the mesh is thinner there. Lower spacing near the walls and around the orifice plate is significant to obtain the behaviour of the natural gas flow more realistic. In the Fig. 3b there is a detail of the mesh around the orifice plate (Kiš, 2012).

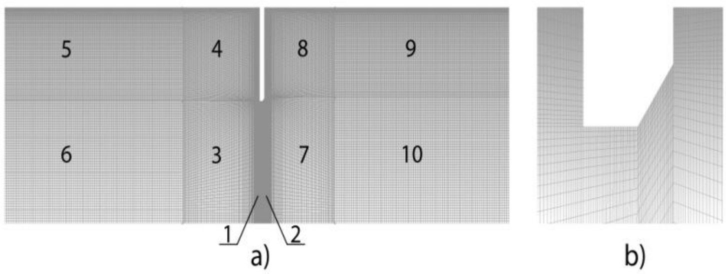

Fig. 3: a) Mesh with the geometry splitting; b) Mesh detail around the orifice plate edge.

4. Boundary Conditions and Model Solver

Behaviour of the model was set for the high-pressure pipe with the flowing methane as the fluid part. All boundary conditions are the same in both analyses. The value of the mass flow was 80 $kg.s^{-1}$. Boundary condition for the inlet was set to the mass flow and for the outlet was set to the pressure outlet. All boundary conditions in the inlet to the pipe are in the Tab. 1.

Tab. 1: Boundary conditions in the inlet to the pipe.

Pressure	**Temperature**	**Density**	**Mass flow rate**
p [Pa]	T [K]	ρ [$kg.m^{-3}$]	m [$kg.s^{-1}$]
5.10^6	288.0	34.1	90.0

Because of the low Mach numbers, the compressible fluid was changed into the incompressible and the density-based model solver into the pressure-based. Due to the high Reynolds numbers and the necessity of the modelling flow near the wall was chosen standard k-ε model (Lenhard, 2010).

5. Pressure Analysis

The measuring of the pressure differentials at the orifice plate is fundamental for the measurement of the mass flow rate. In the Fig. 4 is shown the layout of the pressure fields in the section around the orifice plate for models with undeformed and deformed orifice plate.

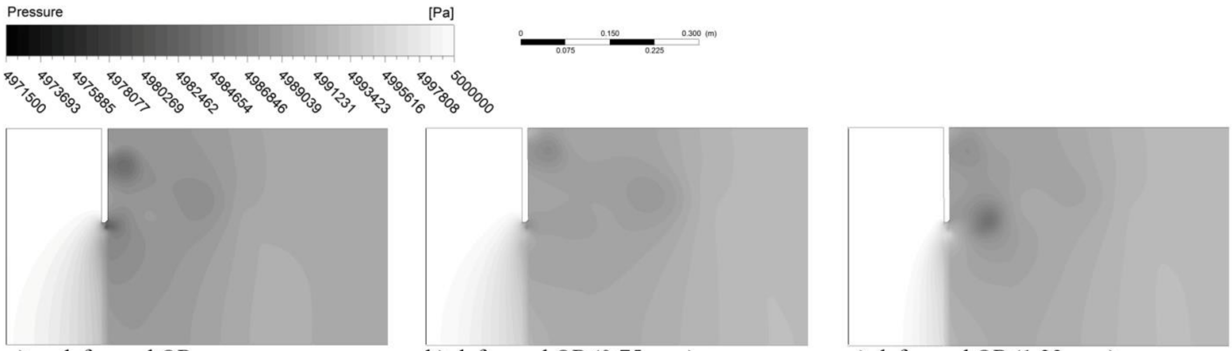

Fig. 4: Pressure fields in the section around the orifice plate: a) undeformed; b+c) deformed.

From the Fig. 4 is visible, that the pressure fields in front of the orifice plate start dropping closer to the plate and the pressure field behind the orifice plate are changed by the deformation of the orifice plate too. The area of the pressure fields with lower pressures became larger, what causes different pressures measured in the downstream. Finally it changes pressure differential from which is the volumetric flow calculated. The place where to measure pressures correctly in the system with the orifice plate is given in the standard ISO 5167-2:2003.

The standard ISO 5167-2:2003 mentions rules how to correctly measure with the orifice plates. For orifice plates with D and D/2 tapings, the spacing l1 of the upstream pressure taping is nominally equal to D. The spacing l2 of the downstream pressure taping is nominally equal to 0.5D (Fig. 5.), where D is diameter of the pipe connected to the orifice plate. The other possibility is to measure with flange tapings, where pressure values are taken from the distances 25.4±1 mm in both sides from the surface of the orifice plate.

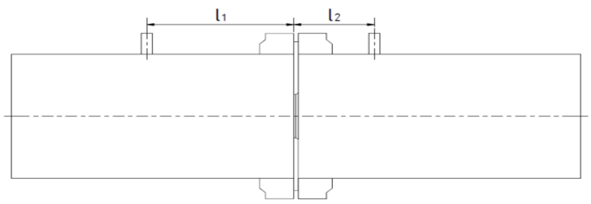

Fig. 5: Spacing of the pressure tappings for the orifice plates with D and D/2 tapings.

Dependence of the pressure on the distance measured near the wall is shown for all three models bellow in the Fig. 6.

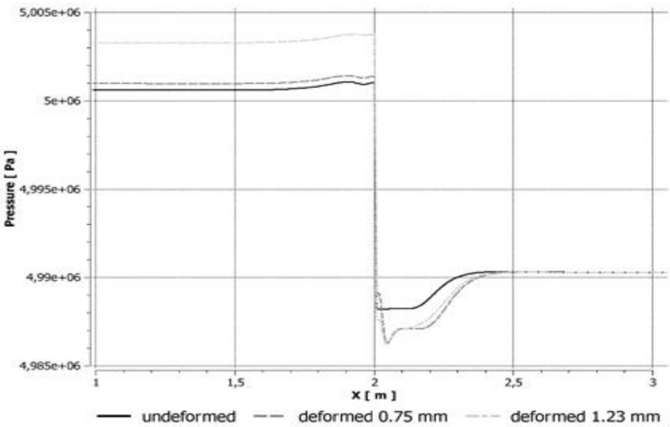

Fig. 6: Dependence of the pressure on the distance from the inlet to the pipe (area near the orifice plate).

It can be seen, that the deformation of the geometry causes the difference in the pressure differentials. With the increasing deformation the value of pressure differential increased too. There are two different values of the pressure differential for each kind of deformation. One value is valid for D and D/2 tapings and the other is for flange tapings. In the Fig. 7 there is a graphical dependence of the deformation on the pressure differential for all three models.

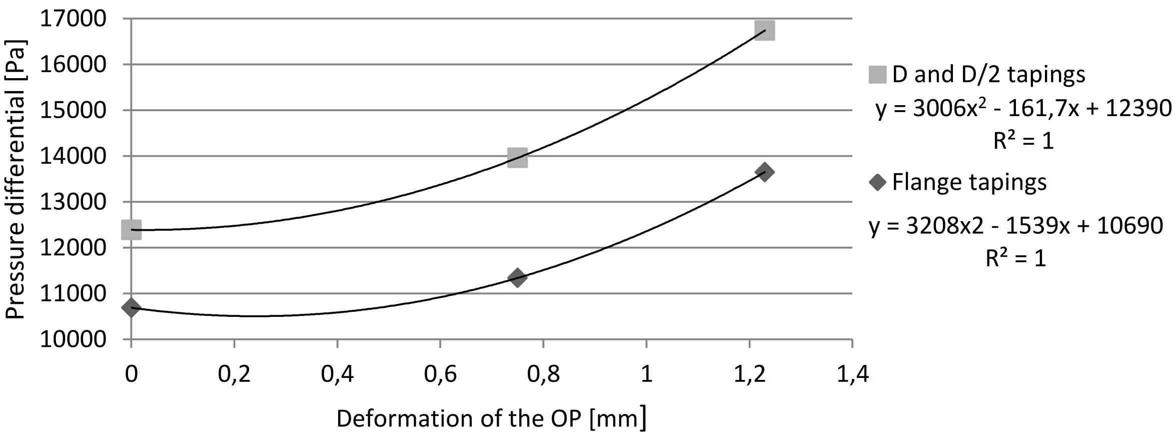

Fig. 7: Graphical dependence of "the deformation of the orifice plate on the pressure differential".

If trend lines are inserted through values in the graph, it will be received two different polynomials of the second grade with reliability equation $R^2 = 1$. Numerical dependence for D and D/2 tapings is valid in (1), for flange tapings is valid in (2):

$$y = 3006x^2 - 161.7x + 12390 \quad (1)$$

$$y = 3208x^2 - 1539x + 10690 \quad (2)$$

6. Conclusion

The analysis shows, that the deformation has a great impact on the stream field in the high-pressure pipeline. The shape deformation causes different behaviour of the natural gas stream. It causes different values of pressure differentials however boundary conditions of all three models are identical. The final accuracy of the measurement could be affected if the deformation is not included in the calculation of the final volumetric flow. Next research will show behaviour of the natural gas in the 3-dimensional space. The results of axisymmetric and 3-dimensional analyses will be compared, if the dimensional difference has impact to the natural gas flow.

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