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# Numerical simulations of natural gas flow in pipe system with flowmeters

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**Abstract.** Numerical simulation of the flow behavior in part of large pipe system is presented in this article. Compressed natural gas is transported through the system in a dynamic unsteady way. Velocities at several points and velocity profiles at certain positions are monitored during the numerical simulation. The aim is to investigate the stability of velocity profiles at the positions of flowmeters in course of flow time. In addition, the possibility of flow conditioning in the system is presented and discussed.

## 1 Introduction

The natural gas transmission pipeline system is used for the international transportation of natural gas from gas fields over several transmission system operators (TSO) and distribution system operator (DSO) to the end user. Natural gas delivered at the entry/exit points from one to another system passes through a system of acceptance and transferal (custody transfer), i.e. it is quantitatively and qualitatively metered and measured at metering (delivery) stations.

Although today's gas market is based on trading in energy units (kWh) still volume flow metering is the basis for energy flow calculation. Thus precise gas flow metering at the station is the key to success. The most common are orifice meters, turbine meters and the latest trend the ultrasonic meters. Flow meters or metering system installed at entry/exit points are always of "class1" (metering uncertainty < 1 %, but operators shall keep it as low as possible) and operated in accordance with recommendations of international standards, e.g. in terms of using upstream and downstream straight lengths for gas flow profile development.

Fully developed flow profile, no swirls and pulsations are essential conditions for precise metering not only for orifice meters but mainly for ultrasonic meters. Although metering runs may be designed according to all standards and the meter manufacturer recommendation the gas flow behavior is always given by the configuration of the piping system up and down stream the metering run.

For this reason, the gas flow in the pipe system is investigated numerically in order to supply relevant information about any possible causes of measurement disturbances and it impacts. As a model exact configuration and dimensions of an existing metering station of an approximate capacity of 100 mio $m^3$/day was used. Also tested scenarios were selected real operating conditions of the station.

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## 2 Computational model

For such a piping system, 1D simulation approach is often used. However, in our case it was decided to model the piping system in fully 3D to be able to cover the gas behavior in detail in pipe branches, T-junctions, and mainly at the positions of gas flowmeters.

Computational model of part of complex metering station pipe system was created from scratch based on the design documentation and pipe system elements (T-junctions, elbows) description from appropriate standards [1]. Only relevant parts are chosen to cover the investigated pipe system. Nevertheless the model covers the pipe system of area about 31 m × 101 m. Horizontal high differences are about 4.5 m.

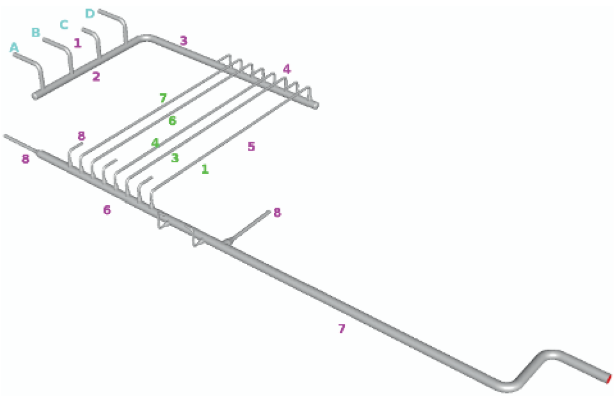


**Figure 1:** Geometry of piping system

The computational model is shown at the picture 1. In magenta numbers, there are labeled main system parts: 1 is the inlet part consisting of four individual inlets of DN 700 pipe. Individual inlets are in blue marked as A, B, C, and D. Magenta 2 is the DN 1200 main collecting inlet pipe, following behind the 90° knee with 17.5 m of DN 1200 of main pipe (3). At the position 4 the DN 1200 pipe is divided via T-junctions into individual metering pipes (runs) at position 5. Metering runs are numbered according to green numbers from #1 to #7.

Metering run itself consists of pipe DN 400 with several ball valves and pressure-flow regulating valve. Because ball valves are fully opened for several metering runs (see subsection 3 for operating scenarios) the smooth ideal pipe wall is used instead. The regulating valve is neglected for these simulations. The reason is the CAD data for detailed geometry of the valve are not available. Moreover, the valve is positioned far enough behind the flowmeters in the metering run so the influence to the velocity profiles at the flowmeters could be small, we suppose.

Individual metering runs are lead through T-junctions to main exiting pipe of DN 1200 and this main pipe is prolonged to its end after about 62 m (7). In the model, also several blind branches (8) are modeled in order to allow the 3D flow field to be simulated correctly.

### 2.1 Computational mesh

Computational mesh is created for each operating scenario. Operating scenarios differ in numbers and positions of used metering runs. Hence the computational model is modified for each scenario and mesh size varies about 10 million of 3D cells as it is shown in the table 1.

**Figure 2:** Combined mesh elements type in the pipe system

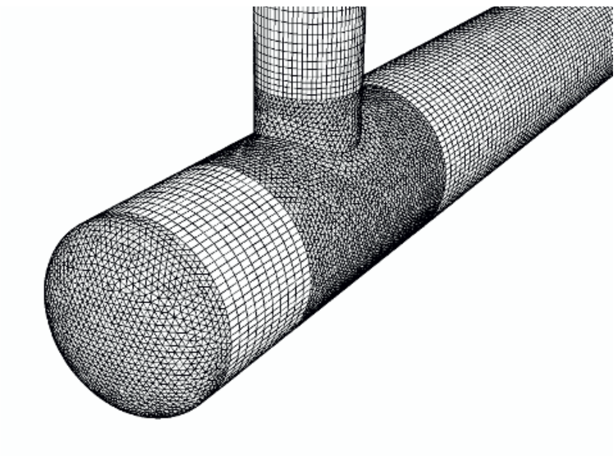

**Figure 3:** Surface mesh at the system inlet part

Boundary layers are used along all the surface to cover correctly the flow behavior in the near-wall region. Boundary layers parameters are first layer 0.5 mm, 6 layers, linear grow factor 1.8, and the total height is about 20.63 mm.

Hexahedral cell blocks are used for pipe sections of the model. Tetrahedral cells are used for T-junctions and pipe cups. The inner volume mesh slice is shown at the picture 2 where the connection between the tetrahedral and hexahedral elements is presented at the position of T-junction pipe element. The surface mesh examples for inlet parts are the pictures 3 and 4.

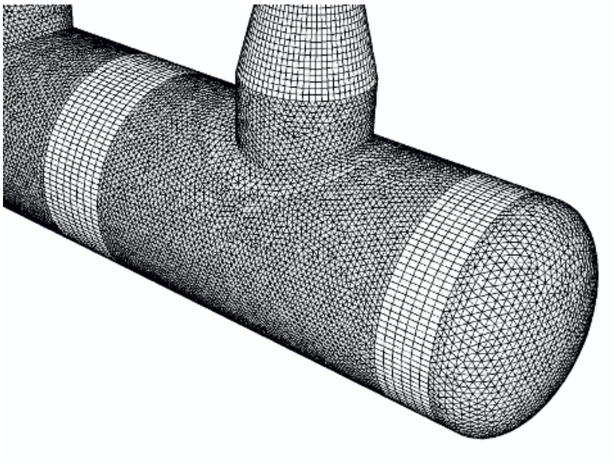

**Figure 4:** Surface mesh near the metering run starts

At the picture 5 the surface mesh of the metering run and its cut is shown. You can see there is not so many cells in the metering run pipe, but much dense mesh could lead to enormous cell number of the whole geometry. The total cell mesh numbers for appropriate scenarios are shown in the table 1 below.

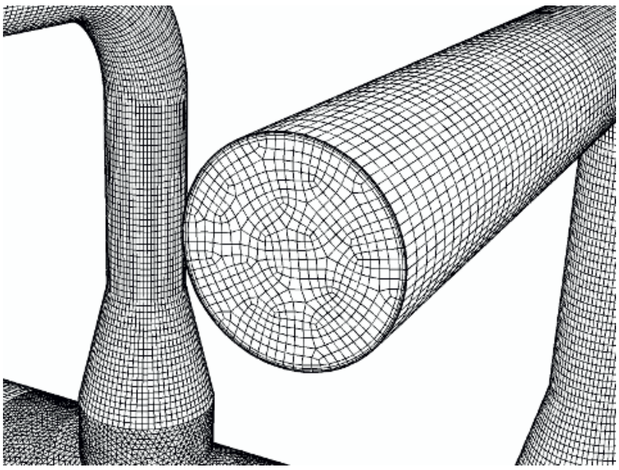

**Figure 5:** Surface mesh of the metering run

## 3 Operating scenarios computed

Three operating scenarios are investigated in this work as it is presented in the table 1 below. The presence of used different metering runs sometimes partially closed at the end results in the need of the separate computational model for every operational scenario.

**Table 1:** Three operational scenarios description

| | Scenario 1 | Scenario 2 | Scenario 3 |
|---|---|---|---|
| Pressure [bar] | 78.0 | 85.0 | 85.0 |
| Density [kg/m$^3$] | 64.70 | 71.56 | 71.56 |
| Temperature [°C] | 5.0 | 5.0 | 5.0 |
| Total system volume flow [m$^3$/h] | 16 600 | 25 000 | 44 800 |
| Inlets opened | B, D | A, B, D | A, B, D |
| Metering lines | | | |
| Opened | #1, #3 | #1, #3, #6 | #2, #3, #4, #6, #7 |
| End-side closed | #4, #5 | #7 | #5 |
| Both-sides closed | #2, #6, #7 | #2, #4, #5 | #1 |
| Mesh size [millions of cells] | 9.8 | 10.1 | 10.5 |

**Table 2:** Mass flow [kg/s] in metering runs

| Metering Run | Scenario 1 | Scenario 2 | Scenario 3 |
|---|---|---|---|
| #1 | 151.4 (50.8%) | 174.1 (35.0%) | – |
| #2 | – | – | 202.1 (22.7%) |
| #3 | 146.9 (49.2%) | 167.7 (33.7%) | 193.5 (21.7%) |
| #4 | – | – | 173.1 (19.4%) |
| #5 | – | – | – |
| #6 | – | 155.8 (31.3%) | 166.8 (18.7%) |
| #7 | – | – | 155.1 (17.4%) |

## 4 CFD numerical setup

Natural gas transported is treated as a pure methane in these simulations because this compound is present in natural gas by 96 %. Based on the operational pressure and temperature, methane density is determined as it is shown in the table 1.

The gas flow is simulated as a 2$^{nd}$ order unsteady problem with a short steady simulation at the beginning. Turbulent flow is covered by the k-$\omega$ SST turbulence model. Spatial discretizations of 2$^{nd}$ order is used. The flow is non-compressible because of relatively small transport velocities.

The computational time step for unsteady simulation is 0.002 s. The flow time of 4 s is computed to get the dynamical stable flow field. Than he unsteady data-sampling method is used during following 11 s of flow time to get the flow mean (average) values and its deviations. Also, the pressure and velocity values are monitored in many points in the system.

The huge number of small time steps to solve leads to numerically demanding simulations. For this reason, we run the CFD code in parallel using our computational Linux cluster, still the computational time counts to several days for every scenario.

During the unsteady run for last 11 s of the flow time, the velocity magnitude and velocity components were monitored in the points in certain places along the flow path in the pipe system. Here for clarity, only records of flow time from 4 s to 7 s are presented in the text below.

## 5 Results

### 5.1 Mass flow in metering runs

Mass flow in kg/s for all scenarios is shown in the table 2 together with the percentage of the total flow. We can see the flow is relatively well balanced for every scenario. With higher number of metering run, the mass flow gets a bit lower, it means the system pressure loss differs for individual metering run flow streams.

### 5.2 Flow behavior in the pipe system

Although the flow situation differs a bit for each scenario, we can now focus only to scenario 2 results to show the main flow behavior in the complex pipe system. In this scenario, the metering runs #1, #3, and #6 are active.

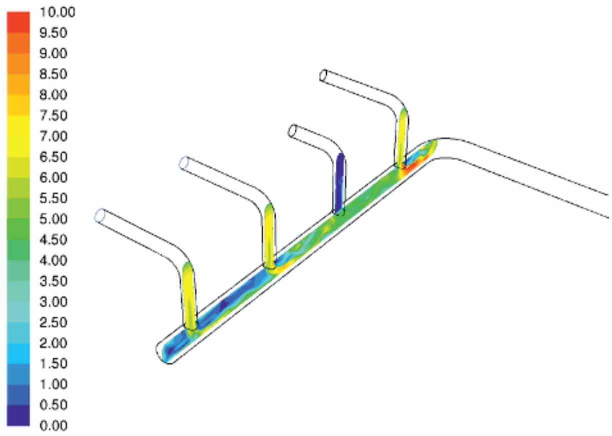


**Figure 6:** Velocity field at the inlet part

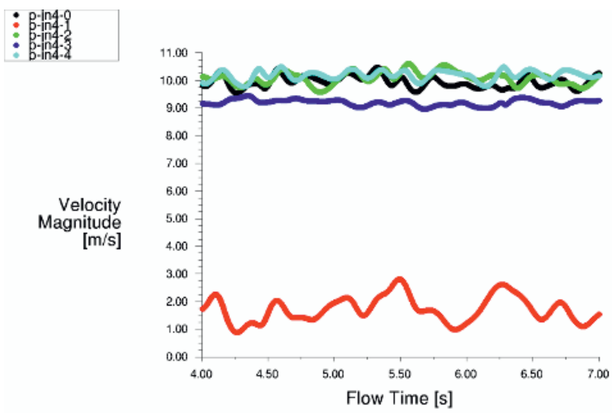


**Figure 7:** Velocity behavior at the inlet main pipe

Gas enter the system by active inlets into DN 1200 main inlet pipe. Yet in front of the knee bending some small flow disturbances are generated because of the inlet partial flows blending at T-junctions, see picture 6. The velocity magnitudes behavior at this place is shown at the graph 7, only small velocity fluctuations are there.

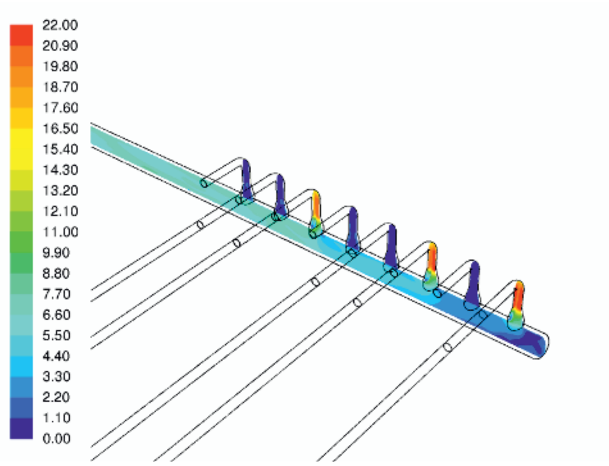


**Figure 8:** Velocity field in front of metering runs

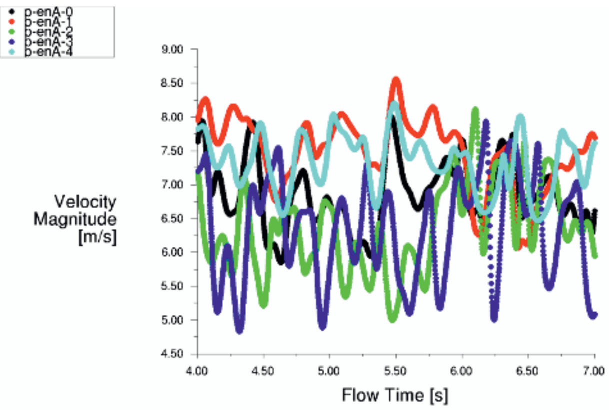


**Figure 9:** Velocity behavior in front of metering run branching

Pictures show the velocity magnitude field in the middle cut of pipe system part. Closely behind the knee bend the flow disturbances are bigger, see the graph 9, but within traveling in the long pipe situation gets calm a bit. The situation in the T-junctions branching area where the flow goes into the metering runs causes again the fluctuations in the flow, see the picture 8. These fluctuations are driven into the metering runs where the flow fluctuations are yet combined with elbowed eddy initiated at the DN 400 knee bend. The velocity magnitudes in course of time are presented at graph 10 at the position of the flowmeter in the metering run #3.

Behind the metering runs in the main exit DN 1200 pipe the partial streams from metering run interact again causing huge flow fluctuations, see picture 11. Another view to the exit pipe is at the picture 12. Instantaneous velocity magnitude is presented here. At the picture 13 is the average velocity magnitude field, you can see much smoother flow compared to instantaneous field.

At the picture 14, velocity magnitude deviation field is presented showing the places where the flow fluctuates a lot. The graph 15 of the velocity magnitudes course be-

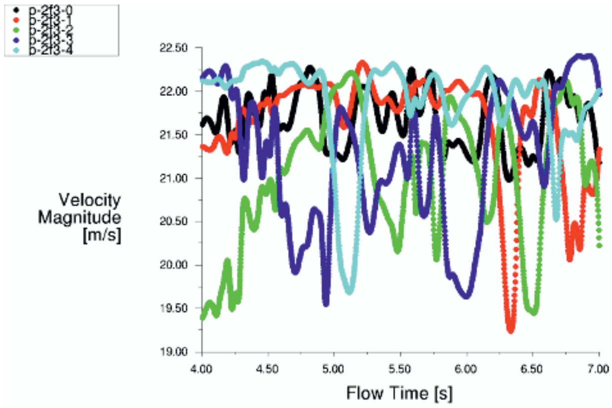


**Figure 10:** Velocity behavior at the flowmeter of metering run #3

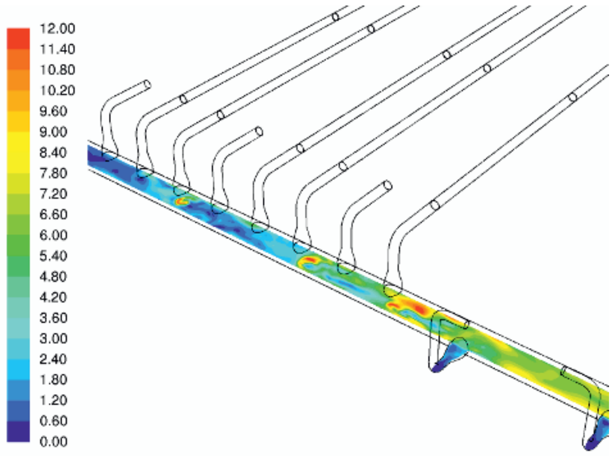


**Figure 11:** Velocity field behind metering runs

hind the T-junction region confirms the highly chaotic flow regime in this area.

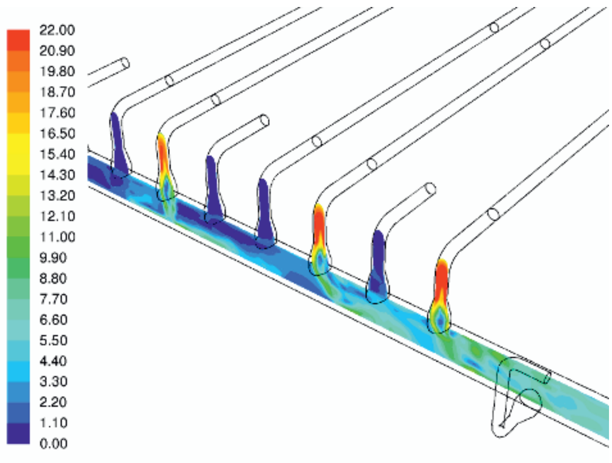


**Figure 12:** Instantaneous velocity in exit pipe

### 5.3 Velocity profiles at flowmeters

The main interest is given to the flow situation in the metering runs at the places where flowmeters are. Also here the situation is presented only for scenario 2 because for

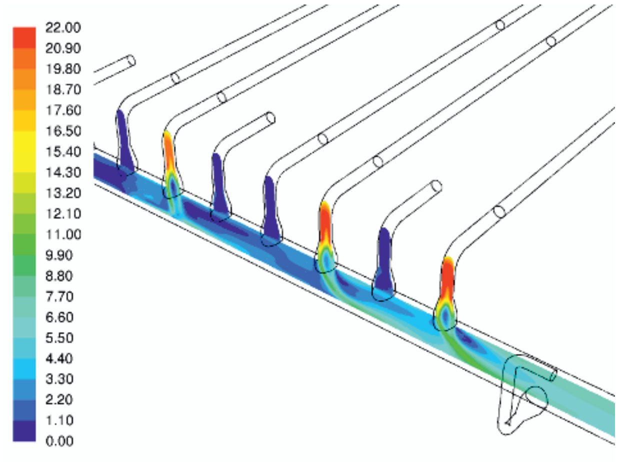


**Figure 13:** Average velocity in exit pipe

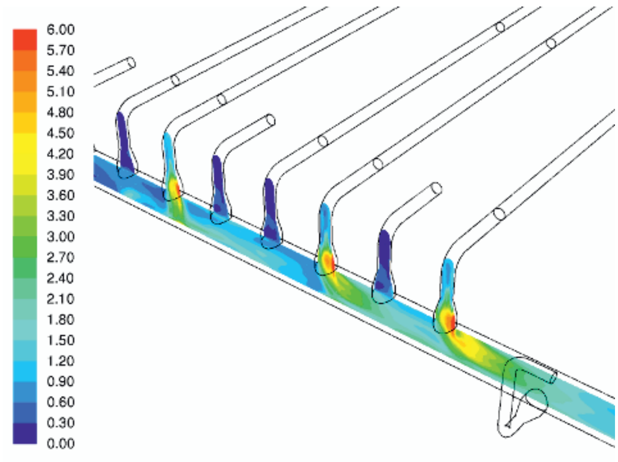


**Figure 14:** Deviation of velocity in exit pipe

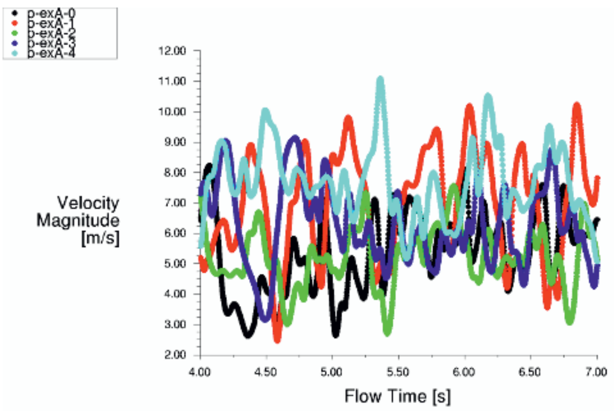


**Figure 15:** Velocity behavior at the outlet DN 1200 pipe

the other scenarios it is roughly the same. From graph 10 we see the flow is not stable at these places. Although the upstream distances of straight clear DN 400 pipe in front of flowmeters are big enough to meet the standards requirements (more than 20 D), the flow is not calmed down.

This is caused by relatively high transport velocities and relatively high gas density. The gas inertial forces are quite high and flow disturbances are traveling in the individual metering runs as it was described above.

When we look to the velocity profile in the metering run cut at the position of the flowmeter, we notice the velocity profile is changing in time. The instantaneous velocity profile is not the ideal turbulent profile, although the average velocity is very close to the symmetrical ideal turbulent velocity profile. At the picture 17 is the instantaneous velocity distribution in metering run #1 for certain flow time. At the picture 18 is the average velocity distribution in metering run #1, and picture 19 shows the deviation distribution. The pictures 20, 21, and 22 present the same distributions for metering run #3.

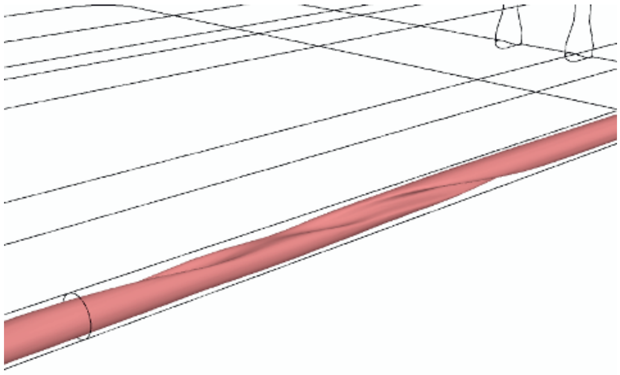

**Figure 16:** Velocity magnitude isosurface of 22 m/s

Namely from deviations pictures we can see the flow changes are located near the metering run walls. The same situation is illustrated by the picture 16, where the isosurface of instantaneous velocity with the magnitude of 22 m/s is colored in the metering run #1. The spiral character of this isosurface points to near-wall flow disturbances traveling in the metering run.

## 6 Conclusions

In this work the build-up of the pipe system model of the border station metering part is presented. The natural gas flow is simulated for given operational scenarios.

The results show the gas flow is unsteady and highly chaotic in the pipe system mostly because of the geometry changes and pipe branching. In almost all monitored points there are velocity fluctuations of low frequencies and relatively high amplitudes. Due to relatively high gas transport velocities and high operational gas density the disturbances are not calmed down and they are traveling in the pipe system [2].

That's why at the positions of the flowmeters in the individual metering runs the instantaneous velocity profiles are changing in time and are distant from the ideal velocity profiles even the average velocity profile is close to awaited ideal velocity profile. This could result into some inaccuracy in case the flowmeter awaits the ideal stable velocity profile for its measurement technique.

Next work will be focused on the method of possible velocity profile fluctuation reduction by using some appropriate flow conditioner [3], [4], [5]. The real pipe system does not allow to place the intended flow conditioner to arbitrary place in the metering run, so we are a bit limited in our further investigations.

We must admit the numerical simulations are influenced by relatively sparse computational mesh to cover the flow dynamics properly. Also, the numerical models

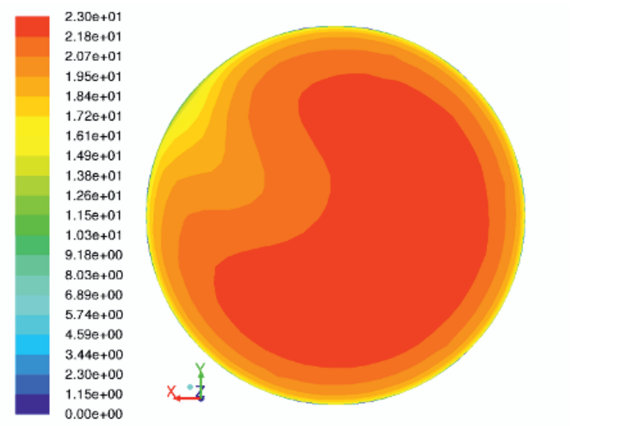


**Figure 17:** Instantaneous velocity distribution in metering run #1

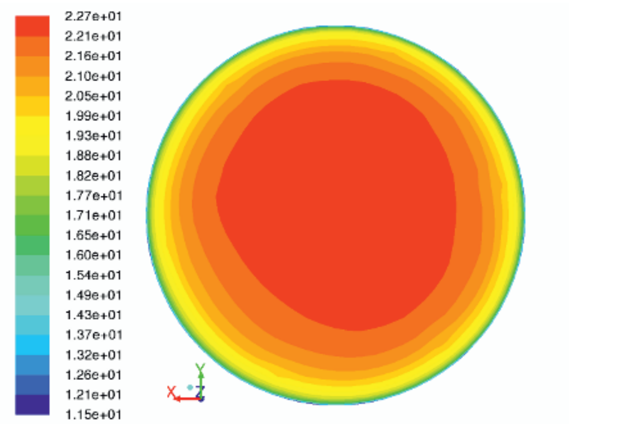


**Figure 18:** Average velocity distribution in metering run #1

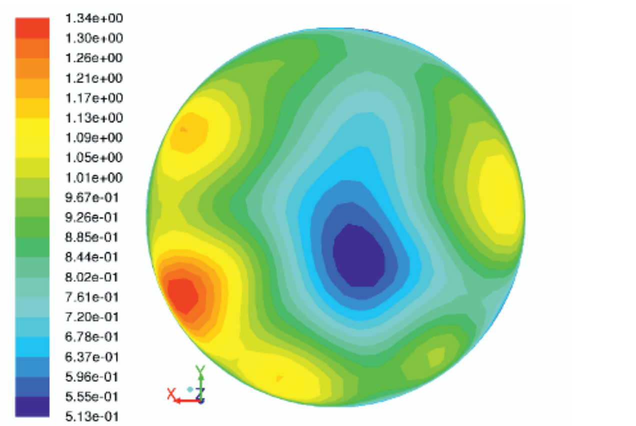


**Figure 19:** Deviation of velocity in metering run #1

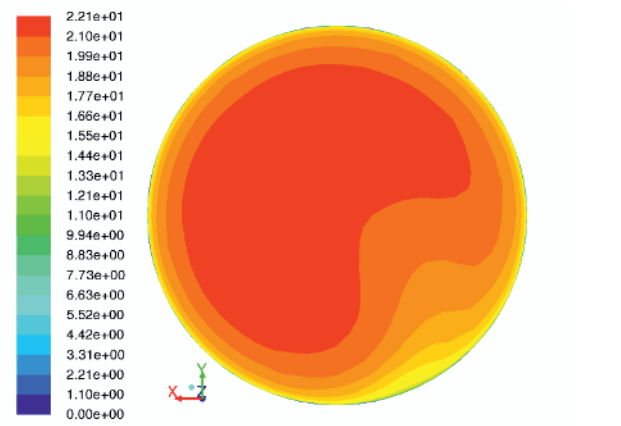


**Figure 20:** Instantaneous velocity distribution in metering run #3

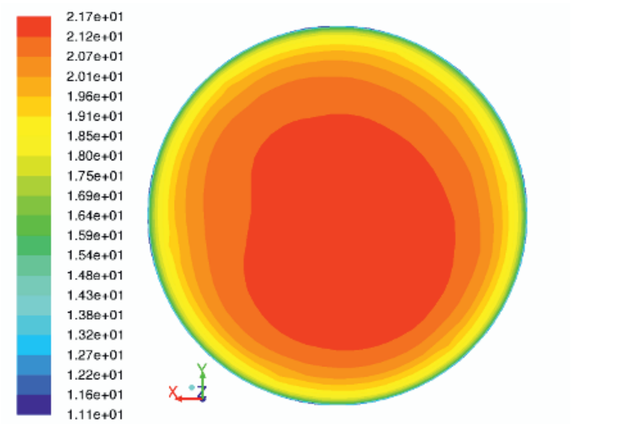


**Figure 21:** Average velocity distribution in metering run #3

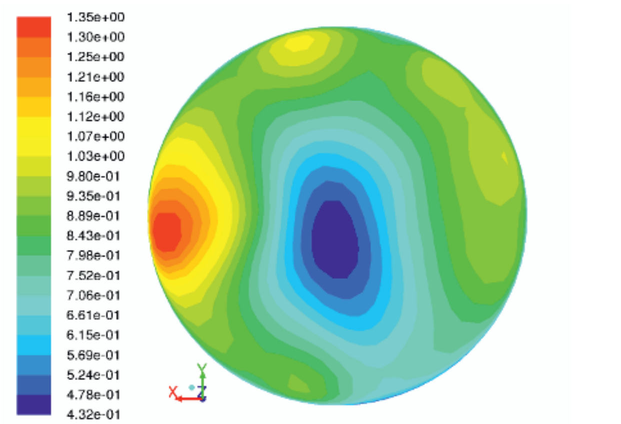


**Figure 22:** Deviation of velocity in metering run #3

including the turbulent model dampen down gas flow disturbances. So it is possible the situation can be yet more dramatic in reality.

## Acknowledgement

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