The Effects of Operating Parameters on the Geometry of a Measurement Section of a Pipeline

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Abstract— *This article deals with the effects of a temperature, pressure, gravity, pipe flanges and saddle supports of a measurement section of the pipeline on changes in the pipe geometry. The investigation was aimed, in particular, at examining changes in diameters of two pipeline sections relative to changes in their internal pressure, which ranged from 0 MPa to 6.0 MPa, and to changes in temperature, which ranged from 0 °C to 25 °C. As indicated by the results of a numerical simulation carried out within this research, a change in a diameter can be expressed most accurately if the effects of gravity, saddle supports and flanges are neglected. Changes in pipe diameters were examined merely as a function of changes in pressure and temperature. Gravity, flanges and saddle supports cause irregular pipe deformities that occur along the pipe circumference and length. These effects prevented identification of real values of changes in the pipe diameter on the measurement sections of the pipeline.*

Keywords— measurement pipe section, saddle supports, flanges, gravity.

I. INTRODUCTION

In investigation into changes in geometry of a measurement section of the pipeline, intended for natural gas transportation, two of the operating parameters play a significant role—a temperature and a pressure of transported gas. These two factors affect the pipe geometry, while their effects depend on particular combinations of pressure and temperature values; eventually, they determine a measured amount of transported gas. This article presents an analysis of the effects of pressure and temperature on the pipe geometry, which was carried out with four different pressure and four different temperature values. The results of the investigation are presented in the concluding section of the article in form of tables for two different types of pipes. Effects of pressure and temperature were evaluated using three calculation models while applying numerical methods: ProMechanika, ANSYS CFX and CosmosM [1-2]. The investigation was aimed at identifying the impact of identical boundary conditions on the results obtained by using the above listed software products. Another examined aspect was a possibility to apply simplified boundary conditions and their effects on the result.

The basic parameters of the investigated geometry, as well as other selected technical data adopted from the data sheets for the materials from which both measurement sections of the natural gas pipeline were made, are listed in Table 1.

TABLE 1
BASIC PARAMETERS OF INVESTIGATED PIPES

Name	Value	Units
Nominal dimensions of the pipe	1) 762 x 25.4 – 1,200 2) 790 x 19.0 – 1,200	mm
Pipe material	S355 JR – 11523.1	-
Highest operating temperature	+50	°C
Lowest operating temperature	0	°C
Welded joint coefficient	0.85	-
Ultimate tensile strength at t = 20–50 °C	470	MPa
Yield strength at t = 20–50 °C	355	MPa
Modulus of elasticity	2.06105	MPa
Poisson ratio	0.28	-
Mass density	$7.85 \cdot 10^{3}$	$kg \cdot m^{-3}$
Thermal expansion coefficient	$2.0 \cdot 10^{-6}$	K^{-1}
Thermal conductivity	52	$W \cdot m^{-1} \cdot K^{-1}$
Specific heat	512	$J \cdot kg^{-1} \cdot K^{-1}$

II. ANALYSIS MODEL

The created calculation model for both pipe types was based on their real geometries, and it was made using the numerical FEM (Finite Element Method) [3-4]. Both pipes were part of a measurement section of the natural gas pipeline at the border acceptance gas station in Veľké Kapušany, Slovakia. The calculation model was created for identical, 1,200 mm long pipe sections. Due to the fact that the pipe structure was symmetrical to three coordinate axes as to its geometry, and to one coordinate axis as to its loading (a gravity effect in the direction of y-axis), the calculation could only be made for one half of the geometry. For both pipe types, the calculations were made for the following calculation statuses:

1. Calculation Status 1: a pipe loaded by internal pressure p = 0 MPa; a temperature of 0, 15, 20 and 25 °C; gravity, saddle supports, and flanges being considered.
2. Calculation Status 2: a pipe loaded by internal pressure p = 5 MPa; a temperature of 0, 15, 20 and 25 °C; gravity, saddle supports, and flanges being considered.
3. Calculation Status 3: a pipe loaded by internal pressure p = 5.5 MPa; a temperature of 0, 15, 20 and 25 °C; gravity, saddle supports, and flanges being considered.
4. Calculation Status 4: a pipe loaded by internal pressure p = 6 MPa; a temperature of 0, 15, 20 and 25 °C; gravity, saddle supports, and flanges being considered.

The article presents the investigation into the pipe specified in Table I, designated as 1), with the dimensions 762 x 25.4 – 1,200. The results presented below correspond to Calculation Status 2, designated as 2), wherein a pressure was p = 5 MPa and a temperature was 20 °C. The pipe model was created at the 1:1 ratio and is plotted in Fig. 1. The pipeline together with flanges and saddle supports on which it was placed formed a compact unit. In this particular status, the effects of gravity were taken into consideration.

In real conditions, the effects of saddle supports, flange joints and the pipe weight are interlinked, hence there were complications with calculating the values of the pipe diameter following the deformation. Deformities that occurred along the pipe circumference were not identical; pipe diameter values exhibited differences at individual points on the pipe. The most significant pipe deformity, in the above specified boundary conditions, was observed in the areas where the saddle supports were located (Fig. 2). The strain value was δ = 0.184 mm. Therefore, in the next step of the investigation the effects of gravity were neglected. In this case again, a maximum strain of the pipe diameter was observed in the saddle support area (Fig. 3). However, its value was a bit lower (δ = 0.172 mm)

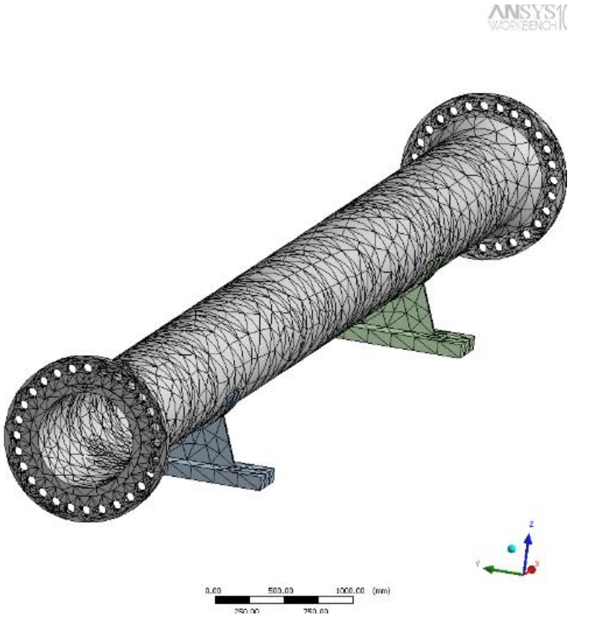

FIGURE 1: The pipe model

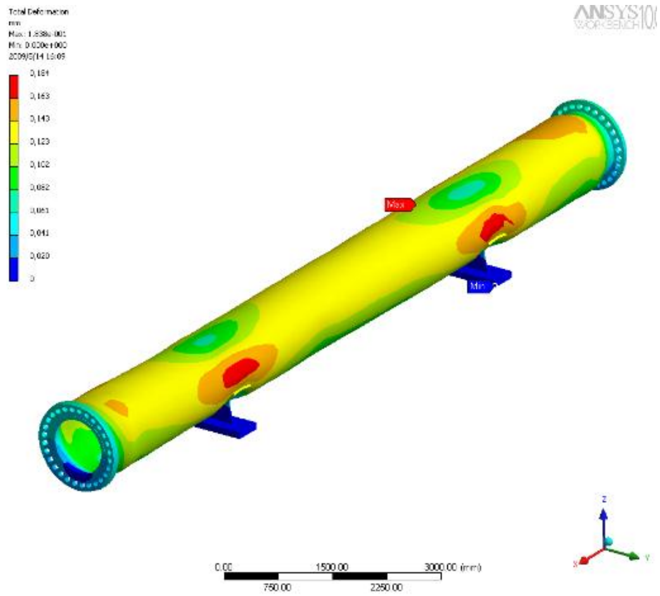

FIGURE 2: Pipe deformities, gravity being considered (*p* = 5 MPa; *t* = 20 °C)

It was decided not to consider flanges, saddle supports and gravity in determination of real changes in the pipe diameter. Hence, the examination of the pipe, aimed at identifying changes in its geometry, was simplified. After the implementation of the aforesaid simplification measures, it was possible to unambiguously evaluate the effects of pressure and temperature on changes in the pipe diameter.

With the gravity of the pipe and of the saddle supports being neglected, at a pressure of 5 MPa and a temperature of 20 °C, the observed diameter strain was δ = 0.428 mm. Resulting values of strain of the metering section of the pipe sized 762 x 25.4 – 1,200 for all the remaining statuses (pressures and temperatures) are listed in Table II.

Another purpose of a stress–strain analysis of the measurement pipe section was to obtain data on stress values along the thickness of the pipe wall. The result of the analysis is presented in Fig. 4. Maximum stress for Calculation Status 2), i.e. at a pressure of 5 MPa and a temperature of 20 °C, while considering the effects of gravity, is indicated by red spots on the pipe. A maximum von Misses stress value was 84.28 MPa. In the flange area, the stress was much lower (σ = 31.70 MPa).

In identical boundary conditions (a pressure of 5 MPa and a temperature of 20 °C, gravity and saddle support being considered), the pipe strain in the axial direction was also examined. In particular, pipe elongation was monitored in the direction of *x*-axis of the pipe (Fig. 5). In this case, a maximum stress value amounted to 0.361 MPa, and it was observed at the point where a flange was attached to an adjacent pipe section. This adjacent pipe section was only fictively taken into consideration as an effect of the reinforcement of the flange joint. The reinforcement disabled shifts in the direction of *x*-axis.

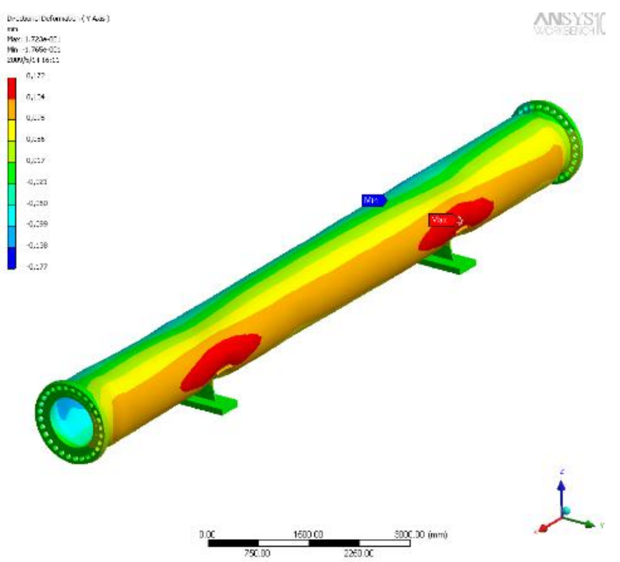

FIGURE 3: Pipe strain without considering gravity (p = 5 MPa; t = 20 °C)

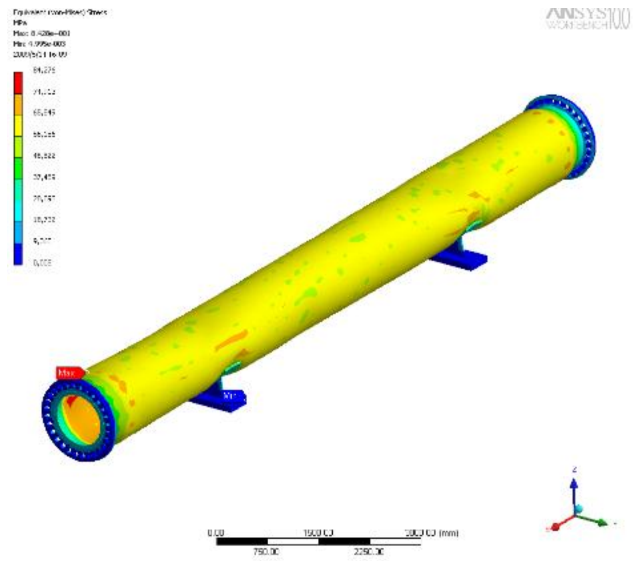

FIGURE 4: Stress-strain status of the pipe with gravity being considered (p = 5 MPa; t = 20 °C)

The strain was also examined in simplified conditions—without considering saddle supports and gravity. In this regard, it was possible to examine only ¼ of the pipe, but for all of the calculation statuses listed above. With the effects of saddle supports, gravity and flanges being excluded from the analysis, the stress identified on the pipe at a pressure of 5 MPa and a temperature of 20 °C is depicted in Fig. 6. A maximum stress value amounted to 86.762 MPa.

The implemented simplification of the boundary conditions had no effects on the accuracy of calculations of changes in the pipe diameter. The application of simplified boundary conditions was based on the principle of elastic deformation of materials, under which even though a pipe shape changes along its circumference, its cross-flow area and hence also a volumetric flow rate of gas do not change.

The investigated factors included the effect of a temperature alone on changes in the pipe diameter; the effect of pressure alone on changes in the pipe diameter; and joint effects of pressure and temperature on changes in the pipe diameter, for all of Calculation Statuses 1) through 4). These effects were examined using ProMechanika, ANSYSE and CosmoseM software environments. The results obtained in all of these environments, in identical boundary conditions, exhibited very good concordance.

Results for the second measurement section of the pipe, which was sized 790 x 19 – 1,200 and examined in identical boundary conditions, are presented in Table III.

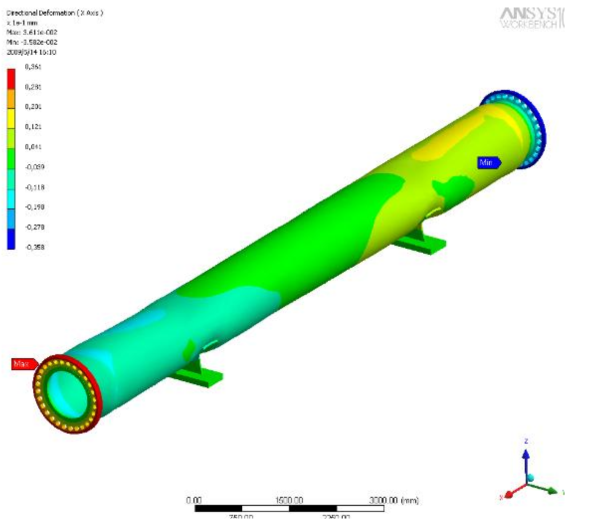

FIGURE 5: Pipe strain in axial direction (p = 5 MPa; t = 20 °C

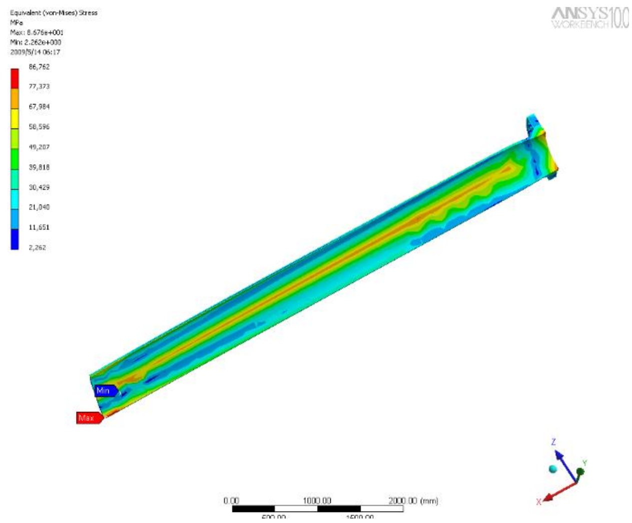

FIGURE 6: Pipe stress without considering gravity and saddle supports (p = 5 MPa; t = 20 °C)

TABLE 2
SUMMARY RESULTS FOR THE PIPE SIZED 762 x 25.4 – 1,200

Summary results of calculations for the measurement section of the pipe						
Nominal dimensions of the pipe	**Nominal inner diameter (mm)**	**Internal pressure (MPa)**	**Gas temperature (°C)**	**Change in diameter (mm)**	**Calculated diameter (mm)**	**Change in pipe length (mm)**
762 x 25.4 – 1,200	711.2	5.0	0	0.251	711.451	-0.814
			15	0.383	711.583	0.186
			20	0.428	711.628	2.519
			25	0.474	711.674	2.799
		5.5	0	0.276	711.476	-1.190
			15	0.407	711.607	0.971
			20	0.453	711.653	1.691
			25	0.498	711.698	2.411
		6.0	0	0.301	711.501	-1.293
			15	0.432	711.632	0.,862
			20	0.477	711.677	1.582
			25	0.523	711.723	2.302
		0.0	0	0.000	711.200	0.000
			15	0.069	711.269	2.160
			20	0.091	711.291	2.880
			25	0.114	711.314	3.600

TABLE 3
SUMMARY RESULTS FOR THE PIPE SIZED 790 x 19 - 1,200

Summary results of calculations for the measurement section of the pipe						
Nominal dimensions of the pipe	**Nominal inner diameter (mm)**	**Internal pressure (MPa)**	**Gas temperature (°C)**	**Change in diameter (mm)**	**Calculated diameter (mm)**	**Change in pipe length (mm)**
790 x 19 – 1,200	752	5.0	0	0.369	752.369	-1.544
			15	0.505	752.505	0.616
			20	0.553	752.553	1.336
			25	0.600	752.600	2.056
		5.5	0	0.406	752.406	-1.699
			15	0.542	752.542	0.462
			20	0.589	752.589	1.182
			25	0.637	752.637	1.902
		6.0	0	0.442	752.442	-1.853
			15	0.578	752.578	0.307
			20	0.626	752.626	1.027
			25	0.667	752.667	1.747
		0.0	0	0.000	752.000	0.000
			15	0.071	752.071	2.160
			20	0.095	752.095	2.880
			25	0.119	752.119	3..600

III. CONCLUSION

The article presents results of investigation into two measurement sections of the natural gas pipeline. The analysis of the effects of pressure alone on pipe deformation revealed an interesting fact. The effect of any pressure at a pipe wall temperature of 0°C always results in a change in the pipe length in the negative direction (pipe length reduction); however, a change in the pipe diameter is positive.

The analysis of the effect of temperature alone on changes in the pipe length indicated that such changes never depend on the pipe diameter; however, they always depend only on a temperature of transported gas (i.e. the temperature inside the pipe). With an increase in the gas temperature, hence also in the temperature of the inner pipe wall, the pipe elongation increases too. The pipe elongation values, measured at identical temperatures, were identical for both pipe diameters.

A particular value of a difference in the pipe diameter, induced by a change in temperature, in the radial direction is directly proportional to the values of a pipe diameter and wall thickness.

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