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RESULTS OF EXPERIMENTAL MEASUREMENTS AND CALCULATIONS OF PRESSURE LOSSES IN HD-PE PIPES

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During experimental measurements carried out at the Faculty of the Mechanical Engineering of the Czech Technical University (CTU) in Prague it was ascertained that HDPE pipelines have different hydraulic characteristics, than usually used in calculating their friction and local losses. The article describes results of the experimental measurements of pressure losses in polyethylene pipelines including. Frictional and local pressure losses in butt-welded joints in pipes with nominal diameters between DN25 and DN250. The measurements results were also compared with the empirical coefficients of the local head losses and friction losses in dependence on the pipe dimensions and the Reynolds numbers and verified by CFD and finite volume calculation method. . The obtained values show that local losses represent important part of the total energy losses and can be used for the hydraulic design of plastic pipeline systems. . A valid turbulent model of the upstream and downstream flow through the internal weld bead was determined based on the experimental data. Combination of experimental values and values obtained by calculation gives dependence of pressure losses on main pipe dimensions.

KEY WORDS: Plastic pipeline, Weld bead, Local head loss, Friction head loss, Butt welded joints.

1. INTRODUCTION

In hydraulic calculations for plastic pipe systems, it is necessary to have correct data available to determine the specific energy losses of the fluid flowing through the pipes. Repeated failures of plastic pipelines have occurred in the past due to underestimation of the need to take into account the hydraulic aspect at the design stage, but also due to the lack of background data needed for the calculations. At present, the calculation of a plastic pipeline design is based on the formulas and background data used in calculations for steel pipeline. Each material has its own specifics that need to be considered when designing a pipeline. The friction losses occurring during the flow of fluid through plastic pipe are not the same as the losses when fluid flows through steel pipes. Until now, plastic pipes have been considered hydraulically smooth, yet the calculations must take into account the roughness of the pipe wall and also the effect of aging and clogging of the inner surface.

A specific type of local resistance in a plastic pipeline is an internal bead that is usually absent in steel pipelines. The internal bead is created when plastic pipes are joined with butt welding, and its size depends on the parameters of the pipes and the fusing process. An example of an actual pipe joint is shown in Fig. 1. The local loss in the pipe joint caused by the butt weld is expressed by the joint-loss coefficient. So far, the determination of the values to calculate the joint-loss coefficient has been based on certain simplifications (e.g. a shutter calculation). Such estimated coefficient values have been only indicative and the assumed parameters of proposed systems often substantially differed from their real parameters, ascertained only after the implementation of the equipment in question.

Fig.1 Weld bead projection of pipe d355x32,2 SDR11 PE100

Long feeder pipelines are made up by joining plastic pipes with lengths of 5 to 6 metres. In a feeder pipeline a few kilometres long, this can mean hundreds or thousands of pipe joints. The pressure loss at a single joint might not be significant, but when there are high numbers of joints, it cannot be considered irrelevant.

The manufacturers of plastic pipes often state in their recommendations to designers that experience has shown that a local pressure drop in pipes joined using the butt-weld method can be ignored. These and similar recommendations based on unverified facts have resulted and will continue to result in fatal consequences.

After repeated failures, a need arose to launch a detailed analysis of the hydraulic design of a plastic pipeline system. The main objective was to determine the coefficients required to calculate the pressure losses in the pipeline due to the plastic material, and to verify the correctness of the values by experiment. The results of the experiment were compared with previous findings available at the Technical University in Prague, Faculty of Mechanical Engineering, comprising the results of long-term research on the hydraulic design of plastic pipes and a series of experiments to determine the values of the loss coefficient. After comparing the results with the previous findings, a general relationship was determined for the friction coefficient and the joint-loss coefficient. This paper contains the results of the experimental measurements and general conclusions.

2. HYDRAULIC CALCULATIONS FOR A POLYETHYLENE PIPELINE SYSTEM

The hydraulic losses in a fluid flowing through a pipeline can be expressed as the specific energy of a fluid Y_z consumed in a given part of the system by friction in straight sections of the pipeline, as well as by local influences. The total loss in the pipeline system is then equal to the sum of the frictional losses $Y_{z\,tř}$ and the local losses $Y_{z\,m}$ as per the equation

$$Y_z = Y_{z\,tř} + Y_{z\,m} \qquad (J.kg^{-1}) \qquad (1)$$

The specific energy $Y_{ztř}$, expressing the loss of energy due to friction in the straight sections of the pipeline from a fluid flow with density of ρ ($kg.m^{-3}$), is expressed by the Darcy-Weisbach formula

$$Y_{z\,tř} = \frac{\Delta p}{\rho} = \lambda \cdot \frac{l}{d} \cdot \frac{c^2}{2} \qquad (J.kg^{-1}) \qquad (2)$$

The influence of the wall roughness is expressed by the friction coefficient λ (1), which is – in the case of the steady turbulent pressure flow of a Newtonian fluid in a hydraulically smooth straight pipeline – only dependent on the Reynolds number. When a fluid with kinematic viscosity of ν ($m^2.s^{-1}$) flows through a completely filled pipeline with a circular cross section of internal diameter of d (m), the Reynolds number is calculated using the formula

$$Re = \frac{c \cdot d}{\nu} \qquad (1) \qquad (3)$$

The size of the friction coefficient for a hydraulically smooth pipeline generally depends on the Reynolds number, but in reality, the size of the coefficient is also influenced by the roughness of the pipeline; the geometric mean roughness of the plastic pipe is often expressed in the range between k = 0.0015 and 0.015 mm, which may be considered as hydraulically smooth pipe. In practice, plastic pipes are often considered hydraulically smooth in terms of the Blasius formula

$$\lambda = \frac{0.3164}{Re^{0.25}} \qquad (1) \qquad (4)$$

Experimentally, however, it has been proven that this condition for hydraulic smoothness does not have to apply generally. The experimentally determined values of the friction coefficient correspond relatively well with the values calculated using the Advani formula

$$\lambda = 0.0032 + 0.221 \cdot Re^{-0,237} \qquad (1) \qquad (5)$$

In addition to the energy losses caused by friction, the calculation must also include another impedimentary effect referred to as local losses. Local losses occur in places where the distribution of velocity and pressure changes in the cross section of the flowing medium. These are places with a change in direction and cross-section in the adapting pieces, or also in fittings, guard valves, flow meters and other elements of a pipeline system.

The size of the local losses is expressed by the local-losses coefficient ζ. The total values of the specific energy losses due to local losses are expressed using the formula

$$Y_{z\,m} = \frac{\Delta p}{\rho} = \Sigma\zeta \cdot \frac{c^2}{2} \qquad (J.kg^{-1}) \qquad (6)$$

The value of the local-losses coefficient of individual components is usually listed in the tables for the calculation of the hydraulic system or the manufacturer’s documentation.

3. EXPERIMENTAL MEASUREMENT AT CTU

1. Over the years, a total of three experimental testing circuits have been built in the fluid-mechanics laboratories to facilitate experimental measurements. Successive measurements carried out on the testing circuits included the use of polyethylene pipes with nominal dimensions ranging between DN 25 and DN 250.

The first experimental test circuit was used to measure plastic pipes with small nominal diameter. The selected polyethylene pipes were of the following dimensions: 63x5.8, 50x4.6, 40x3.7 and 32x2.9. The results of the experimental measurements are given in the publication by Melichar and Veselský (2009). Subsequently, based on the data obtained for pipes of small and medium diameter, an experimental testing circuit was built for measuring pipes with larger nominal sizes. The actual measured section was made of a polyethylene pipe with dimensions of 160x9.1. The experimental testing circuit was then rebuilt to measure pipelines with dimensions of 280x25.4.

During the experimental measurements, it was shown that the friction coefficient corresponds very well to the calculation of hydraulically smooth pipes according to Advani (see equation 5). There is also proof of a direct relationship between the size of the joint-loss coefficient, the size of the internal bead, and the nominal pipe size.

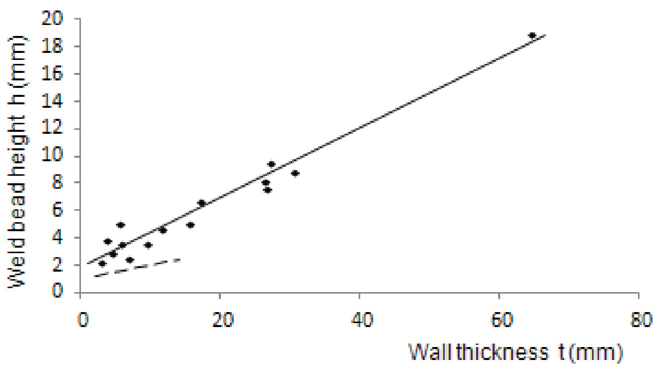

Fig.2 Dependency of weld bead height on pipe wall thickness.

During the research, a number of pipe joint samples were accumulated to obtain the dependency of the size of the internal bead on the typical dimensions of pipes. A linear dependency between the size of the bead's height and pipe wall thickness was proven. The resulting dependency is shown in Fig. 2. The dependency of the height of the weld bead on the pipe wall thickness was already defined by Buchin (1975). The height of the measured pipe beads was significantly greater than the dependency defined by Buchin. Fig. 2 shows the dimensions of the joint samples and the resultant dependency depicted by a solid line. For comparison purposes, the dotted line shows the bead height dependency defined by Buchin. The difference in the size of the height of the internal bead may be caused by different properties of the polyethylene and the varied processes for making joints.

From the resulting comparison, we can obtain the linear dependency between the height of the bead and the wall thickness of the joined polyethylene pipes. The resulting dependency of the height of the interior bead on the wall thickness of the joined pipes can be expressed using the empirical formula

$$h = 1.95 + 0.25 \cdot t \qquad (mm) \qquad (7)$$

where h (mm) is the height of the bead and t (mm) is the mean thickness of the wall of the joined pipes.

4. RESULTING DEPENDENCY OF JOINT-LOSS SIZES

The first traceable experimental verification of the size of the local-loss coefficient of a joint is mentioned in a paper by Buchin (1975). The pressure loss in a pipeline with a nominal dimension of DN 50 and a wall thickness of 2.5 mm was experimentally measured.

In addition to the research department of the Czech Technical University in Prague, Faculty of Mechanical Engineering, modern experimental research was carried out by Lizel (2010) who, within a context of an internal company research report, conducted measurements on pipes with nominal dimensions of DN 63, DN 125 and DN 180 from HD-PE material.

No other experimental work in plastic pipeline losses is known. Tab. 4 presents the values of the resulting joint-loss coefficients for polyethylene pipes according to various authors.

Table 1

Experimentally ascertained values of local-loss coefficients of joints

Pipe OD x wall thickness (mm)	Pipe material	Diameter ratio d/d_i (1)	Head loss coefficient ζ (1)	Reference
32x2.9	HDPE	0.823	0.85	Melichar and Veselský (2009)
40x3.7	HDPE	0.754	0.84	Melichar and Veselský (2009)
50x4.6	HDPE	0.849	0.41	Melichar and Veselský (2009)
63x5.8	HDPE	0.854	0.35	Melichar and Veselský (2009)
50x2.5	MRTU	0.9	0.150	Buchin (1975)
63x5.5	HDPE	0.79	1.02	Lizel (2010)
125x11.5	HDPE	0.91	0.13	Lizel (2010)
160x9.1	HDPE	0.95	0.049	Mosler and Melichar (2014)
180x17	HDPE	0.92	0.04	Lizel (2010)
280x25.4	HDPE	0.93	0.023	Mosler and Melichar (2016)

By comparing the experimentally determined values of the local-loss coefficient in a joint, it is possible to demonstrate the resulting dependency of the coefficient size on the main dimensions of a pipe. The dependency of the local-loss coefficient in a joint with a diameter ratio of d_i/d is given in Fig. 3. The comparison clearly shows that the experimentally determined values mutually correspond, and also shows the linear dependency of the coefficient values on the ratio of the inside diameters.

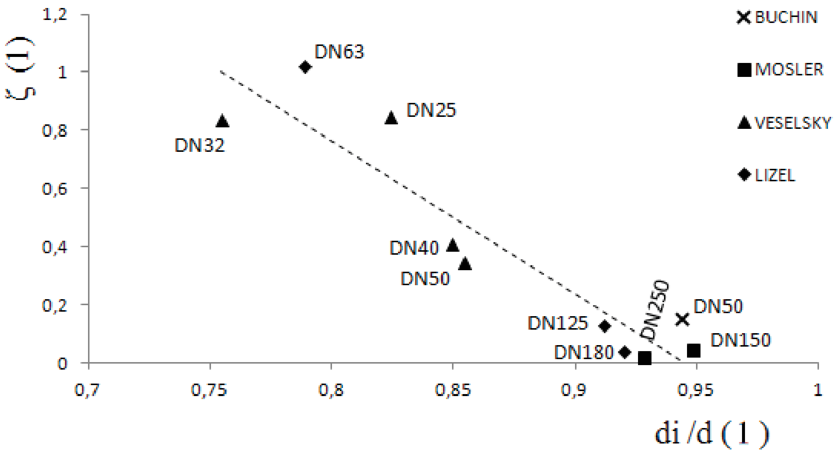

Fig. 3 Comparison of experimentally ascertained values of the local-loss coefficient with dependency on the pipe diameters ratio

The dependency of the local-loss coefficient on the joint to diameter ratio d_i/d has relatively large scatter in low values of the diameters ratio. This involves pipeline joints of small diameter with a very high internal bead. The mean value of the linear dependency is shown in Fig. 3 by dashed lines. The dependency of the local-loss coefficient in the joint on the inner diameter of the pipe d is more illustrative. The dependency of the experimentally determined values of the local-loss coefficient in the joint on the inner pipe diameter is shown in Fig. 4. The pipe internal bead height values are indicated for the individual coefficient values in Fig. 4.

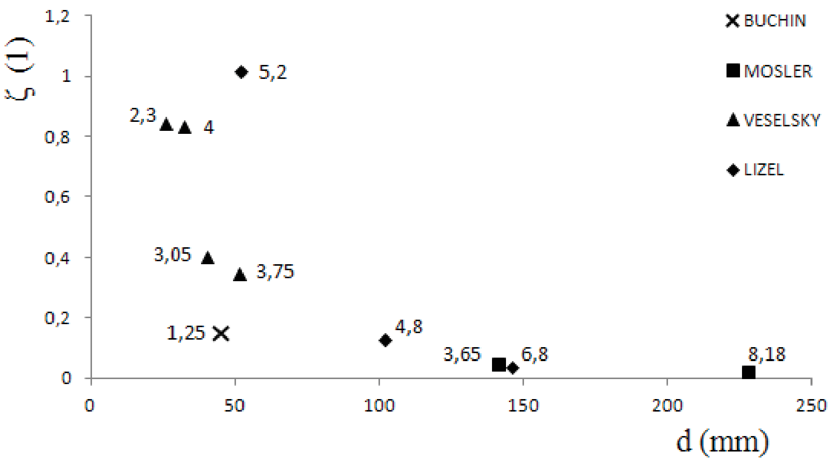

Fig. 4 Comparison of experimentally ascertained values of the local-loss coefficient in the joint in dependency on the pipe inner diameter

The comparison shown in Fig. 4 shows that the local-loss coefficient in the joint is particularly prominent in pipelines with an internal pipe diameter of up to 150 mm. The local-loss coefficient in the joints of pipelines with an internal pipe diameter greater than

150 mm is nearly constant and not dependent on the height of the internal bead of correctly finished joints.

By joining the areas where internal beads are of the same height, we reach the range of the local-loss coefficient area in the joint for different internal bead heights. The resulting dependency of the local-loss coefficient size in the joint on the inner pipe diameter and the internal bead height of the joint is shown in Fig. 5.

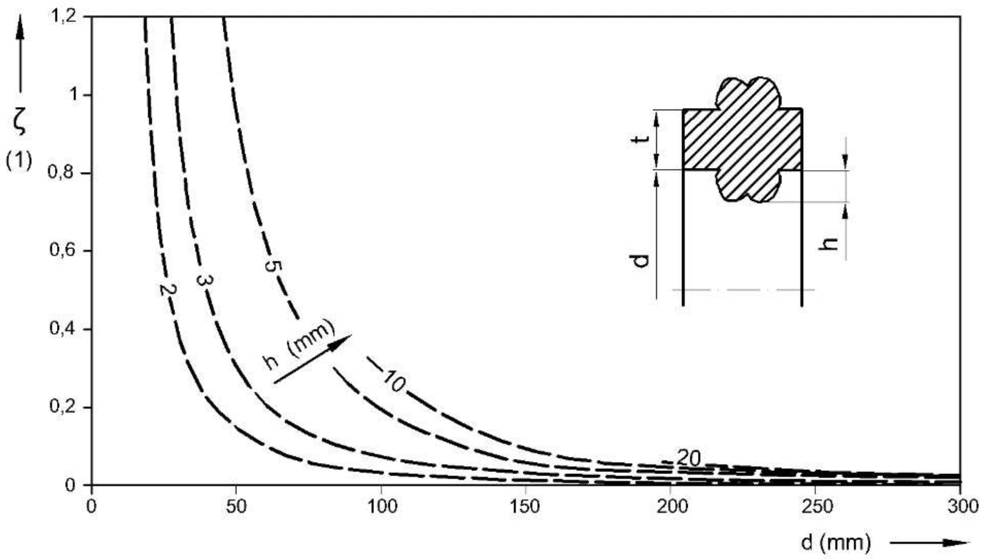

Fig. 5 Resulting dependency of the joint-loss coefficient on the internal pipe diameter and the height of the internal pipeline bead

The hydraulic calculation is often performed by computer software, for which it is necessary to define the exact mathematical formulation for the calculation. Using theoretical models and formulas taken from literature, and mainly based on the experimentally determined values of the local-loss coefficient, it is possible to define a formula to calculate the local-loss coefficient in the joints of butt-welded polyethylene plastic pipes. Based on the conducted experimental measurements, it is possible to define an empirical formula to calculate the butt-welded pipeline joint-loss coefficient as follows

$$\zeta = \frac{k}{1.12} \cdot \left(\frac{1}{\gamma^2 \cdot \varepsilon} - \gamma \right)^2 \qquad \textit{(1)} \qquad \textit{(8)}$$

where γ is the coefficient of proportional diameter narrowing, expressed using the formula

$$\gamma = \frac{d_i}{d} \qquad \textit{(1)} \qquad \textit{(9)}$$

k is the correction coefficient of the internal bead shape in the joint, and ε is the contraction coefficient. The size of the correction coefficient is selected depending on the shape of the internal bead as follows

$$k = 0.9 \div 1.4 \qquad \textit{(1)} \qquad \textit{(10)}$$

where the lower values of the correction coefficient for the shape are chosen for wide beads, and higher values are chosen for sharp-edged or asymmetrical beads.
The fluid stream contraction coefficient ε is expressed using the formula

$$\varepsilon = 0.78 + \frac{0.021}{1.09-\gamma} \quad (1) \qquad (11)$$

The mentioned formula is limited to pipeline dimensions with an internal diameter of up to 150 mm. For pipelines with an internal diameter greater than 150 mm, the influence of the internal bead height in a joint is minimal, and the values of the local-loss coefficient are almost constant.
For the values of the local-loss coefficient in the joints of pipelines with internal diameters greater than 150 mm, it is recommended to choose a coefficient in the range

$$\zeta = 0.02 \div 0.05 \quad (1) \qquad (12)$$

5. CONCLUSION

The evaluation of the experimental measurements and subsequent comparison enabled the determination of friction coefficient values and specific local loss values in the hydraulic calculation of a polyethylene butt-weld pipeline system. The values of the friction coefficient correspond to the values expressed by the Advani equation (5).
The size of the joint weld loss coefficient is dependent on the size of the inner diameter of the pipeline and the height of the internal bead. For pipelines with an internal diameter greater than 150 mm, the influence of the internal bead height in the joint is minimal and the value of the coefficient is almost constant. The bead height size is linearly dependent on the pipe wall thickness.

REFERENCES

1. Buchin, V.E., 1975. Poteri napora v svarnych trubach iz polietilena. Gidrotechnika i melioracija.
2. Lizel, F. 2010. HDPE Internal Weld Bead Tests. HSP-1172.3/LAB-6018. Paterson and Cooke.
3. Melichar, J., Veselsky, J. 2009. Local Head Loss in Polypropylene and Polyethylene Pipeline Joint Welded by Butt Fusion. Int. J. Heating, Ventilation, Installation.
4. Mosler, P., Melichar, J., 2014. Determination of Pressure Loss in Plastic Pipeline. 15th International Freight Pipeline Society Symposium. Prague.
5. Mosler, P., Melichar, J., 2016. Experimental Determination of Head Losses in Polyethylene Pipeline with Nominal Diameter DN250. 22nd International Conference Engineering Mechanics. Svratka.
6. Mosler, P., Melichar, J., Tašek, M. 2016. Determination of Hydraulic Resistance of a Thermoplastic Pipe Joint. Int. conference SKMTaT 2016, STU in Bratislava.