Local Head Loss in Polypropylene and Polyethylene Pipeline Joint Welded by Butt Fusion

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Abstract

The article deals with experimental determination of local energy loss in polypropylene and polyethylene pipelines joint connected by butt welding. This article is related to the former introductive works and its results published in "Vytápění, větrání, instalace 15" magazine (Heating, ventilation, installation) volume 1, 2006, pp.15-18.The ascertained values of local loss coefficients in the jointing point of concrete plastic pipelines of number of selected dimensions are introduced as well as the values of the friction loss coefficients for turbulent flow of water in straight plastic pipeline of a circular cross-section. These values are of a great importance for designers of pipeline systems where the above introduced thermoplastics are used.

Key words:

Local loss, friction loss, plastic pipelines, butt weld

1. Introduction

The thermoplastic pipelines are becoming a standard pipeline material. Polyethylene and polypropylene pipelines are nowadays commonly used for pressurized distribution of diverse fluids. Nevertheless, the designers of plastic pipeline systems do not have sufficient amount of complex and verified data at their disposal in order to make a reliable hydraulic calculation. The knowledge of values of the local loss coefficients in the joining points of the pipeline components in particular is very important. The specific shape of a butt weld joint has an adverse influence on the fluid flow characteristics. Neglecting the influence the joints have on the energetic balance of the system or inaccurate quantification of the local losses might in some cases have a negative effect on the optimum operation of the system due to the fact that it fails to meet the required parameters of fluid in the realized pipeline system (flow rate, pressure). Butt welding is the most common way of connecting the PP and PE pipelines in the design practice. During this process of connecting inner butt weld is created which represents a specific type of inner resistance. Further information about this welding type, shape of the butt welds created and their influence on head losses is introduced in the previous article [1]. Despite the fact that the value of the local loss coefficient ζ in etalon pipeline joint in case of 90 x 8.2 βPPH S5/SDR11 pipeline determined by measuring [1] is to a certain degree in compliance with the value computed according to the CFD method [3], the experimental determination of the local loss coefficients plays for the present an irreplaceable role. In order to obtain further data useful in the design practice additional series of measurements with reference to the initial experimental works were carried out using a new experimental test loop realized at the Faculty of Mechanical Engineering, Czech Technical University in Prague. This test loop enables quantification of local losses in joint welded PP and PE pipelines of various diameters.

2. Experimental determination of the local energy loss coefficient for the inner butt weld in the PP and PE pipeline jointing point

An experimental test loop (see fig.1) was constructed in order to assess the values of local losses for the pipeline butt weld.

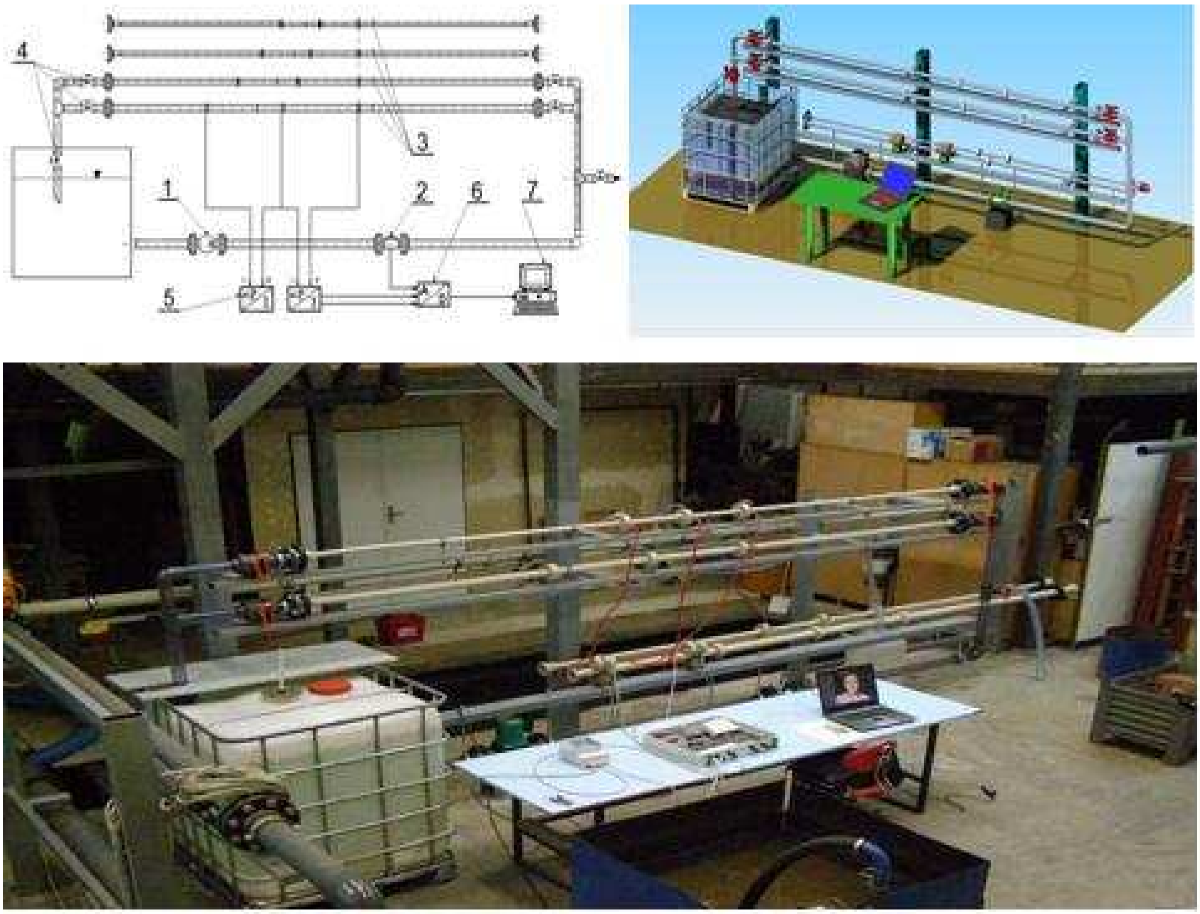

Fig. 1 *Experimental test loop for local pressure loss measurement at jointing points of plastic pipes from PP and PE materials*

Equipment scheme (above): 1 - circulating pump, 2 - magnetic flow-meter, 3 - changeable test sections of PP and PE pipeline of specific inner diameters with welded joint and circular pressure taps, 4 - flow regulation valve, 5 - differential pressure sensors, 6 - A/D conversion unit, 7 - PC

The flow rate of water through the actual test section of the experimental loop is possible to change by means of closing or eventually opening of the flow regulation valve at constant pump speed. The actual alternative horizontal test sections of the experimental loop were made of PP and PE tubes, commercially manufactured by Georg Fischer. In particular, the polypropylene-homopolymer β modification pipes (βPP-H) and PE-HD pipes of the third generation were used. Identical pipe dimensions were chosen for both materials:
DN50/PN16, 63 x 5,8 (f= 51,4mm); DN40/PN16, 50 x 4,6 (d = 40,8 mm) ; DN32/PN16, 40 x 3,7 (d = 32,6 mm) ; DN25/PN16, 32 x 2,9 (d = 26,2 mm) .

Allowed manufacturing tolerance of the external diameter and wall thickness are prescribed and must comply with the DIN 8077 standard and the ISO 4065 standard. The average value of the inner tube diameter in joints (referential diameter) and the average value of the static pressure taps *d* were determined by measurement. The tube jointing points were made by a butt welding machine according to DVS 2208/1 in compliance with the requested technological process (direction DVS 2207/1).

The way of measurement and assessment of the local energy loss coefficients in the jointing points of tubes of various dimensions remained the same as in case of the previous measurements carried out on the 90 x 8,2 βPPH S5/SDR11 (d = 72,5 mm) pipeline. For further details see [1]. The distances between the annular pressure taps at a pipeline cross-section (metering locations) in the experimental section were identical for all pipelines $l \approx 15\,d$. The length of the horizontal straight pipeline between a static pressure tap placed before the butt weld in the pipeline joint was always $l_1 \approx 5\,d$, the pipe length between the butt weld in the pipeline joint and a pressure tap behind the jointing point was always $l_2 \approx 10\,d$.

The static pressure difference Δp was measured using the calibrated differential pressure sensors with range 0 ÷ 16 kPa / 4 ÷ 20 mA. The estimated sensor accuracy was within 0.25% of the full range. The zero and span shifts were insignificant. The flow rate Q was measured using a magnetic flow-meter of type MQI 99 SMART. The accuracy 0.5% of measured flow rate was guaranteed within the range of 10 to 100% of the Q_{max} value. A mercury thermometer was used to measure the water temperature. The analogue output signals from the magnetic flow-meter and the differential manometers were compiled by a A/D converter UDAQ – 1208 and transmitted and stored into PC using a program for UDAQ - 1208 processing unit.

Inner butt weld geometry in the PP and PE pipelines welded by a butt-joint method is different in the design practice and depends on the pipeline material, the inner and external diameter of joined pipelines and in particular the exact welding techniques are important. Particular characteristic dimensions of the inner butt weld created in thermoplastic pipelines are generally shown at the schematized fig. 2. The allowed butt weld width *b* depends in particular on the wall thickness. The figure 3 shows the range of permissible PP and PE butt weld widths in dependence on the material wall thickness as prescribed by the DVS 2207 standards, volume 1 and 2. The range of permissible butt weld widths A refers to the pipeline systems that are subject to specifically high requirements (chemical industry, pharmaceutical industry and food industry). B and C range are used for systems where no specific requirements are necessary (e.g. adjacent circuits of technological operations, gas, air and water distribution networks). Rate of dependence indicated by a dot-and-dashed line corresponds to the etalon joint manufactured in compliance with the DVS 2207 instructions under the laboratory conditions. Average values of width in the monitored etalon joints *b* are indicated in the figure 3, in accordance to the fig. 4 and 5.

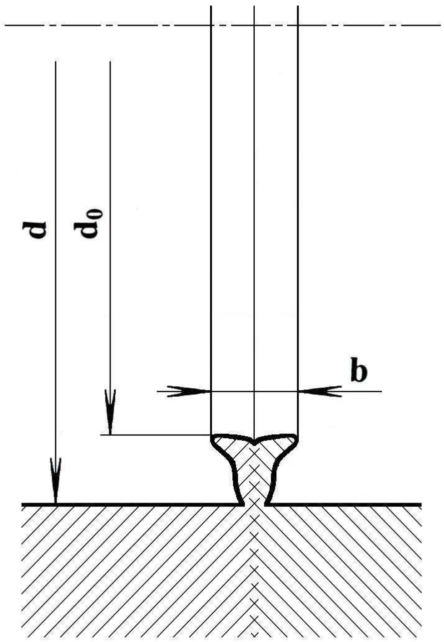

Fig. 2 *Basic dimensions of the inner butt weld in pipelines joint welded by butt fusion*

In the bottom row of the figure 4 there are cut outs from the PP pipeline test sections of the experimental loop with the etalon joints, in the upper row the joints made as comparative samples. Corresponding joint points were made by the same attendant using the identical welding equipment in compliance with the requested production process, the exact prescribed times were met as well as the heating temperature and the adherence pressure size. Yet, the different shape of the inner butt weld is apparent.

Fig. 5 shows the butt welds in the PE pipeline joints made likewise by identical attendance using identical welding machine and according to the process prescribed by the direction for welding of polyethylene. The shape of the inner butt welds in the PE pipelines of even dimensions is different as well, hence, they do not differ as much as in case of the PP pipelines.

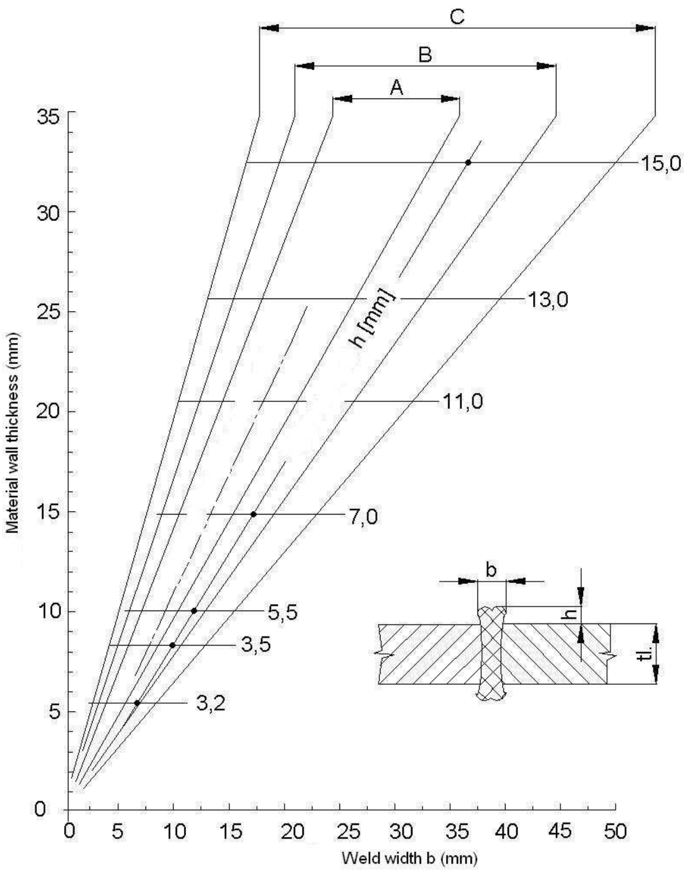

Fig. 3 *Permissible width of the inner butt weld joint of PP and PE pipes according to direction DVS 2207*

Given the experience from the design practice, we can conclude that the bigger the inner pipeline diameter, the more regular shape the inner butt weld has, whereas the PE tube projections have more rounded edges than it is the case in the PP tubes.

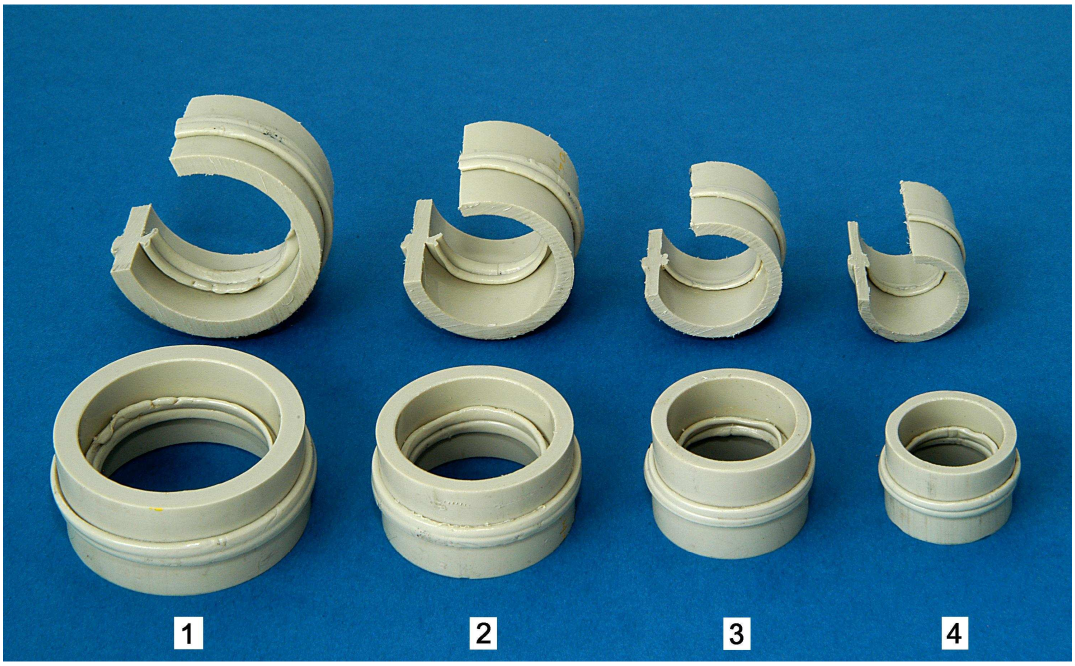

Fig. 4 *Shapes of the inner butt welds in the PP pipeline joints*
1 - 63 x 5,8 ; 2 - 50 x 4,6 ; 3 - 40 x 3,7 ; 4 - 32 x 2,9

***Fig. 5** Shapes of the inner butt welds in the PE pipeline joints*
1 - 63 x 5,8; 2 - 50 x 4,6; 3 - 40 x 3,7; 4 - 32 x 2,9

The tube inner diameter *d* represents a critical measure, as well as the width of the butt weld *b* and the relationship between diameters d_0/d are of a great importance for the more general relevance of the experimentally assessed values of the coefficients ζ. Table 1 shows average values of the selected etalon joints and d_0/d relation values. Approximately 10mm from the inner butt weld the inner diameter of the pipeline $d*$ was ascertained by measuring, that means probably in the zone influenced by the welding process. In addition, the table 1 also states the range of the Reynolds numbers and corresponding range of mean flow velocities *c* at which the measurement was carried out. These values are referred to the diameter *d*. The range of the Reynolds numbers was chosen particularly with regard to the mean velocity of fluids in the plastic pipeline systems used in the practice in order to prevent flow from high flow velocities that could result in cavitation.

***Table 1** Selected referential dimensions of the etalon joints in PP and PE tubes*

PN	16							
DN	50		40		32		25	
Tube	63 x 5,8		50 x 4,6		40 x 3,7		32 x 2,9	
Sample number	1		2		3		4	
Material	PP	PE	PP	PE	PP	PE	PP	PE
d [mm]	51,4		40,8		32,6		26,2	
$d*$ [mm]	50,6	51,4	40,3	40,5	32,3	32,6	26,1	26,1
d_0 [mm]	44,3	43,9	33,6	34,4	25,6	24,6	22,5	21,5
d_0/d [1]	0,862	0,854	0,823	0,843	0,785	0,754	0,858	0,820
$d_0/d*$[1]	0,875	0,854	0,834	0,849	0,792	0,754	0,846	0,823
b [mm]	8,5	8,0	7,6	5,8	6,4	4,8	5,0	3,9
Re [1]	53 000 - 225 000		45 000 - 225 000		30 000 - 200 000		50 000 - 150 000	
c [$m \cdot s^{-1}$]	1,04 – 4.42		1,11 – 5.57		0,95 – 6.20		1,92 – 5,78	

Mutual comparison of the joints shows that in case of the PE pipeline shapes of the inner butt welds is more regular than in the PP pipelines; the projections have more rounded edges and their characteristic diameters introduced in fig. 2 are more definite and better measurable. More favorable value of melt flow rate results in more regular shape of the butt weld in the PE tubes. PPH material is the worst out of the three manufactured types of PP (PPB, PPR, PPH) in terms of its melt flow properties (it had the highest melt flow rate value). Prediction of the possible shape of the inner butt welds in pipelines of various diameters for a given material cannot be precise with respect to the impossibility to ensure completely identical welding conditions (in particular thermal) due to the variable conditions and random influences that play role in the practice. Non-alignment of joint connected pipes represents another restrictive factor for generalization; its amount is dependent on a number of additional factors. Stochastic model and its creation would mean significant time and financial costs and outputs would probably fail to be reliable anyway. Therefore it is important to bear in mind that particular simplifications have to be adopted in connection with the description of inner butt welds geometry necessary for both generalization of the measured values and especially for prospective use of CFD methods (Computational Fluid Dynamics) and possibilities it offers.

Hydraulic losses for fluid flow in the pipeline under velocity c (m. s^{-1}) can be expressed in the form of fluid specific energy Y_z (J. kg^{-1}), that is being consumed in particular due to friction losses in straight pipeline sections and local losses. The concrete values of Y_z are determined by computation from the measured values of pressure difference (pressure loss) between two following pressure taps Δp_1 (Pa) a Δp_2 (Pa) placed in the flow direction. The Darcy-Weisbach equation is used for fluid specific energy $Y_{z\,tř}$, that means energy of fluid of density ρ (kg. m^{-3}) lost due to friction in straight pipeline with the length l (m) without inner butt weld.

$$Y_{z\,\text{tř}} = \frac{\Delta p_1}{\rho} = \lambda \cdot \frac{l}{d} \cdot \frac{c^2}{2} \qquad (1).$$

The friction loss coefficient λ (1) is in case of developed turbulent flow of Newton fluid in hydraulically smooth straight pipeline dependant only on the Reynolds number Re (1) can be computed according to the following formulas, in most cases named after their authors. Usually the Blasius formula is used, one of the wide range of formulas published in the professional literature:

$$\lambda = 0{,}3164 \cdot \mathrm{Re}^{-0{,}25} \qquad (2),$$

or formula given by Advani:

$$\lambda = 0{,}0032 + 0{,}221 \cdot \mathrm{Re}^{-0{,}237} \qquad (3),$$

formula by Mach, published in [5]:

$$\lambda = 0{,}738 \cdot \frac{d^{0{,}068}}{\mathrm{Re}^{0{,}3}} \qquad (4),$$

formula given by Ševelev:

$$\lambda = \frac{0,288}{\mathrm{Re}^{0,226}} \qquad (5),$$

The Reynolds number in case of flow of fluid of the kinematic viscosity ν (m^2. s^{-1}) at a given pipeline that has circular cross-section with inner diameter *d* (m) and which is filled by fluid can be computed from the following equation:

$$\mathrm{Re} = \frac{c \cdot d}{\nu} \qquad (6).$$

The calculation of the mean velocity *c* (m. s^{-1}) was carried out according to the flow rate *Q* (m^3. s^{-1}) using the continuity equation for steady one dimensional flow. In the course of measurements only the fluid density and the kinematic viscosity of water and their dependence on the temperature *t* (°C) were taken into consideration.

The validity of formula (2) is usually given in literature for the range of the Reynolds numbers $2300 < \mathrm{Re} \leq 100\,000$, but for $4000 < \mathrm{Re} \leq 200\,000$ too. Formula (3) is usually valid in the range $20\,000 < \mathrm{Re} < 80\,000$, but as well as for $60\,000 < \mathrm{Re} < 10^8$, in the case of formula (4) up to Re = 200 000.

Pressure loss caused by the inner butt weld projection can be expressed as follows:

$$\Delta p_\mathrm{S} = \Delta p_2 - \Delta p_1 \qquad (7).$$

The common formula can be used for the computation of local loss in a given pipeline joint $Y_{\mathrm{z\,S}}$:

$$Y_{\mathrm{z\,S}} = \zeta \cdot \frac{c^2}{2} = \frac{\Delta p_\mathrm{S}}{\rho} \qquad (8),$$

where ζ (1) is the basic local loss coefficient of the joint:

$$\zeta = \frac{2 \cdot \Delta p_\mathrm{S}}{\rho \cdot c^2} \qquad (9).$$

The fig. 6 shows the comparison of the computed values of the friction loss coefficient λ from equations (2), (3) and (4) for given dimensions of the PP and PE pipelines with the values λ calculated from the equation (1) according to the measured values of pressure differences Δp_1 in the test section of the loop with the length *l* valid for concrete Reynolds numbers.

Fig. 7 shows the experimentally determined values of the basic local loss coefficient ζ in the PP and PE pipeline joints computed according to the equation (9) in dependence on the Reynolds number.

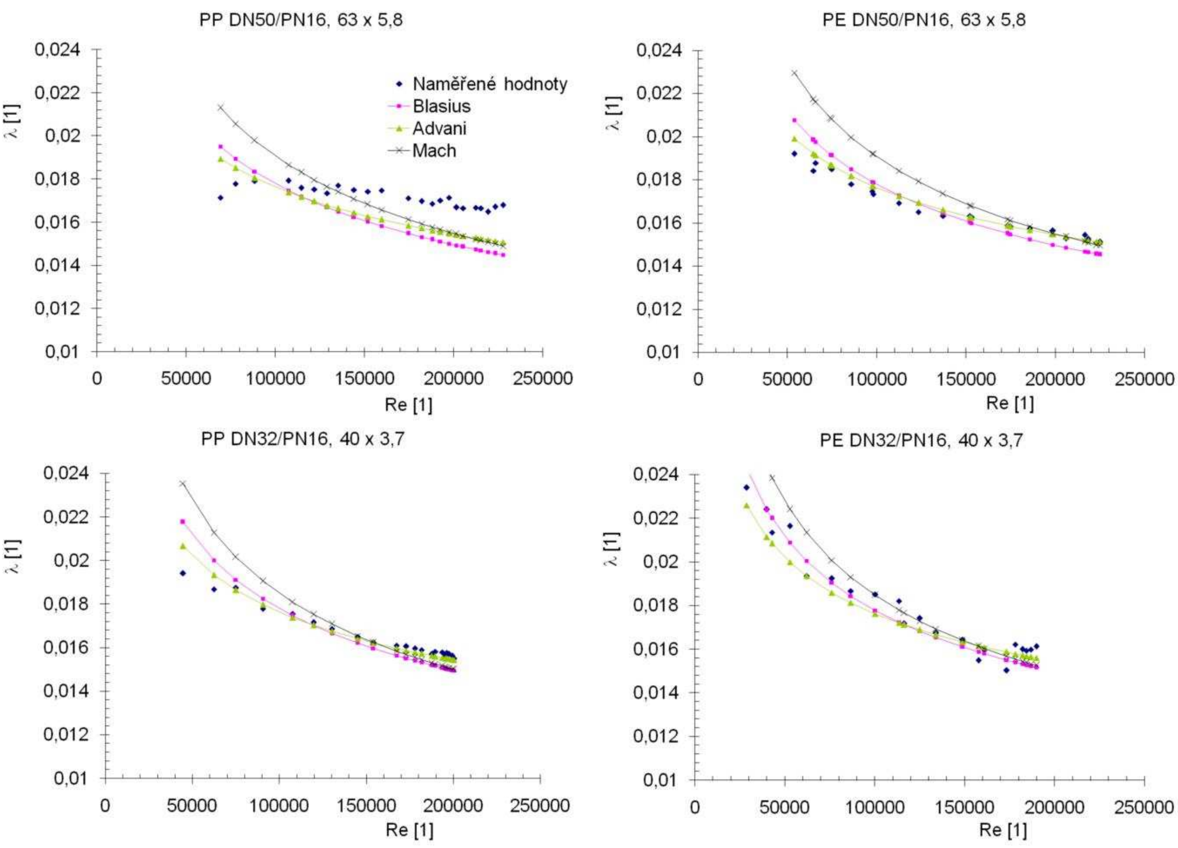

Fig. 6 *Comparison of dependency of the friction loss coefficient on the Reynolds number $\lambda = f\,(Re)$ computed according to the Blasius, Advani and Mach equations with dependency of $\lambda = f\,(Re)$ computed from the Darcy-Weisbach equation;*

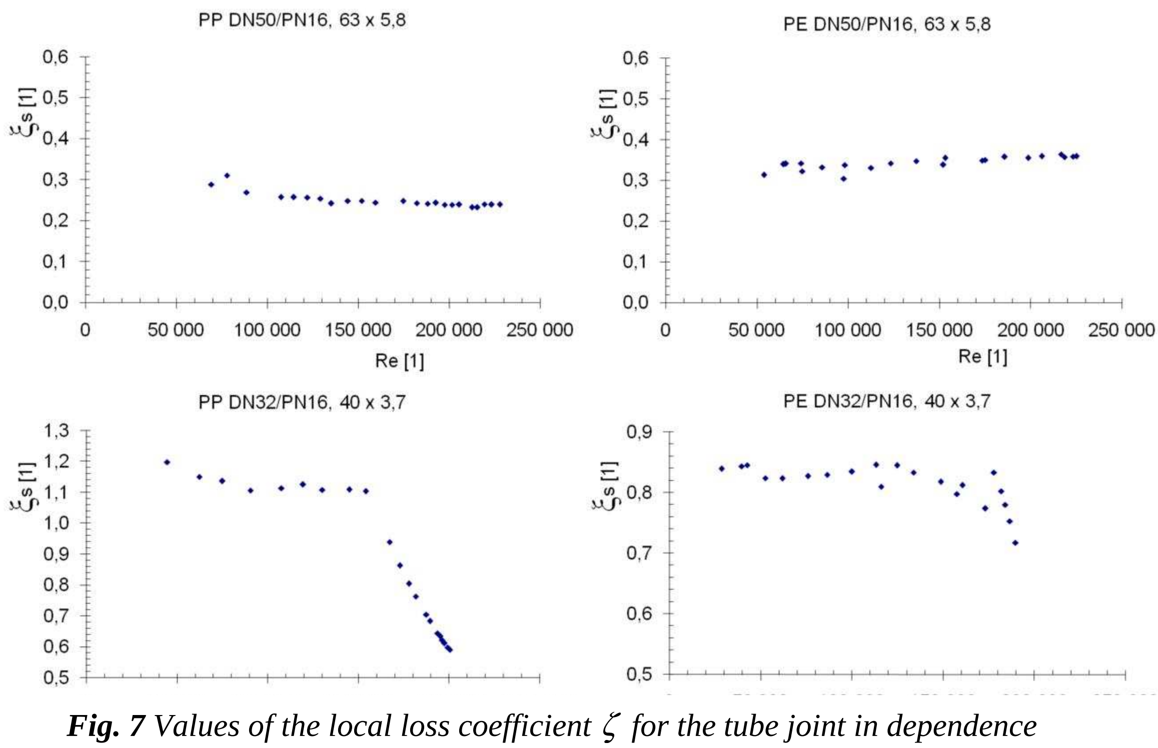

Fig. 7 *Values of the local loss coefficient ζ for the tube joint in dependence on the Reynolds number; PP - left, PE - right*

The points on fig. 6 and 7 represent the average measured and computed values. Fig. 6 illustrates a relatively good agreement between the experimentally determined values of the friction coefficient λ and the values computed from the Advani equation. The PP and PE tubes do not have the same hydraulic characteristics as the hydraulically smooth pipelines within the above-mentioned range of the Reynolds numbers (in accordance with the Blasius equation).

The value of the local loss coefficient of the joint ζ within the corresponding range of the Reynolds numbers was ascertained as practically constant in the case of tubes of the following dimensions: 63 x 5,8 and 50 x 4,6. In the case of tubes with a smaller inside diameter there occurred a sharp fall of the coefficient ζ from a particular value of the Reynolds numbers. This could be due to the change in the flow pattern in the neighborhood of the butt weld at higher flow velocities, or eventually due to cavitation. Table 2 shows the approximate ascertained values of the local loss coefficients ζ for the joints of given dimensions in the range of the Reynolds numbers, where $\zeta \approx$ constant.

Table 2 *Local loss coefficients for the PP and PE tube joints*

PN	16							
DN	50		40		32		25	
Tube	63 x 5,8		50 x 4,6		40 x 3,7		32 x 2,9	
Material	PP	PE	PP	PE	PP	PE	PP	PE
*d*0/*d* [1]	0,862	0,854	0,823	0,843	0,785	0,754	0,858	0,820
b [mm]	8,5	8,0	7,6	5,8	6,4	4,8	5,0	3,9
ζ [1]	0,25	0,35	0,54	0,41	1,12	0,84	0,98	0,85
Re [1]	53 000 - 225 000		45 000 - 225 000		30 000 - 200 000		50 000 - 150 000	

3. Conclusion

In the past, it has already been proved [5], that the PE pipelines, for example, do not have the same hydraulic characteristics at low Reynolds numbers as the hydraulically smooth pipeline in accordance with the Blasius equation. This is in compliance with the finding referring to the PE tubes of the 40 x 3,7 diameter, where the ascertained values of the coefficient λ in the range of the Reynolds numbers Re = 50000 – 100000 comply with the values computed from the equation (4). Currently as well as in the case of the measurements carried out in the past [1], [2], relatively good agreement between the experimentally determined values of the friction coefficient λ and values computed in accordance with the Advani equation was found. The reason for the difference between the measured course of dependence $\lambda = f(Re)$ and dependence computed according to the Blasius equation can lie in the uneven wettability of fluid on the plastic and copper tubes, or can be due to various adhesive forces causing adhesion of fluid to the tube surface [6].

The article further introduces experimentally determined values of the local loss coefficient for the inner butt weld in the PE and PE pipelines joint connected by butt-welding. Considering the possible expansion of the inner but weld width b when d = const a d_0/d = const, the general dependence of the value of the coefficient ζ on the but weld dimensions valid for a large scale of the PP and PE tube dimensions cannot be determined for the present. In case of the pipelines joint welded by butt fusion with the growing inner diameter of the joint d, the value of d_0/d ratio falls. The hypothesis saying that in case of PP and PE tubes the bigger diameter *d* is, the smaller the coefficient ζ gets, in not in conflict with the measured values. The value of ζ grows with the decreasing diameter *d* and at the same time the difference between coefficient ζ for PP pipelines and for PE pipelines increases, the value of the coefficient for PP pipelines ζ gets bigger than it is the case for PE pipelines. The values of the local loss coefficients for concrete joints given in the table 2 have been quantified for the first time in the course of the measurements. The size of the coefficients ζ is directive, because in the practice the shape of the inner butt weld can differ from the measured one, even though they are both in compliance with the direction DVS 2207.

Nowadays the CFD technology (e.g. programs such as Fluent and Gambit) makes it possible to create a pipeline flow model in the place of butt weld in the PP and PE tubes and helps to predict potential energy loss. These devices enable graphical evaluation of flow in the place of intake of the flow cross-section on the basis of the butt weld geometry, networking an assessment of border conditions. Coefficient ζ determined by means of mathematical flow simulation in the place of the inner butt weld in the 90 x 8,2 βPPH S5/SDR11 pipeline was in compliance with the value assessed experimentally [3], [4].

Acknowledgement

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Nomenclature

b	butt weld width	[m, mm]
c	flow velocity	[$m\cdot s^{-1}$]
d	pipe diameter	[m, mm]
DN	diameter nominal	[-]
h	butt weld high	[m, mm]
l	pipe length	[m, mm]
p	static pressure	[kPa, Pa]
PE	polyethylene	[-]
PN	pressure nominal	[-]
PP	polypropylene	[-]
Q	flow rate	[$m^3\cdot s^{-1}$]
Re	Reynolds number	[1]
t	temperature	[°C]
tl.	thickness	[m, mm]
Y	fluid specific energy	[$J\cdot kg^{-1}$]
Δy	cavitation	[$J\cdot kg^{-1}$]

λ	friction loss coefficient	[1]
ν	kinematic viscosity	[$m^2 \cdot s^{-1}$]
ρ	density	[$kg \cdot m^{-3}$]
ζ	local loss coefficient	[1]
Δ	difference	[-]
η	efficiency	[%]

Index

c	total
č	pamp
i	inner
P	pipe
pož	required
S	joint
st	static
tř	friction
*	measured
0	

References

[1] MELICHAR, J., HÁKOVÁ, J., VESELSKÝ, J., MICHLÍK, L. Místní energetická ztráta spoje plastového potrubí, zhotoveného svařováním na tupo. *Vytápění, větrání, instalace*, 2006, roč. 15, č. 15 – 18.

[2] MELICHAR, J., HÁKOVÁ, J., VESELSKÝ, J., MICHLÍK, L. Local Head Loss of Plastic Pipeline Joint Welded by Butt Fusion. *Journal of Hydrology and Hydromechanics*, 2006, roč. 54, č. 3, s. 299 – 308.

[3] VESELSKÝ, J. Local loss of plastic pipeline joint welded by butt fusion. In: Power system engineering ES 2007, Plzeň 2007

[4] VESELSKÝ, J., MELICHAR, J. Místní ztráta spoje plastového potrubí, spojovaného svařováním na tupo. In: Strojné inžinierstvo 2007 - mezinárodní konference. Bratislava: STU, 2007, CD

[5] MACH, V. Tlakové ztráty třením v polyetylenových trubkách. *Zdravotní technika a vzduchotechnika*, Praha: ČSAV, 1964, č. 6. s. 250 – 259.

[6] POCHYLÝ, F., aj. Smáčivost kapalin vůči pevným povrchům. Brno: VUT v Brně, 2006, Výzkumná zpráva