Stanovení tlakové ztráty spoje polyetylénového potrubí zhotoveného svařováním na tupo
Determination of pressure loss in butt fusion joints of polyethylene pipeline

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Abstrakt
Plastové materiály v potrubní technice jsou dnes již velmi často používaným materiálem, přesto se stále vyskytuje jejich nesprávné použití. Důvodem je nedostatek komplexních a ověřených podkladů nutných pro spolehlivý hydraulický výpočet. V příspěvku je uveden popis chystaného experimentálního měření, při kterém bude zkoumána velikost místní ztráty ve spoji polyetylénového potrubí svařovaného metodou na tupo. Právě tato ztráta na rozdíl od ocelového potrubí může v plastovém potrubí významně ovlivnit celkovou charakteristiku potrubního systému.

Klíčová slova
Místní ztráta, třecí ztráta, plastové potrubí.

Abstract
Plastic materials are nowadays frequently used type of materials in hydraulic piping systems. The plastic materials in piping systems are still used improperly due to the lack of comprehensive and verified data necessary for the reliable hydraulic calculation. In this article is included a description of the planned experimental measuremen where local head loss in plastic pipe joint welded by butt fusion will be determined. Local head loss in the plastic pipe can significantly affect the overall characteristics of the piping system.

Keywords
Local head loss, plastic pipelines, butt fusion.

1. Introduction

Plastic piping is the material that has the widest range of applications. Plastic piping includes many materials that have significant differences in characteristics and uses. It is important that the correct plastic material be specified for the various applications.
Each project is different and can have unique conditions. A design or installation necessity for one project might be excessive for another project. The ways the engineer and designer interpret and approach the various conditions are important to achieve an effective and efficient project. The proper design and installation of plastic piping systems require the use of sound engineering judgment and principles [1].

2. Plastic piping materials

Thermoplastic is one of the most used material for plastic pipelines and has the widest range of application. On this account this article is mainly focused on this type of material. In Fig. 1 is shown historical growth of thermoplastic material shipment in North America.

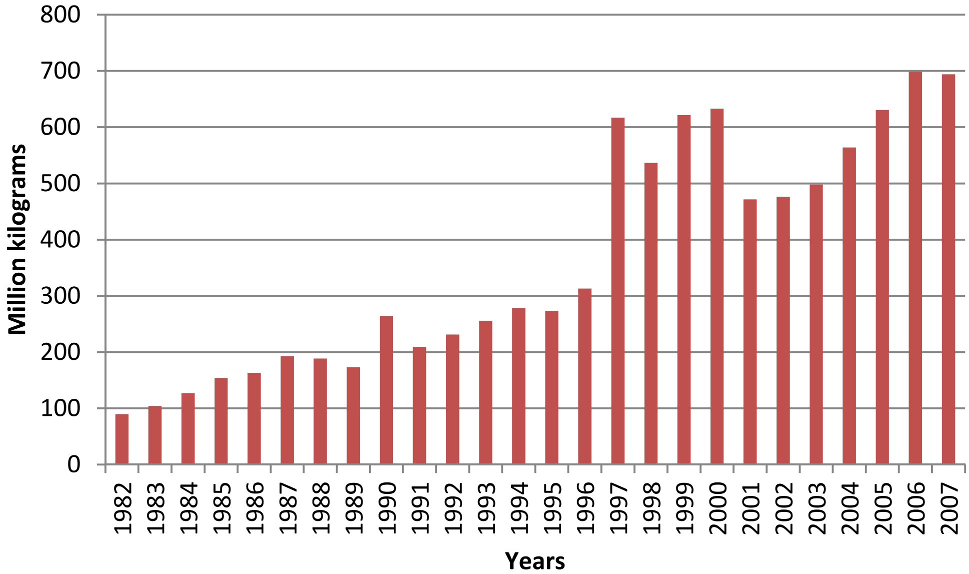

Fig. 1 *Historical growth of polyethylene shipment in North America [2].*

2.1. Major features and benefits of plastic pipe

Plastic pipe is used in a variety of commodities such as acid solutions, chemicals, corrosive gases, corrosive waste, crude oil, drainage, fuel gases, mud, sewage, sludge, slurries, and water. One major reason for the growth in the use of plastic pipe is the cost savings in installation, labor, and equipment as compared to traditional piping materials. Add to this the potential for lower maintenance costs and increased service life and plastic pipe is a very competitive product [1].

On the other hand there are many limitations in using plastic for piping system. In comparison with other piping material, plastic has lower strenght and temperature resistance. Also thermal expansion of plastic material is not indispensable. Because of these limitations, thermoplastic piping materials have been used mainly in low-pressure applications with low temperature limits. Major features and benefits are shown in Fig. 2.

Features and Benefits	**Disadvantages**
Corrosion & Chemical Resistance Fatigue Resistance and Flexibility Seismic Resistance Durability Ductility Leak Free Joints Ease of handling Variety of joining methods	Low strenght Thermal expansion Temperature Resistance Fire resistance

Fig. 2 *List of major features and disadvantages of PE pipe.*

Some of the other common uses of plastic piping are:
Natural gas
Municipal aplication
Chemical processing
Food processing
Power plants
Sewage treatment
Water treatment
Plumbing
Home fire and lawn sprinkler systems
Irrigation piping

3. Difficulties with improperly designed plastic piping system

The knowledge of correct values of friction and local loss coefficients is important for the designers of pipeline systems that consist of straight plastic pipes and constructional elements. Sufficient amount of experimental data is important for correct determination of losses. The precise evaluation of losses enables to obtain the required fluid operation parameters in the system (flow rate, pressure) and can markedly affect the optimum operation in long or complex pipeline conduits [3].
A number of problems were occured recently during the operation of plastic pipe system caused by improper hydraulic design. Typical problem in operation of long pipe conduits in power plants are unsatisfactory flow and pressure due to higher pressure loss along the pipeline. Incorrect calculation of hydraulic losses in the piping system and hence undersized pump stations caused the result parameters were below required. Piping system which is not operated in optimum condition is economically disadvantageous. Globally piping system can significantly affect the overall efficiency of whole energy unit.
Designers of pipeline systems still do not have sufficient comprehensive and verified data for reliable hydraulic calculation. The local head loss in plastic pipeline joint welded by butt fusion is nowadays topical issue. Due to the recent problems in practise during operation of plastic piping system, designers often required accurate and verified data of local head loss of joint. Precise data are necessary for proper design of plastic piping system.

4. Local head loss in plastic pipeline joint welded by butt fusion

When a fluid is transported inside a pipe, the pipe's inside diameter determines the allowable flow rate. Several factors might cause the energy loss in a piping system, with the main cause friction between the fluid and the pipe wall. Liquids in the pipe resist flowing because of viscous shear stresses within the fluid and friction along the pipe walls. This friction is present throughout the length of the pipe. As a result, the energy grade line and the hydraulic grade line drop linearly in the direction of flow. Flow resistance in pipe results in a pressure drop, or loss of head, in the piping system.
Localized areas of increased turbulence and disruption of the streamlines are secondary causes of energy loss. These disruptions usually are caused by valves, meters, or fittings and are referred to as minor losses. When considered against the friction losses within a piping system, the minor losses often are considered negligible and sometimes are not considered in an analysis. While the term minor loss often is applicable for large piping systems, it might not always be the case. In piping systems that have numerous valves and fittings relative to the total length of pipe, the minor losses can have a significant impact on the energy or head losses [1].

One of the often neglected energy loss is a loss of joint in butt welded pipeline system. Besides classical and standard connecting components for tube connections (e.g. flanged connection, screwed fitting) in particular glue connecting (eventually chemical welding while cold) and thermal welding methods are used.
Butt-welding is the most common, most simple and most reliable way of connecting pipes for long pipeline conduits from polyethylene and polypropylene materials. During this process of connecting, which consists of warming-up and melting the ends of elements prepared for the connection and following their pressing down, the inner roughness – the emanation of the material inside pipeline is created (Fig. 3) [3].

Fig. 3 *The thermoplastic pipeline joint welded by the butt-welding method*

The size of a butt weld joint is for certain material and wall thickness dependent on the welding process. The exact welding techniques are recommended for example by instructions of DVS (Deutscher Verband für Schweisstechnik). The inner butt weld in the tube represents the specific kind of inner resistance and results in additional losses of the fluid flow. The effect of local losses caused by butt welds on total energy balance for long pipelines is important. However, in design practice it is often underestimated or neglected.
Insufficient amount of information for the determination of a local loss coefficient ζ for the butt weld with a projection is the main problem in design practice. Experimental works in the Czech Technical University in Prague, Faculty of Mechanical Engineering were carried out in order to obtain quantitative values that provide more accurate assessment of the local losses for butt welds in jointing point of plastic pipe from materials. The main aim of research was to determine the fundamental data on the local losses that should be usable in design practice [3].

5. Pipe joining procedure

Common methods for the joining of thermoplastic pipe for liquid are heat fusion, threading, flanged connections, grooved joints, mechanical compression, flaring etc. In selecting a joining method for liquid process piping systems, the advantages and disadvantages of method should be evaluated and the manner by which the joining is accomplished for each liquid service should be specified. Recommended procedures and specification for these joining methods are found in codes, standards and manufacturer procedures for joining thermoplastic pipe [1].

5.1. Thermal Heat Fusion Methods

There are three types of conventional heat fusion joints currently used in the industry; Butt, Saddle, and Socket Fusion. Additionally, electrofusion joining is available with special couplings and saddle fittings. The principle of heat fusion is to heat two surfaces to a designated temperature, then fuse them together by application of a sufficient force. This force causes the melted materials to flow and mix, thereby resulting in fusion. When fused according to the pipe and/or fitting manufacturers' procedures, the joint area becomes as strong as, or stronger than, the pipe itself in both tensile and pressure properties and properly fused joints are absolutely leak proof. As soon as the joint cools to near ambient temperature, it is ready for handling [2].

Butt Fusion

The most widely used method for joining individual lengths of PE pipe and pipe to PE fittings is by heat fusion of the pipe butt ends as illustrated in Figure 4.

Fig. 4 *A standard butt fusion joint [2].*

This technique produces a permanent, economical and flow-efficient connection. Quality butt fusion joints are produced by using trained operators and quality butt fusion machines in good condition.

Optional Bead Removal

In some pipe systems, engineers may elect to remove the inner or outer bead of the joint. External, or both beads are removed with run-around planing tools, which are forced into the bead, then drawn around the pipe. Power planers may also be used but care must be taken not to cut into the pipe's outside surface. It is uncommon to remove internal beads because removal is time-consuming. Internal beads may be removed from pipes after each fusion with a cutter fitted to a long pole. Since the fusion must be completely cooled before bead removal, assembly time is increased [2].

6. History of measurement of local head loss in plastic pipeline at Czech Technical University

At the Faculty of Mechanical Engineering proceed long term research in determining local head loses in plastic pipeline. During this time there were realized many measurement of specific local head loss polyethylene and polpropylene pipeline. In laboratory was realized measurement of pipe nominal dimension in range DN32 to DN80.

Results from experimental measurement has been published in international journals [3, 4, 5]. Based on the requirements of design companies, it is necessary to extend the obtained data to the pipe with a larger diameter. Equipment of the laboratory of mechanical engineering allows us to extend the experimental measurement up to nominal pipe dimension DN250.

7. Design of an experimental measurements

Local head loss of plastic pipe joints should be determined from the difference of static pressures measured at point 1 and 2 (Fig. 5). The pressure drop measured between section 2 and 3 is necessary for determination of friction loss along the pipe [3].
The proposed experiment has several basic phases. In the first phase of the eperiment the test circuit consisting of a plastic pipeline of nominal dimension DN150 will be build.
The hydrodynamic pump powered by an asynchronous electric motor provides flow of water through pipeline. The hydrodynamic pump is conected to the existing water reservoir at the laboratory. The flow rate through measuring part of the pipe is possible to change by alternation of the pump rotation speed through frequency converter with full open regulation valve situated in the end of the test circuit or by closing and/or opening of the valve at constant pump speed [3]. The basic scheme of the test circuit is shown in Fig. 5.

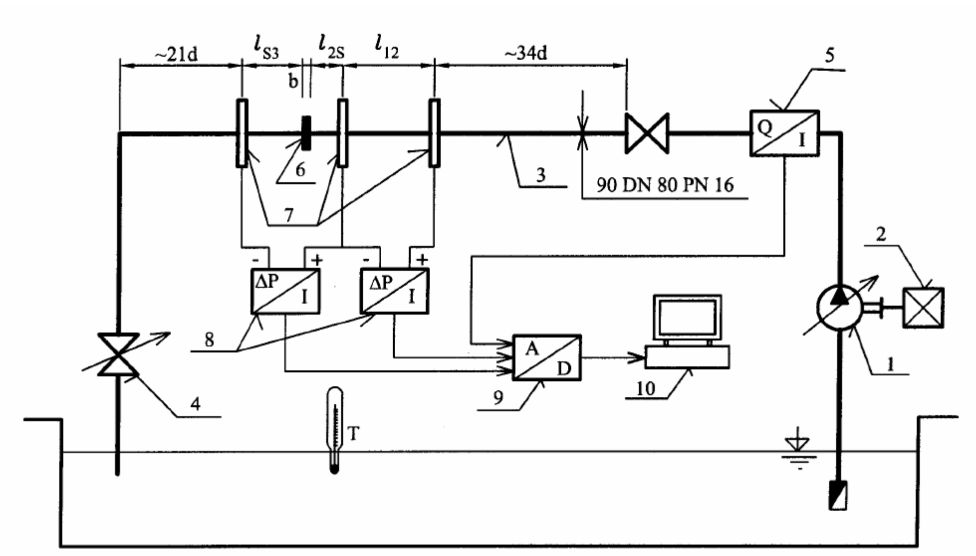

Fig.5 – Basic scheme of experimental test circuit [3]: 1- hydrodynamic pump, 2- electromotor with frequency converter, 3- βPP-H pipeline, 4- flow regulation valve, 5- magnetic flow-meter, 6- butt welded joint, 7- pressure taps for static pressure, 8- differential pressure sensors, 9- A/D conversion unit, 10- PC [3].

The test section of the circuit is composed of the proper metering pipe length sufficient straight pipeline length before and behind the jointing point where the influence of jointing point on flow pattern is anticipated. In front of this measuring section there is a straight pipeline with the corresponding length due to stabilization of the flow. The static pressure differences, Δp_{12} is measured with the use of calibrated differential pressure sensors. The flow rate, Q, is measured using magnetic flow meter. The mercury thermometer was used to measure the water temperature. The analogue output signals from the magnetic flow meter and the differential manometers are compiled by A/D converter [3]. Detailed design of the experimental arrangement is in fig. 6.

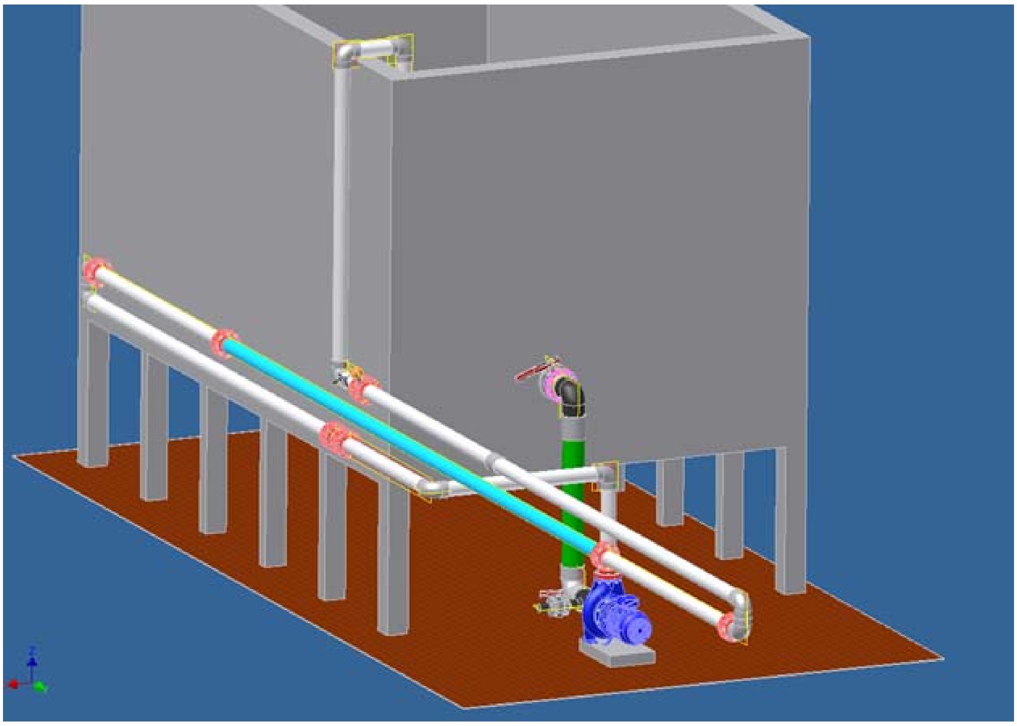

Fig. 6 *3D view of the experimental arrangement.*

In the next phase the experimental test circuit will be extended for measuring plastic pipe of nominal dimension DN200 and DN250. The experimental test arrangement is designed so that it can be effectively extended as needed.
After that in next phase the experimental test circuit will be subsequently expanded for other experiments. The aim is to determine pressure loss of plastic piping components such as elbows, expansion joints, reducers, fittings etc.
Obtained data will be compared with computational model using CFD calculation. Based on the obtained data, the determination of pressure loss of plastic pipe components of larger nominal pipe size will be possible.

8. Calculation of local head loss from measured values

The head loss generated at the joint of straight pipeline (local loss) is given by an increase of theloss at the straight pipeline section with given local loss against frictional loss at the same system without local loss. The head losses can be expressed in terms of fluid specific energy Y_z (J kg^{-1}), which is consumed in a given pipeline section. The concrete values of Y_z are determined by computation from the measured values of pressure difference, Δp_{12} and Δp_{23}. Along the straight pipeline length between cross sections 1 and 2 the pressure drop through the frictional losses can be computed from the Darcy-Weisbach equation

$$Y_{zf} = \frac{\Delta p_{12}}{\rho} = \lambda \cdot \frac{l_{12}}{d} \cdot \frac{c^2}{2} \qquad (1)$$

The friction factor λ in the case of turbulent flow in hydraulically smooth straight pipeline depends only on Reynolds number. For this type of flow it is possible to use a number of formulas. Usually, the Blasius formula is used

$$\lambda = 0.3164 \cdot Re^{-0.25} \qquad (2)$$

or formula given by Advani

$$\lambda = 0.0032 + 0.221 \cdot Re^{-0.237} \qquad (3)$$

where Reynolds number is

$$Re = \frac{c \cdot d}{\nu} \qquad (4)$$

The continuity equation for steady one dimensional flow can be used for the calculation of mean velocity c at a given pipeline that has circular crosssection and which is filled by fluid

$$c = \frac{4 \cdot Q}{\pi \cdot d^2} \qquad (5)$$

After the substitution of Eqs. (5), (4), (2) into Eq. (1) it is possible for the above-mentioned type of flow with constant temperature to express the dependence of pressure drop through the frictional losses Δp_{12} on the flow rate Q from the following formula

$$\Delta p_{12} = \rho \cdot \nu^{0.25} \cdot \frac{0.3164 \cdot 4^{1.75} \cdot l_{12}}{2 \cdot \pi^{1.75} \cdot d^{4.75}} \cdot Q^{1.75} \qquad (6)$$

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

$$\Delta p_s = \Delta p_{23} - \Delta p_{12} \quad (7)$$

For the local loss computation in a given pipeline joint $Y_{z\,l}$ it is possible to use the common formula

$$Y_{zl} = \xi \cdot \frac{c^2}{2} = \frac{\Delta p_s}{\rho} \qquad (8)$$

where ξ is basic local loss coefficient of the joint.

The local loss coefficient ξ is for each flow rate computed from the corresponding measured values using the formulas (5), (7), (8). Since the water temperature T during the measurement was constant the following formula for the local loss coefficient ξ should be used:

$$\xi = \frac{\pi^2 \cdot d^4}{8 \cdot \rho} \cdot \frac{(\Delta p_{23} - \Delta p_{12})}{Q^2} \qquad (9)$$

In design practice it may be much easier to work with equivalent pipe length, le. This is the length of straight pipeline of the same diameter as the fitting, which would have the same pressure drop as the fitting, in our case the pipeline joint with the inner butt weld. Considering the condition $Y_{z\,f} = Y_{z\,l}$ from Eqs. (1) and (8) the equivalent pipeline length can be computed as follows [3]

$$l_e = \frac{\xi}{\lambda} \cdot d \qquad (10)$$

9. Characteristics of the proposed test circuit

Operational characteristics of the test circuit was determined by local head loses and friction along the pipe. Friction loss (coefficient of friction loss) is calculated using the equation (2). Coefficient of local head loss of common components of piping system was determined from literature and data provided by producers.
Pump characteristics was taken from the data sheet of the pump. The resulting characteristics of the hydraulic system is shown in Fig. 7. The characteristic shows a theoretical operational point in which the system will be operate.

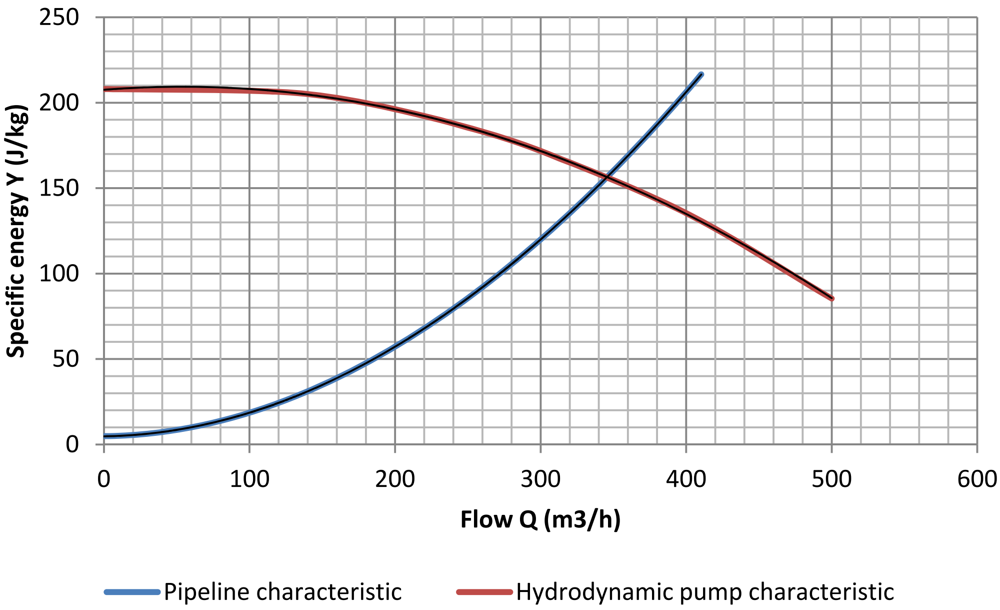

***Fig.** 7 Operational characteristics of the hydraulic system.*

Operating point of the hydraulic system
From the theoretical characteristics of hydraulic system was determined the operating point. Maximum operational flow Q, specific energy, pump hydraulic performance P and efficiency are as follows

Q_{max}= 345 m^3/h (0,0958 m^3/s)
Y_{max}=156 J/kg
P=18,5 kW
η=81%

In Fig. 8 are shown theoretically available parameters of velocity and Reynolds numbers in dependence on nominal diametr of the plastic pipe.

Nominal Diameter	Dimension	Flow velocity c (m/s)	Reynolds number Re (-)
DN100	Ø110x10	13	1167253
DN150	Ø 160x14,6	6,2	803155
DN200	Ø 225x20,5	3,13	570939
DN 250	Ø 280x25,4	2,01	458345

Fig. 8 *Theoretical maximum flow velocity and Reynolds number.*

10. Conclusion

The pressure drop along the plastic pipeline system depends on friction and local head loss components of piping system. During process of connecting plastic pipes using commonly used butt fusion method, the inner and outer beads is created. The inner beads is a specific type of local head loss. The local head loss in plastic pipe joint of plastic pipes is significant, but it is very often neglected due to lack of verified data.

The proposed experimental test arrangement allows us to obtain exact values of local head loss of butt welded joint. Measurement extend previous experimental measurements and together with computer calculations allows us to obtain complete overview about losses in plastic pipeline for wide range of nominal pipe dimension.

Nomenclature

c	mean flow velocity [$m.s^{-1}$],
d	inner pipeline diameter [m], [mm],
l	length of straight pipelines sections [m], [mm],
p	static pressure [Pa],
Q	flow rate [$m^3. s^{-1}$],
Re	Reynolds number [–],
T	fluid temperature [0°C],
Y	specific energy [$J.kg^{-1}$],
Y_z	specific energy loss[$J.kg^{-1}$],
λ	friction factor [–],
ν	kinematic viscosity [$m^2. s^{-1}$],
ρ	fluid density [$kg.m^{-3}$],
ζ	local loss coefficient [–],
Δ	difference.
η	efficiency [%]
P	hydraulic performance [W]

Index

e	equivalent,
f	frictional,
l	local loss,
s	pipeline joints,
z	loss-making,
0	at pipe contraction,
12, 23	at cross sections between marked locations

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