Hydrodynamics of "jet" type outflow from process installations
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Hydrodynamics of "jet" type outflow from process installations

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The outflow of liquids from orifices and fissures of constant width and different lengths was examined. The size of outflowing liquid as well as its range and propagation on a plane were analyzed. Results presented in the study refer to the outflow of water through fissures situated horizontally on a vertical pipeline wall.

1. Introduction

During transport of flammable or toxic materials through pipelines, there is a serious risk of damaging the transporting system. Main hazards which can occur on the areas on which pipelines lie and in their vicinity, include unsealing and "jet" type outflow. Fuel leakage can be a reason of environmental pollution of soil, air and water. Beside the environmental hazard, there is also a risk of explosions and fire.

In this situation, it is very important to assess results of a possible piping failure which might induce leakage, and first of all, to estimate the size and range of a liquid jet which flows from the damaged pipeline. A possibility to estimate these values is surely very helpful not only in the assessment of liquid and related losses in the pipeline, and in the estimation of environmental pollution on site of the failure, but also in appropriate designing of future pipelines, and in particular in setting routes along which the pipelines should be situated and determining their safe location in the existing infrastructure.

In this study we deal with the investigation of various types of wall damages in the pipelines operating under pressure and possible leakage. The outflow of liquid from orifices of different shapes and sizes was investigated with special attention focussed on the analysis of the size, range and propagation of a flowing liquid jet. The investigation was carried out using a specially constructed experimental setup which enabled testing the pipelines in horizontal and vertical system geometry. Horizontal pipelines were analyzed in this study.

2. Experimental setup

The experimental set-up is shown schematically in Fig. 1. The system consisted of a storage tank (1) which provided liquid to a high capacity screw pump (2) pumping the liquid to a measuring segment (4) equipped with an exchangeable section mounted on flanges. The orientation of this section could be changed. The exchangeable section of the installation was equipped with a flange which enabled mounting of flat covers with orifices of different shapes and cross-sections (Fig. 2). The covers were built from two spliced layers of organic glass. In one of the layers there was a tested orifice, while in the other one an orifice was made to put a fitted rubber stopper which was removed when the measurement started. Outflows from orifices with cylindrical cross section and from fissures of constant width were analyzed. The tested cylindrical orifice was 2 mm in diameter, while fissures of constant width of 1 mm, were 24.4, 64.4 mm and 90 mm long. All orifices were made by precision technique on a numerical milling machine. Organic glass in which the orifices were made, was 8 mm thick. So, the tested leakage was not from thin-wall orifices which are most often described in literature. Such wall thickness was closest to real conditions in which leakage from disrupted pipe walls could occur.
The outflowing liquid jet was directed to measuring vessels with inlets of rectangular cross-section arranged on a big plane. The measuring vessels were grouped tightly one by the other on the plane, without leaving any free space, which enabled collection of the whole liquid jet flowing out. Tightness of the vessels contact was ensured by sheet metal sections applied on the contacting edges. This method of collecting liquid jets offered a possibility of assessing their propagation on a plane.

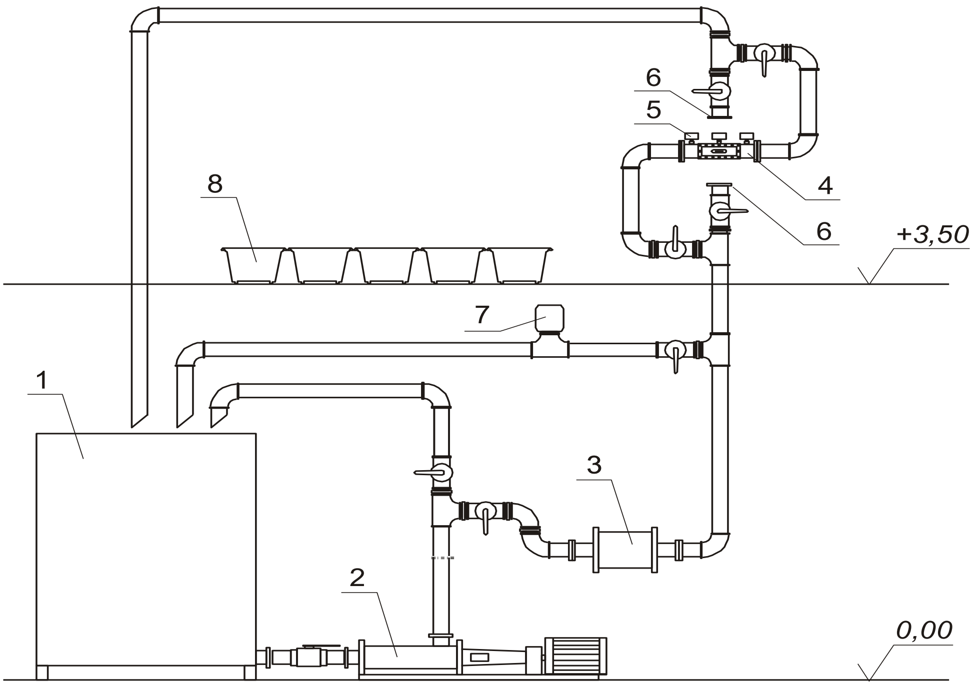

Figure 1. Schematic of the experimental setup:
1 – storage tank, 2 – screw pump, 3 – electromagnetic flowmeter, 4 – measuring section, 5 – pressure transducer, 6 – flange for vertical mounting of the measuring section, 7 – pneumatic nozzle, 8 – measuring vessels.

The time of outflow of the jet received in the measuring vessels was measured, the mass of liquid in particular vessels was determined, the jet range was specified and the size of liquid jet was assessed by the volumetric method. During the outflow, the pressure in the pipeline was also measured. Pressure measurements were taken in three points: before the outflow orifice, in the outflow orifice axis and behind the orifice. Electronic pressure transducers were used. They were connected to a computer data acquisition card. Analog signals registered by pressure sensors with sampling time of 0.01 s could be recorded. In parallel, using the electromagnetic flowmeter, the volume of liquid jet flowing in the pipe before the measuring section was measured.

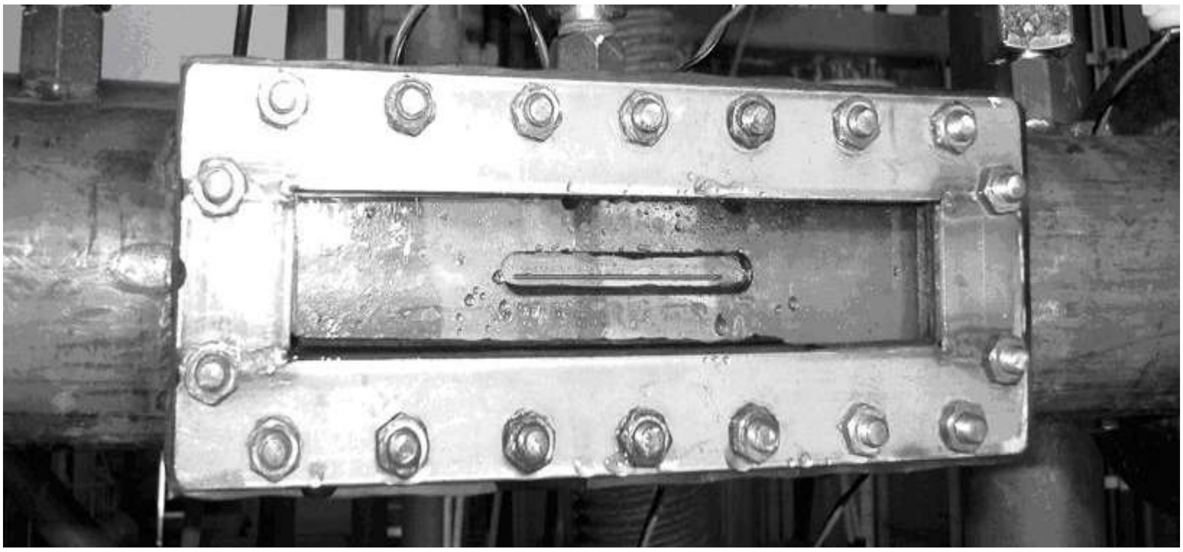

Figure 2. Measuring segment.

3. Analysis of experimental data

The observation of liquid jets confirms that their shapes and forms change with the distance from the outflow orifice. In each case one can distinguish a compact initial form of the jet, its dispersed middle part (the compact jet starts dividing into separate streams flowing one by the other) and sprayed final section, where the streams begin to disperse into separate droplets as shown in Fig. 3. In the outflow from fissures, already the initial jet flow is not an ideal undisturbed flow of a compact jet with smooth surface. Disturbances are visible on the surface – Fig. 4, but the jet is still compact and is not divided into separate streams. In the case of outflow from the fissures, there are also random changes such as torsion of the jet cross section which initially was flowing parallel to the ground surface. This is shown in Fig. 5. A white line marks jet edges in this figure.

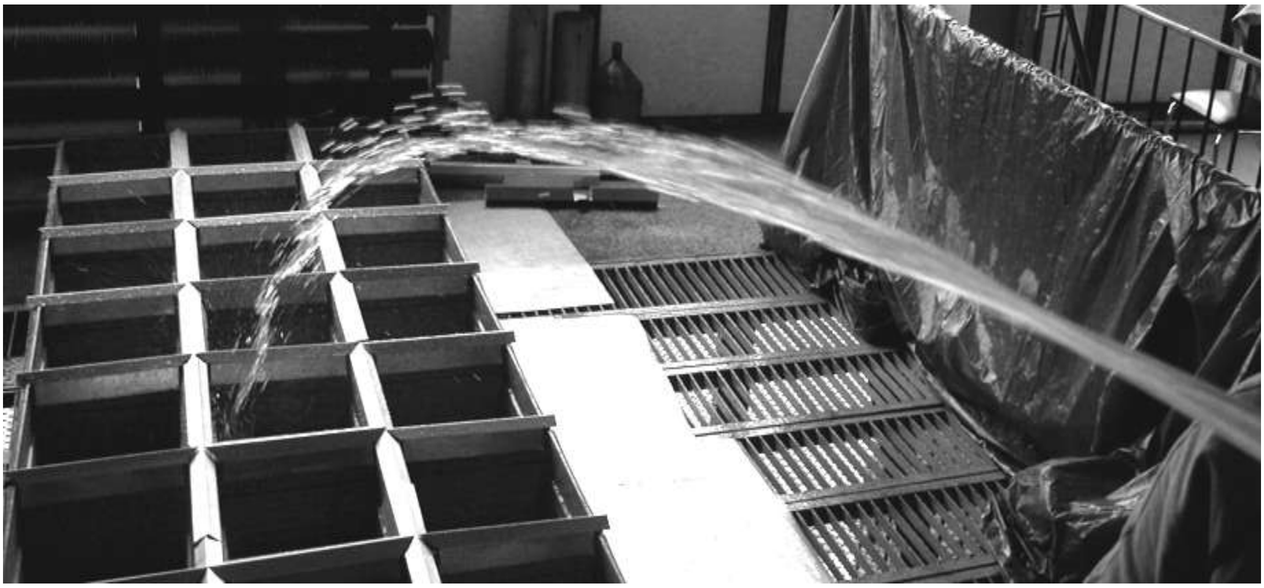

Figure 3. Outflowing liquid jet – a change of the stream form.

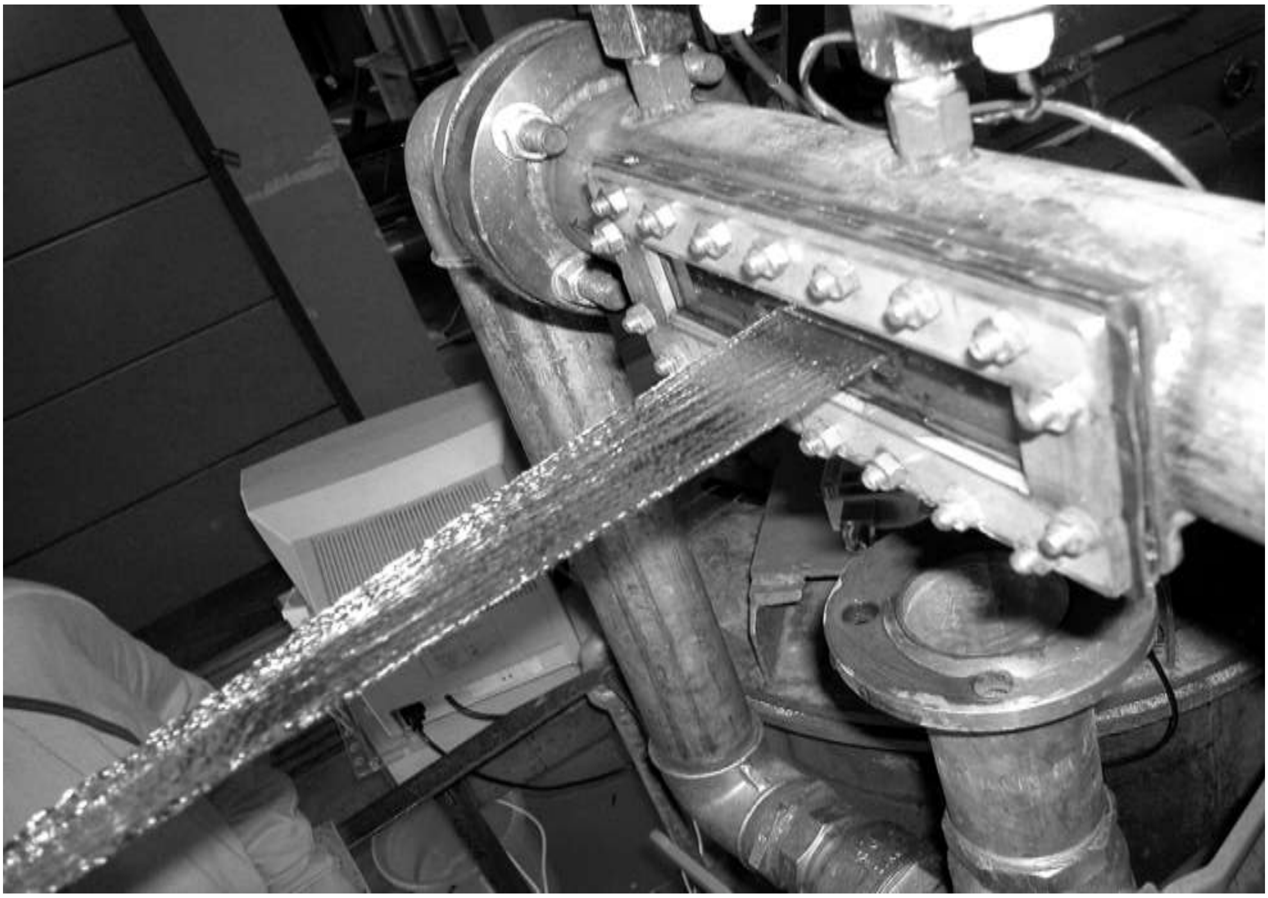

Figure 4. Initial shape of the outflowing jet.

Our investigations we were not able to collect relevant data on the dispersion of jet cross sections in its final segment. It can only be stated that in the analyzed outflows and at given heights of outlet orifices lying above the inlet to the measuring vessels and the distance of measuring vessels to the outflow plane, the surface of transverse cross section of the jet end was changing dozen times, and in some cases even several hundred times in relation to the outlet orifice surface. Detailed data will be available after the analysis of outflows recorded by cameras located on two planes.

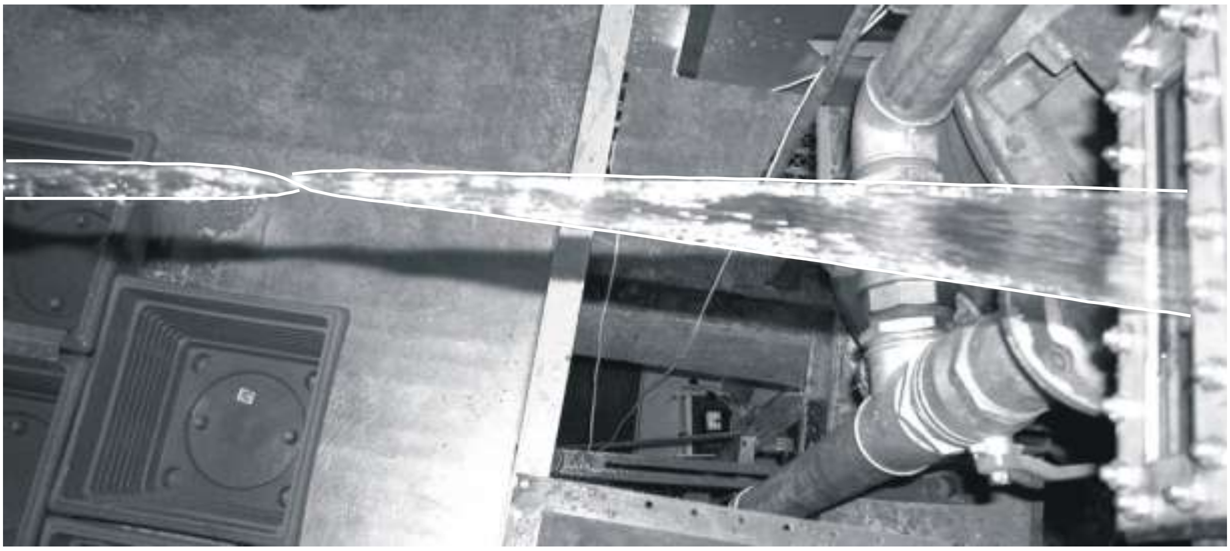

Figure 5. Change in the orientation of a transverse jet cross section.

The range of the flowing jet was determined for its axis in the jet final position (in the plane of inlet to the measuring vessels) and compared with a theoretical range calculated on the basis of the equation for oblique projection.

$$z_t = 2 \cdot \beta \sqrt{\frac{p_o \cdot y}{\rho \cdot g}} \qquad (1)$$

The velocity coefficient was defined by the equation

$$\beta = \frac{Q_v}{S_o} \sqrt{\frac{\rho}{2 p_o}} \qquad (2)$$

Figure 6 shows a comparison of experimental and theoretical ranges of the liquid jet flowing from the orifice in a pipe wall.

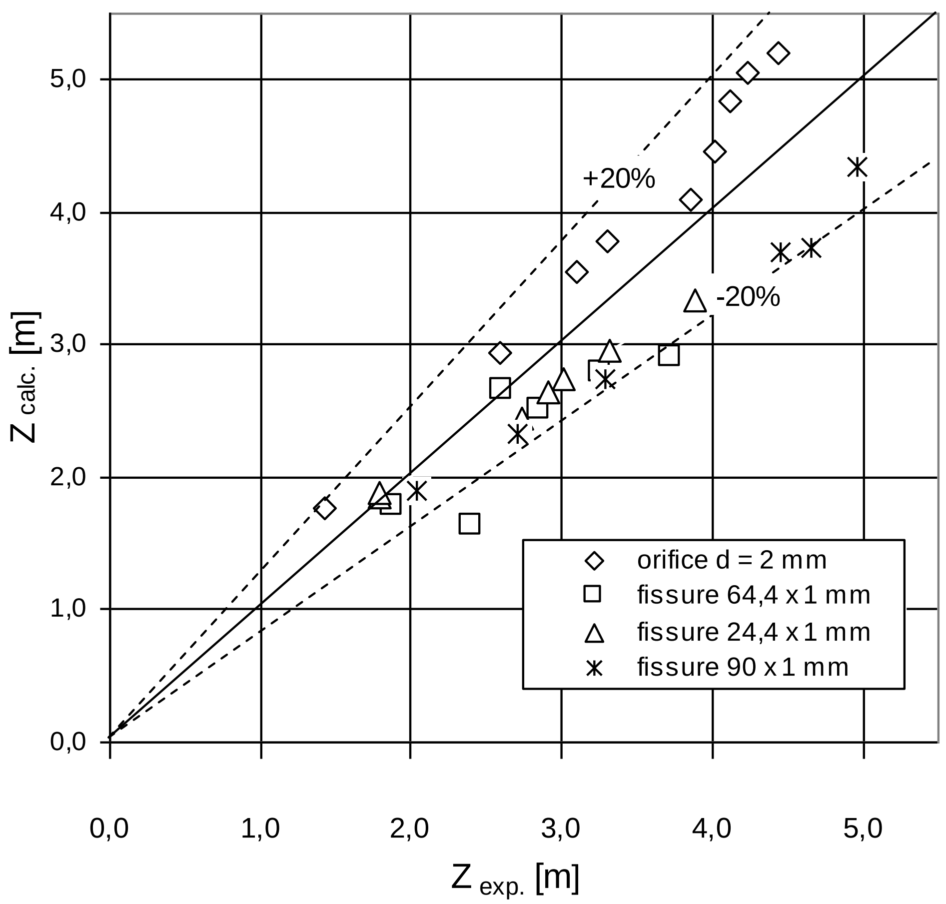

Figure 6. Comparison of the theoretical and experimental range of flowing jets.

As is seen in the diagram, theoretical ranges of the jet for outflow from the fissures are underestimated, with a maximum error of ca. 20%. In the case of outflow through the cylindrical orifice, the real value is overestimated with a maximum error of ca. 20%.

The next value, whose theoretical determination is very useful for the analysis of emergency outflows from pipelines, is the liquid jet volume. For the measurements carried out in this study, this value was calculated basing on the equation for an outflow from orifice in the tank

$$Q_{vo} = \varphi \cdot S_o \sqrt{2gH} \tag{3}$$

where:

$$\varphi = \alpha \cdot \beta \tag{4}$$

the value of H was the hydraulic thrust calculated from the relation:

$$H = \frac{p_o}{\rho g} + \frac{v_o^2}{2g} \tag{5}$$

The value of outflow coefficient φ was determined basing on literature data [1,2] which specify the range of these values to be from 0.6 to 0.65. The outflow coefficient was assumed to be 0.65, because this value approximated experimental data in the best way. A comparison of theoretical and experimental volumes of liquid jets is shown in Fig. 7.
Initial velocities of the flowing jet were calculated in the same manner as in theoretical range of the outflow. Only results of the calculations referring to the outflow through a cylindrical orifice are in satisfactory agreement with experimental results. In the case of outflow through the fissure 24.4 mm wide, part of theoretical calculations is confirmed experimentally, while in the case of outflow through the fissures 64.4 mm and 90 mm wide, the theoretical values are overestimated. Significant differences can also be observed in the position of points reflecting separate experiments, which can provide evidence of big changes in the real outflow coefficient.

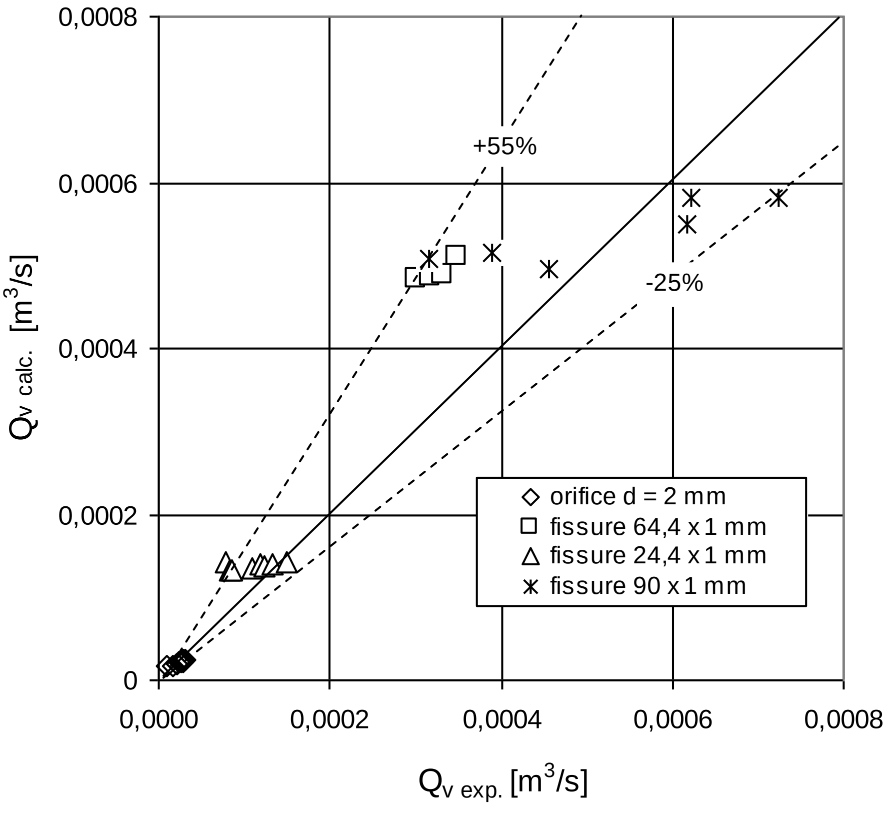

Figure 7. Comparison of theoretical and experimental jet volumes.

The presented results refer to initial investigations of outflows from orifices of different shapes and cannot provide detailed information on these phenomena in the case of a bigger range of changes in the geometry of outlet orifice cross sections. The studies are continued and only a broader range of experimental results will allow us to verify the presented trends and to correlate the results:

4. Conclusions

Results presented in this study cover initial investigations of liquid outflow from orifices of different shapes in the pipe wall. The collected experimental data were used to estimate the problem and propose conclusions on the theoretical method for determination of the outflow range and volume of the jet flowing from the orifices. The results cannot provide extensive information on the observed phenomena in the case of a broader range of changes in the cross section geometry of outlet orifices. Studies are continued and only a broader range of experimental results will allow us to verify the obtained relations and correlate appropriate parameters.

5. Notation

g	–	acceleration of gravity, m/s^2
H	–	hydraulic thrust, m
p	–	pressure, Pa
Q_v	–	volumetric liquid jet, m^3/s
S	–	surface area, m^2
y	–	height, m
z	–	outflow range, m
α	–	contraction coefficient
β	–	velocity coefficient
ϕ	–	outflow coefficient
ρ	–	density, kg/m^3

Subscripts and superscripts

o	–	refers to outflow orifice
t	–	theoretical

6. References

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[3] MITOSEK M, *Fluid mechanics in engineering and environmental protection*, PWN, Warszawa, 2001 (in Polish).

Acknowledgement:

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