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Experimental study of air–oil–water flow in a balancing valve

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ABSTRACT

This paper reports the results of research into air–oil–water flow through balancing valves. The testing applied commercial Zetkama valves. The tests were performed with the use of 4 balancing valves with the nominal diameters of 15, 25, 32 and 40 mm. The testing enabled the determination of the flow patterns forming in the vicinity of the valve. It was concluded that the examined valves do not significant result in flow pattern disturbances. In addition, a correlation was derived which can be used for determining the value of the local pressure drop for the examined type of valves. The presented correlation could be potentially applied for determining pressure drop during gas–liquid mixture flow in industrial installations and apparatus.

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1. Introduction

Each correctly designed industrial installation consists of a number of various and mutually influencing components which lead to local pressure drops. In this respect, it is necessary to secure balance of hydraulic installations whose aim is to secure the supply of flow parameters suited for a specific purpose. In this manner it is possible to maintain adequate operation of the installation, limit the excessive use of energy and eliminate noise in it. The balancing in the installation can be achieved as a result of installing static and dynamic balance valves. Static valves play the role of limiting the flow rate of a medium in an installation, whose aim is to limit fluctuations in the flow in the installation following a change of the parameters of the system resulting from such factors as increase or decrease in the pressure. The preservation of balance in a hydraulic installation is possible as a result of applying dynamic balance valves. This group of valves contains a flow controller, whose role is to reduce the effect of pressure drop in the system and, thus, ensure that constant flow parameters are preserved. As a result of the design, the flow in such installation is constant and regardless of the fluctuating pressure. The application of dynamic balance valves makes it possible to eliminate the time- and money-consuming constant installation supervision. It is only necessary to adjust the designed flow rate on the valve and the installation is ready to operate. The selection of appropriate balance valves makes it possible not only to protect the environment, but also saves money: easy fitting reduces the time necessary for an investment and it is possible to reduce the number of the installed valves.

The determination of energy losses resulting from local pressure drops is based on the selection of the value of the local loss coefficient. Such loss coefficient should be derived on the way of experiment due to the complex nature of flow phenomena, as the latter involves both viscous friction as well as flow disturbances, which are difficult in mathematical description. The value of the loss coefficient is decided mostly by the flow pattern formed in the section behind a local obstacle.

A number of literature items are available on the topic of hydrodynamics of gas–liquid flow through valves with various design, examples of which include papers (Adair and Fisher, 1999; Aprea and Renno, 1999; Bahajji et al., 2005; Boccardi et al., 2008; Chern et al., 2007; Darby, 2004; Ibrahim, 2001; Kavehsnikov and Sivak, 2006; Kendoush et al., 1999; Kim and No, 2001; Lenzing et al., 1998; Leung, 2004; Liu et al., 2007; Moncalvo and Friedel, 2006; Morris, 1996; Park et al., 2007; Shanwei et al., 2005; Varlamov, 2001; Ye et al., 2007; Zhifang et al., 2008), which deal with a variety of measurements necessary for determining parameters used to describe the conditions in which balance valves are applied. The research in this field is numerous and deals with mostly with

(1) research and modeling of operating conditions of valves applied in the power industry, heating and cooling apparatus,
(2) research and modeling of throttle valves to be used in various cooling unit applications, and
(3) research into exploitation conditions of cut-off and control valves applied in industrial installations.

The authors of this paper are familiar with examples of

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Nomenclature

d	internal diameter of pipe, mm
f	friction factor, dimensionless
L	length of pipe, mm
u	superficial velocity, m s^{-1}
Re	Reynolds number, dimensionless
Q	volumetric flow rate, m^3 s^{-1}
ΔP	pressure difference, Pa
α	insitu void/volume fraction, dimensionless
β	inlet void/volume fraction, dimensionless
β^*	concentration of phases, dimensionless
ζ	loss coefficient, dimensionless
η	dynamic viscosity, Pa s
ρ	density, kg m^{-3}

Subscripts

3P	three-phase mixture
g	gas
i	phase
L	liquid
o	oil
w	water
cal	calculated value
exp	measured value

installations, in particular in the petro- and carbochemical industries in which classical gas–liquid mixture transport occurs, such as in the case of processes of transporting petroleum mixed with water and coal tars, which are all examples of three-phase gas–liquid–liquid flows. The review of the existing literature in this subject does not yield information regarding the hydrodynamics of multi-phase gas–liquid flow in the perspective which is specific for analysis of this flow type. Hence, the studies of gas–liquid mixture pressure drop were undertaken for selected types of regulation valves. Novel method for calculation of pressure drop was developed in the result of this study.

Balancing valves are used in steam condensate cooling systems in petrochemical plants and refineries. The proper operation of such systems requires appropriate regulation by balancing hydraulic installations. The use of modern balancing valves ensures flow rates calculated by the designer. The result of their application is an ideal plant operation, lower power consumption and elimination of noise in the system. The static or dynamic balancing valves ensure maintenance of a balance in the installation. The static valves act as limiters of flow in the system to enable a change of flow in the system. Consequently, changes of system load occur, such as an increase or decrease in pressure results. This solution is perfectly fulfills its role in the variable flow systems. The dynamic balancing valves are used to keep a balance in the hydraulic system. They have built-in a steady flow regulator. This design provides constant and independent of pressure changes flow in the installation. Due to the use of such valves, the activities involving installation control have become less time-consuming and expensive. This scope of this work is restricted to discussion regarding the adjustment of the projected flow in the valve. The use of intelligent balancing valves in hydraulic systems currently offers the best method of ensuring the optimal operation of the system, by providing the required internal temperature at the expense of the lowest energy use.

2. Materials and methods

The research into hydrodynamics of multi-phase flow through pipes with installed valves was undertaken in regard to assessment of their impact on the disturbance of the flow patterns in the connection section of a pipeline and determining the formula for use in the calculation of local pressure drops in such types of installations. The testing was conducted by changing flow parameters in the range which is given in Table 1. Accounting for the parameters in the installation, 4 valves with different diameters, i.e. 1/2″, 1″, 11/4″ and 11/2″ were selected for the tests. They were installed in horizontal pipelines with the diameters of 15, 25, 32 and 40 mm, which are respective for the nominal diameters of the selected valves. ZETKAMA Type 221 balance valves were selected to be used in the experiment. The length of the distance from (8) to (10) was selected for the largest diameter of the channel, i.e. 40 mm. This length was 2500 mm and L/d ratio was 62.5. Fig. 1 contains diagrams of the selected valves and Table 2 contains a summary of their dimensions.

Table 1
Conditions of the experiment.

Phase – i	Superficial velocity u_i [m/s]	Reynolds numer Re_i	Inlet void/volume fraction β_i
Air	0.07–3.29	67–5555	0.13–0.95
Water	0.018–0.49	289–7946	0.09–0.85
Oil	0.08–0.49	38–342	0.024–0.96

In order to derive energy losses on the way of experiment and subsequent loss coefficient caused by an obstacle, the measurement of pressure drop was undertaken in specific tapping points along the installation so as to ensure that the flow was fully developed.

The test stand for testing hydrodynamics during flow through balance valves, whose diagram is presented in Fig. 2. consisted of two pump – Grundfos CR 10 for water and PZ 25 for the oil phase (3,4), water tank (1), oil tank (2), mixing chamber (8), replaceable test channel (9), separator (14) and rotatameters (6). The central part of the test stand consisted of a test channel made of axial plaxiglas pipes (9). The measurement channel contained valves (10) with different diameters, which were the object of the testing. The volume flow rates of the liquids were controlled by control valves and rotameters (both float and electronic ones). The pumps were used to feed the media into the mixing chamber into which compressed air was also supplied from the grid (5). The multiphase mixture formed in this way was pumped through the measurement section and was subsequently drained into a separator (14), where the phases could be separated. The oil was reversed into the tank and remained in circulation, while the water was drained into the sewage. The testing applied LAN 15 oil, whose density and viscosity at the temperature of 20 °C were equal to 856 kg/m^3 and 29.20 mPa, respectively. After separation from water in the decantation process, the oil was re-used in the circulation of the installation. Prior to each reversal of the oil, the measurements of rheological properties was undertaken, in particular with regard to the values of the density, viscosity and surface tension. The measurements of the density of oil was performed by float method using aerometer. The value of dynamic viscosity coefficient was taken by means of a cone and plate Brookfield DV-II+ digital viscometer, while the value of the

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