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An instrument for the measurement of density of a liquid flowing in a pipeline

Leszek Remiorz, Piotr Ostrowski *

Institute of Power Engineering and Turbomachinery, Silesian University of Technology, ul. Konarskiego 18, 44-100 Gliwice, Poland

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ABSTRACT

This article presents a system of the measurement of density of a liquid flowing in a pipeline based on a quasi-hydrostatic measurement. A concept of a density meter is discussed. A physical and mathematical description of the new solution is presented together with an assessment of pressure losses along the measuring section and results of numerical modelling of the design parameter selection. Also, the meter prototype which has been tested in the sugar industry is presented. The meter is intended for industrial measurements of density of liquids and solutions of liquids flowing in a pipeline and automation of installations for separating, combining or concentrating liquid solutions. This instrument could be of special importance in areas such as the food, oil or chemical industries to perform density measurements and to correct variable density in flow measurements.

1. Introduction

The on-line measurement of density of liquids and liquid solutions flowing in a pipeline is very important, particularly in the food and petrochemical industries [1,2]. The measurement of density has so far been performed by means of the radioisotope method based on the measurement of attenuation of the radioisotope beam [2]. This requires individual calibration of the densimeter and can be troublesome to use due to the need for appropriate radioisotope protection. The liquid densimeter (usually combined with flow meters using the Coriolis effect [3–5]) has not found popular application for economic reasons. Another method is known from the patent [6]. It uses two volumetric flow meters: a Venturi flow meter installed on the main pipeline and a turbine flow meter installed on the bypass pipeline of the reducer, measuring density at the same pressure difference arising in the reducer. Other methods using ultrasounds [8] or microwaves [7] are also applied for aqueous solutions of organic compounds (e.g. sucrose). It can be seen, however, that there is no "simple and cheap" method of measurement of density for liquid solutions or two-phase liquid mixtures [1,9].

This article presents a system of the measurement of density of a liquid flowing in a pipeline which is based on a quasi-hydrostatic measurement covered by a Polish patent [11,12]. A concept of a density meter is analyzed. A physical and mathematical description of the innovative solution is presented together with an assessment of pressure losses along the measuring section and results of numerical modelling of the design parameter selection. Also, the meter prototype which has been tested in the sugar industry is presented.

The meter is intended for industrial measurements of density of liquids and liquid solutions flowing in a pipeline and automation of installations for separating, combining or concentrating liquid solutions. This instrument could be of special importance in areas such as the food, oil or chemical industries.

2. Description of the new solution

The instrument for on-line determination of density ρ of a liquid flowing in a horizontal pipeline makes use of the measurement of pressure difference δp, at constant difference in length l between hydrostatic pressure measuring points (Fig. 1).

The measured difference in hydrostatic pressure values is expressed by the following formula:

$$\delta \mathrm{p} = 9.80665 \rho l, \mathrm{Pa}$$
$$\text{hence, density}: \rho = 0.1019716 \delta \mathrm{p}/l$$
$$\text{for a known difference in height, e.g.} \, l = 1.0 \, \mathrm{m}$$
$$\rho = 0.1019716 \delta \mathrm{p}, \mathrm{kg/m^3} \quad (1)$$

The instrument for the measurement of density of a liquid flowing in a pipeline is presented in Fig. 2. The basic element of the device is a measuring tube in a form of a vertical measuring bypass (1) joined to the pipeline (3) by means of a flange connection ensuring due tightness. The pipes making up the vertical bypass (1) in the part installed in the pipeline (3) end

* Corresponding author. Tel.: +48 32 2371368; fax: +48 32 2372680.
E-mail address: piotr.ostrowski@polsl.pl (P. Ostrowski).

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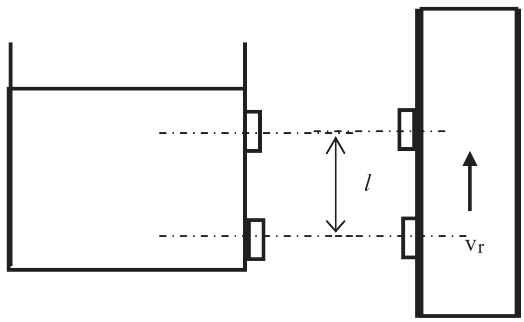

Fig. 1. Measurement of the liquid density at a constant difference in the distance between hydrostatic pressure measuring points. (a) in the container if the liquid is at rest, (b) in the pipeline vertical bypass if linear losses in the pipeline are negligibly small.

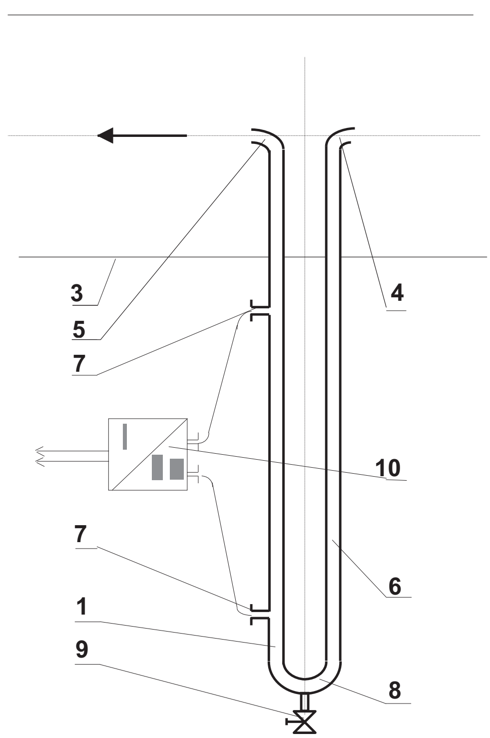

Fig. 2. Diagram of the instrument for the measurement of density of a liquid flowing in a pipeline: 1. vertical measuring bypass, 3. pipeline, 4. inflow knee-bend, 5. outflow knee-bend, 6. downcomer , 7. connectors of the pressure difference transducer, 8. return chamber, 9. cut-off valve, 10. *Dp* transducer.

with knee-bends – the inflow knee-bend (4) and the outflow knee-band (5) – directed in opposite directions and placed in the stream of the liquid flowing in the pipeline (3) to cause a pressure difference between the inflow and outflow end of the measuring bypass (1), thus forcing the liquid to flow through the bypass, according to the Bernoulli equation.

In the inlet section of the inflow tube (directed opposite to the liquid velocity vector v_r) the total pressure is

$$\mathrm{p}'_{\mathrm{c}} = \text{static pressure } \mathrm{p}'_{\mathrm{s}} + \text{dynamic pressure} \mathrm{p}'_{\mathrm{d}},$$

where

$$\mathrm{p}'_{\mathrm{d}} = 0.5\rho v_{\mathrm{r}}^2$$

In the outlet section of the outflow tube (directed in the same direction as the liquid velocity vector v_r) the total pressure iswhere

$$\mathrm{p}''_{\mathrm{d}} = \mathrm{p}'_{\mathrm{d}} = 0.5\rho v_{\mathrm{r}}^2,$$

hence, the pressure difference forcing the liquid to flow in the measuring bypass is:

$$\Delta p_c = p'_s + 0.5\rho v_r^2 - (p''_s - 0.5\rho v_r^2) \qquad (2)$$

$$i.e.\Delta p_c = p'_s - p''_s + \rho v_r^2 \qquad (3)$$

The inflow knee-bend (4) is extended by the downcomer (6), where the liquid flows with velocity v_2, flowing out in the bottom part of the bypass – the return chamber (8). The vertical measuring bypass (1), ended with the outflow knee-bend (5), at the section beyond the pipeline (3) creates the measuring space with two connectors (7) of the pressure difference transducer (10), which are perpendicular to the direction of the liquid flow and are separated from each other by the measuring section length *l* – the location of the connectors of the pressure difference measurement complies with the principles of the static pressure measurement in pipelines. The measuring bypass (1) also has a cut-off valve (9) installed at a point which is vertically as distant from the pipeline centre as possible. The valve is used to empty, degas or rinse the densimeter.

It should be noted that the liquid stream velocity profile in the bypass measuring space should be quasi-level, with a low value of the liquid velocity v in the direction opposite to the flow direction in the pipeline, satisfying the condition $v \ll v_{\mathrm{r}}$. A low value of the flow velocity v through the measuring space results in a negligible linear loss of pressure at a change in efficiency (linear velocity v_{r}) in the main pipeline. It results from the stream continuity equation that the requirement is met if the inflow downcomer tube (6) diameter d_z (inside diameter d) is substantially smaller than the diameter D_{w} of the bypass (1) measuring part, on the side surface of which the pressure difference transducer connectors are located.

Table 1
Values of pressure losses. Hstr, mH2O.

d,	m	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
Dw,	m	0.08	0.08	0.08	0.08	0.125	0.125	0.125	0.125	0.08	0.08	0.08	0.08	0.125	0.125	0.125	0.125
dz,	m	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
vr,	m/s	1	3	1	3	1	3	1	3	1	3	1	3	1	3	1	3
		9.82	6.72	1.47	1.00	4.62	3.16	6.91	4.73	9.77	6.68	1.46	9.99	4.60	3.15	6.88	4.71
		E-07	E-06	E-06	E-05	E-07	E-06	E-07	E-06	E-07	E-06	E-06	E-06	E-07	E-06	E-07	E-06
ν 10^6,	m^2/s	1	1	5	5	1	1	5	5	1	1	5	5	1	1	5	5
		9.82	6.72	1.47	1.00	4.62	3.16	6.91	4.73	9.77	6.68	1.46	9.99	4.60	3.15	6.88	4.71
		E-07	E-06	E-06	E-05	E-07	E-06	E-07	E-06	E-07	E-06	E-06	E-06	E-07	E-06	E-07	E-06
l,	m	0.25	0.25	0.25	0.25	1	1	1	1	0.25	0.25	0.25	0.25	1	1	1	1
		9.82	6.72	1.47	1.00	4.62	3.16	6.91	4.73	9.77	6.68	1.46	9.99	4.60	3.15	6.88	4.71
		E-07	E-06	E-06	E-05	E-07	E-06	E-07	E-06	E-07	E-06	E-06	E-06	E-07	E-06	E-07	E-06
g,	m/s^2	9.7741	9.7741	9.7741	9.7741	9.7741	9.7741	9.7741	9.7741	9.8217	9.8217	9.8217	9.8217	9.8217	9.8217	9.8217	9.8217
		9.82	6.72	1.47	1.00	4.62	3.16	6.91	4.73	9.77	6.68	1.46	9.99	4.60	3.15	6.88	4.71
		E-07	E-06	E-06	E-05	E-07	E-06	E-07	E-06	E-07	E-06	E-06	E-06	E-07	E-06	E-07	E-06