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Algorithm for Calculating Flowrate of Fluid Energy Carrier for Flowmeter Based on Standard Long Radius Nozzle

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Abstract

New equation and algorithm are developed for non-iterative calculating flowrate of fluid energy carrier for pressure differential flowmeter based on long radius nozzle. This equation implicitly contains three build-in iterative cycles for calculating flowrate. According to the results of comparing the flowrate values obtained by developed non-iterative algorithm to the flowrate values by standard iterative algorithm, the authors found that the developed non-iterative algorithm ensures the accuracy of flowrate calculation specified by the requirements of DSTU GOST 8.586.5:2009. Therefore, the proposed equation and algorithm for calculating flowrate can be used for flowmeters based on standard long radius nozzle for both technological and commercial metering flowrate of fluid energy carriers. Application of the developed algorithm makes it possible to increase the speed of calculating flowrate of fluid energy carriers by means of microprocessor controllers.

Keywords: flowrate; pressure differential method; primary device; long radius nozzle; algorithm.

1. Introduction

Pressure differential method is widely used for metering flowrate of fluid energy carriers. The basic principles of this method and the requirements for its application are presented in many sources, particularly, in the international standards ISO 5167-1,2,3,4: 2003 [1]–[4] and in the national standards DSTU GOST 8.586.1, 2, 3, 4, 5-2009 [5]–[9], which are implemented in Ukraine.

Pressure differential method is a complex indirect method of measuring flowrate and quantity of fluid energy carrier, which provides for measuring differential pressure across a primary device, absolute pressure and temperature of fluid and calculating flowrate and quantity of fluid energy carrier using these measured values. Since the coefficients of the flowrate equation depend on fluid flowrate, the process of it calculating is iterative. In addition to iterative calculating the fluid parameters and the coefficients of flowrate equation, algorithm for calculating the fluid flowrate should also provide for checking in a certain sequence conditions and limitations of pressure differential method. Following characteristics should be checked:

- range of permissible values of fluid energy carrier parameters;
- characteristics of primary device;
- characteristics of measuring pipeline, its rectilinear sections and equipment;
- eccentricity;
- protrusions and difference in diameters of adjacent sections of measuring pipeline.

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By meeting all these requirements, one obtains a complex algorithm for calculating flowrate and quantity of fluid, which should be implemented in microprocessor flowrate calculators. The flowrate calculator implements this algorithm in real time within the limited duration of the program cycle and the limited computing power of the calculator. Therefore, it is an urgent task to simplify the algorithm for calculating flowrate and eliminate the iterative process of calculating the flowrate, which takes considerable part of the computer program cycle.

2. Analysis of publications and research

When designing a new pressure differential flowmeter for fluid energy carrier based on standard primary device, it is necessary to solve the following problems:

- to do a direct calculation of pressure differential flowmeter, during which the diameter of hole or throat of a standard primary device for a given flowrate of fluid energy carrier should be determined;
- to make a standard primary device and to check its characteristics for compliance with the requirements of the standards;
- to do a reverse calculation of pressure differential flowmeter, which consists in determining the flowrate of fluid energy carrier for specified characteristics of standard primary device and measuring pipeline.

Pressure differential flowmeters for flowrate and quantity of fluid energy carriers use the following standard primary devices: orifice plates [2], [6], [10]; ISA 1932 nozzles, long radius nozzles, Venturi nozzles [3], [7], [10]; Venturi pipes of different types [4], [8], [10]. The use of a long radius nozzle has some advantages for measuring the flowrate of fluid energy carrier compared to the orifice plate:

- it has stable characteristics during long operation time;
- it has less pressure loss than orifice plate;
- it may have diameter ratio of throat up to 0.8.

Therefore, it is often used to measure flowrate of dry saturated steam.

Discharge coefficient of long radius nozzle depends on Reynolds number and, therefore, on flowrate of fluid energy carrier. So, nozzle flowrate equation is an implicit equation and calculation of flowrate of fluid energy carrier through long radius nozzle is carried out iteratively. According to ISO 5167-1: 2003 [1], iterations are recommended to be performed by the value of Reynolds number or by the value of mass flowrate of fluid energy carrier [5], [10]. This increases the amount of memory and the time required for calculating the mass flowrate and the quantity of fluid energy carrier, and thus increases the requirements to microprocessors or microcontrollers used in flowrate calculators of fluid energy carrier.

It should be noted that simplified algorithms could be used to calculate the fluid flowrate, but these algorithms would increase the relative error of calculation of fluid flowrate. The additional error caused by simplified algorithm may be systematic, and therefore can create an additional imbalance in the accounting of energy carriers in distribution and transmission systems.

To check the algorithms for calculating the values of fluid flowrate, it is necessary to have tables of control points (tests), by which fluid flowrate and relative extended uncertainty of flowrate for the specified ranges of pressure and temperature of fluid are determined. Such tables can be obtained using CAD “Raskhod-RU” [11], [12].

Based on mathematical model of pressure differential flowmeter, a technique for calculating the flowrate of fluid energy carrier is implemented in CAD “Raskhod-RU” [11], [12]. It is implemented in a form of optimized algorithm with cyclic calculation. The body of the cycle calculates the coefficients of flowrate equation, which depends on fluid flowrate, in particular discharge coefficient C, Reynolds number Re, fluid parameters, as well as a number of other coefficients of flowrate equation that do not depend on fluid flowrate. At the end of the cycle body the relative deviation δ_{q_m} of the current value of the mass flowrate q_{mi} of fluid energy carrier from its previous value q_{mi-1} is calculated. Exit from the cycle is carried out when the relative deviation of flowrate becomes less than the allowable calculation error which equals 0.001 % according to the standards [9] and [15].

3. Goal of the paper

The goal of this paper is to develop a non-iterative algorithm for calculating mass flowrate q_m of fluid energy carrier in order to reduce the required controller memory and to increase the speed of calculating the flowrate and the quantity of fluid energy carrier by means of microprocessor calculators of fluids.

4. Presentation and discussion of the research results

Mass flowrate q_m is determined according to equations of the standards [1], [5], [9] and [11]:

- for liquid energy carrier

$$q_m = \frac{\pi}{4} d^2 EC \sqrt{2 \Delta p \rho}\ ; \tag{1}$$

- for gaseous energy carrier

$$q_m = \frac{\pi}{4} d^2 EC \varepsilon \sqrt{2 \Delta p \rho}\ , \tag{2}$$

where d is the diameter of the long radius nozzle throat at temperature of energy carrier; E is the velocity of approach factor; Δp is differential pressure across long radius nozzle; ρ is the density of fluid energy carrier at temperature and static pressure of fluid energy carrier; ε is the expansibility factor of energy carrier.

Velocity of approach factor E depends on diameter ratio β of long radius nozzle. It is calculated by the equation

$$E = \frac{1}{\sqrt{1 - \beta^4}}\ . \tag{3}$$

Diameter ratio of primary device installed in a pipeline is the ratio of the diameter throat of long radius nozzle to the internal diameter D of measuring pipe upstream the primary device:

$$\beta = \frac{d}{D}\ . \tag{4}$$

Diameter d of the long radius nozzle throat at a temperature of fluid energy carrier is determined by formula

$$d = d_{20} K_{\mathrm{CY}}\ , \tag{5}$$

where d_{20} is the diameter of throat of long radius nozzle at fluid temperature 20 °C; K_{CV} is the coefficient that takes into account the change in the diameter of the throat of long radius nozzle caused by deviations of fluid temperature from 20 °C.

Internal diameter D of the measuring pipe upstream the primary device at a temperature of fluid energy carrier depends on the internal diameter D_{20} of the measuring pipe upstream the primary device at a temperature of energy carrier 20 °C. It is calculated by following equation

$$D = D_{20} K_{\mathrm{T}}\ , \tag{6}$$

where K_T is the coefficient that takes into account the change in the internal diameter D of the measuring pipe upstream the primary device caused by deviations of fluid temperature from 20 °C.

Discharge coefficient C of a long radius nozzle with small and large diameters ratio is determined according to [3], [7], [10]:

$$C = 0.9965 - 0.00653 \sqrt{\frac{10^6 \beta}{\mathrm{Re}}}\ , \tag{7}$$

where Re is Reynolds number, which is the ratio of the inertia force to the fluid viscosity force and it is determined by the equation

$$\mathrm{Re} = \frac{\bar{w} D \rho}{\mu}, \tag{8}$$

where $\bar{w}$ is the longitudinal component of the average local velocity of fluid energy carrier in the measuring pipeline; μ is the dynamic viscosity of the fluid energy carrier in the measuring pipeline.

Expansibility factor ε of fluid energy carrier is calculated according to [3], [7], [10]:

$$\varepsilon = \begin{cases} \sqrt{\left(\dfrac{\kappa \tau^{\frac{2}{\kappa}}}{\kappa}\right)\left(\dfrac{1-\beta^4}{1-\beta^4 \tau^{\frac{2}{\kappa}}}\right)\left(\dfrac{1-\tau^{\frac{\kappa-1}{\kappa}}}{1-\kappa}\right)} & \text{for gaseous energy carrier} \\ 1 & \text{for liquid energy carrier} \end{cases}, \tag{9}$$

where the values of τ are calculated by formula

$$\tau = 1 - \frac{\Delta p}{p}. \tag{10}$$

Equation (9) is applied for the ratio $\dfrac{\Delta p}{p} \le 0.25$.

Let's write the equation (1) or (2) for determining the mass flowrate q_m of fluid energy carrier using average fluid velocity $\bar{w}$ the in the following form

$$q_m = \frac{\pi D^2}{4} \rho \bar{w} \tag{11}$$

and determine the average local velocity $\bar{w}$ of fluid the in the measuring pipeline as

$$\bar{w} = \frac{4 q_m}{\pi D^2 \rho}. \tag{12}$$

Substituting the average local velocity $\bar{w}$ of fluid in the measuring pipeline into equation (8), we obtain the formula for calculating Reynolds number in terms of mass flowrate q_m of fluid

$$\mathrm{Re} = \frac{4 q_m}{\pi D \mu}. \tag{13}$$

Taking into account formula (7), we obtain an equation for determining mass flowrate q_m of fluid energy carrier in the form

$$q_m = \frac{\pi}{4} d^2 E \varepsilon \left(0.9965 - 0.00653 \sqrt{\frac{10^6 \beta}{\mathrm{Re}}} \right) \sqrt{2 \Delta p \rho}. \tag{14}$$

Taking into account formula for determining the Reynolds number (13), we obtain the equation for determining mass flowrate q_m of fluid energy carrier as a function of mass flowrate $q_m = f(q_m)$. This equation can be solved with respect to q_m using iterative methods for solving the equation. These methods increase the time that processor or microprocessor controller spends to solve such iterative problem.

The authors developed an equation for non-iterative calculating mass flowrate of fluid measured by using long radius nozzle. The initial form of the equation is obtained by substituting expression (13) in equation (14):

$$q_m = 0.9965\frac{\pi}{4}d^2E\varepsilon\sqrt{2\Delta p\rho}\left(1-\frac{0.00653}{0.9965}\sqrt{\frac{10^6\pi d\mu}{4q_m}}\right). \quad (15)$$

The equation (15) is presented in the form

$$q_m = A\left(1+\frac{B}{\sqrt{q_m}}\right), \quad (16)$$

where

$$A = 0.9965\frac{\pi}{4}d^2E\varepsilon\sqrt{2\Delta p\rho}\,; \quad (17)$$

$$B = -\frac{0.00653}{1.993}\sqrt{10^6\pi d\mu}\,. \quad (18)$$

Substituting the equation for determining the mass flowrate q_m of fluid energy carrier in equation (16), we obtain the following formula

$$q_m = A\left(1+\frac{B_0}{\sqrt{1+\frac{B}{\sqrt{q_m}}}}\right), \quad (19)$$

where

$$B_0 = \frac{B}{\sqrt{A}}. \quad (20)$$

In the third iteration step we've written the equation for determining the mass flowrate q_m of the fluid energy carrier and substituted formula (20) into it. Finally, we've obtained the equation for calculating the mass flowrate of fluid energy carrier in the form

$$q_m = A\left(1+\frac{B_0}{\sqrt{1+\frac{B_0}{\sqrt{1+\frac{B_0}{\sqrt{1+\frac{2B}{\sqrt{\pi d\mu}\sqrt{\mathrm{Re}_a}}}}}}}}\right), \quad (21)$$

where Re_a is the average value of the Reynolds number, which should be calculated by the equation

$$\mathrm{Re}_a = 10^{0.5[\lg(\mathrm{Re}_{\min})+\lg(\mathrm{Re}_{\max})]}, \tag{22}$$

$\mathrm{Re}_{\min}$, $\mathrm{Re}_{\max}$ are the minimum and the maximum allowable values of Reynolds number, which for the long radius nozzle are $\mathrm{Re}_{\min} = 10^4$ and $\mathrm{Re}_{\max} = 10^7$ [7].

According to the equation (22), the average value of Reynolds number for a long radius nozzle is $\mathrm{Re}_a = 316228$.

Replacing the equation

$$B_1 = \frac{2B}{\sqrt{\pi D\mu}\sqrt{\mathrm{Re}_a}} = -0.01165295\sqrt{\beta}\,; \tag{23}$$

and substituting it in equation (22), we obtain the equation for determining the mass flowrate of the fluid energy carrier

$$q_m = A\left(1+\frac{B_0}{\sqrt{1+\frac{B_0}{\sqrt{1+\frac{B_0}{\sqrt{1+B_1}}}}}}\right). \tag{24}$$

It is obvious from the presented procedure for obtaining equation (24) that this equation implicitly contains three build-in iterative cycles for calculating flowrate. As the authors will show below, these build-in iterative cycles are sufficient to achieve the accuracy of fluid mass flowrate calculation specified in standards [9] and [10]. Fig. 1 shows a flowchart of algorithm for calculating fluid mass flowrate, developed by the authors on the basis of equation (24).

We can see from Fig. 1 that developed algorithm for calculating mass flowrate provides sequential non-iterative process for implementing the equation (24). A disadvantage of equation (24) and respectively of proposed algorithm is that it can be used to calculate the fluid mass flowrate through only primary device of a certain type – a standard long radius nozzle.

The developed algorithm was used to calculate the mass flowrate for two sets of fluid parameters and flowmeter characteristics (see Table 1).

Table 2 presents the results of calculating mass flowrate of the fluid energy carrier (natural gas), which is determined using the iterative method and the non-iterative algorithm developed on the basis of equations (17), (18), (20), (23) and (24). The relative deviation of the values of the mass flowrate of the fluid energy carrier obtained during the iterative process (see Table 2), is calculated by the formula

$$\delta_{q_m} = 100\left(\frac{q_{mi-1} - q_{mi}}{q_{mi}}\right), \tag{25}$$

where q_{mi-1} and q_{mi} are the mass flowrate of fluid at the previous time and at the current time, respectively.

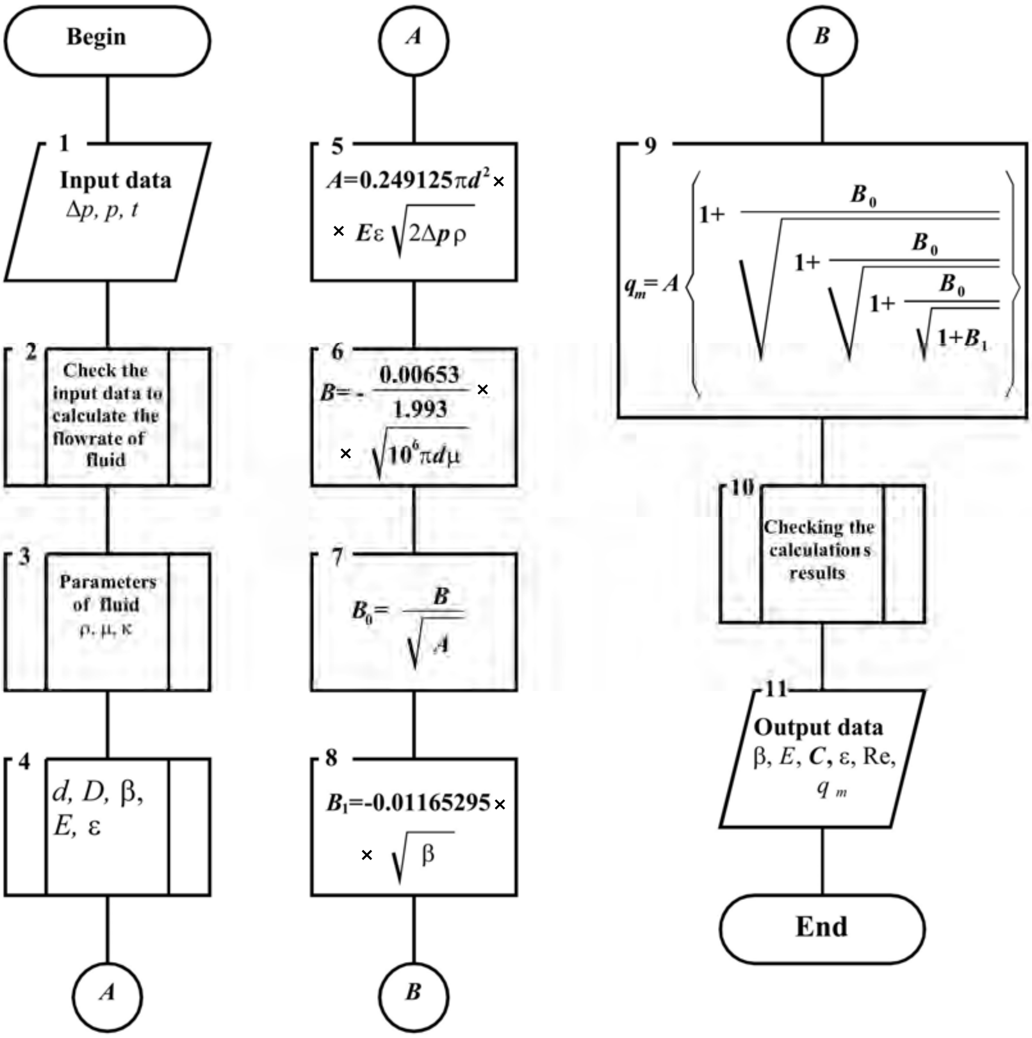

Fig. 1. Flowchart of a non-iterative algorithm for determining the mass flowrate of fluid energy carrier

Table 1. Input data for calculating the mass flowrate of fluid energy carrier

Fluid parameter or flowmeter characteristic	Parameter or characteristic value	
	Flowmeter 1	Flowmeter 2
Differential pressure across long radius nozzle, Pa	240	12000
Absolute pressure of fluid energy carrier, Pa	250000	250000
Temperature of fluid energy carrier, °C	10	10
Density of fluid energy carrier at standard conditions, kg/m^3	0.68	0.7
Molar fraction of carbon dioxide in natural gas, %	0	0.2
Molar fraction of nitrogen in natural gas, %	0	0.9
Density of fluid energy carrier at working conditions, kg/m^3	1.79445	1.79455
Isentropic exponent of fluid energy carrier, 1	1.30375	1.30175
Dynamic viscosity of fluid energy carrier, Pa·s	$1.0619\ 10^{-5}$	$1.0619\ 10^{-5}$
Throat diameter of long radius nozzle at fluid temperature 20 ^{o}C, mm	14.77	480
Material of the long radius nozzle	12X18H10T	12X18H10T
Internal diameter of the measuring pipe upstream the primary device at fluid temperature 20 °C , mm	50.2	600
Material of the measuring pipe	St. 20	St. 20
Roughness of the inner surface of the measuring pipe is selected from the table DSTU GOST 8.586.1:2009 [10]	All drawn steel and cold drawn (new)	

Table 2. Comparison of the results of calculating the mass flowrate for fluid energy carrier obtained by using iterative algorithm (columns 1–3) and new non-iterative algorithm (columns 4–6)

Parameter	Value		Parameter	Value	
	Flowmeter 1	Flowmeter 2		Flowmeter 1	Flowmeter 2
Diameter ratio β of long radius nozzle, (4)	0.294208	0.799959	Diameter ratio β of long radius nozzle, (4)	0.294208	0.799959
Velocity of approach factor *E*, (3)	1.00377	1.30136	Velocity of approach factor *E*, (3)	1.00377	1.30136
Expansibility factor of gaseous energy carrier ε, (9)	0.999441	0.948368	Expansibility factor of gaseous energy carrier ε, (9)	0.999441	0.948368
Reynolds number, Re_0	10^6	10^6	Coefficient *A*, (18), kg/s	0.004955281	46.17047
Discharge coefficient C_0 of long radius nozzle, (7)	0.992958	0.99065954	Coefficient *B*, (19), $(kg/s)^{0.5}$	–0.00230179	–0.0131102
Mass flowrate of fluid energy carrier q_{m0}, (2), kg/s	0.00493521	45.89986184	Coefficient B_0, (21)	–0.032706934	–0.001929415
Reynolds number, Re_1 (13)	11767.9	9173504	Coefficient B_1, (25)	–0.006320671	–0.01042245
Discharge coefficient C_1 of long radius nozzle, (5)	0.963849	0.994572	Mass flowrate of fluid energy carrier q_{m0}, (24), kg/s	0.00478806	46.0813
Mass flowrate of fluid energy carrier q_{m1}, (2), kg/s	0.00479053	46.0811	–	–	–
Relative error of calculation result of mass flowrate of fluid energy carrier δ_{q_m},(25), %	3.020	-0.393	–	–	–
Reynolds number, Re_2, (13)	11422.95	9209731	–	–	–
Discharge coefficient C_2 of long radius nozzle, (5)	0.963360	0.994575	–	–	–
Mass flowrate of fluid energy carrier q_{m2}, (2), kg/s	0.00478810	46.0813	–	–	–
Relative error of calculation result of mass flowrate of fluid energy carrier δ_{q_m},(25), %	0.050	0.000<0.001	–	–	–
Reynolds number, Re_3, (13)	11417.16	–	–	–	–
Discharge coefficient C_3 of the long radius nozzle, (5)	0.963352	–	–	–	–
Mass flowrate of fluid energy carrier q_{m3}, (2), kg/s	0.00478806	–	–	–	–
Relative error of calculation result of mass flowrate of fluid energy carrier δ_{q_m},(25), %	$0.001 \leq 0.001$	–	–	–	–

We can see from Table 2 that four iterations of iterative algorithm for calculating flowrate make it possible to meet the requirements to the accuracy of flowrate calculation specified by standards [9] and [10]. Applying the equation (24) and non-iterative algorithm, one can achieve the same accuracy of calculating flowrate, while reducing the calculation time.

5. Conclusion

A simplified equation (24) for calculating the fluid flowrate measured by using a standard long radius nozzle is proposed in the paper. The equation makes it possible to calculate the flowrate of gases and liquids. Based on equation (24), a non-iterative algorithm for calculating the fluid flowrate is developed, which is proposed for implementation into pressure differential calculators of fluids flowrate and quantity.

According to the results of comparing the flowrate values obtained by developed non-iterative algorithm to the flowrate values by standard iterative algorithm, the authors found that the developed non-iterative algorithm ensures the accuracy of flowrate calculation specified by the requirements of DSTU GOST 8.586.5:2009. Therefore, the proposed equation and algorithm for calculating flowrate can be used for flowmeters based on standard long radius nozzle for both technological and commercial metering flowrate of fluid energy carriers. Application of the developed algorithm makes it possible to increase the speed of calculating flowrate of fluid energy carriers by means of microprocessor controllers.

References

[1] ISO 5167-1:2003. *Measurement of Fluid Flow by Means of Pressure Differential Devices Inserted in Circular Cross-Section Conduits Running Full–Part 1: General Principles and Requirements*.

[2] ISO 5167-2:2003. *Measurement of Fluid Flow by Means of Pressure Differential Devices Inserted in Circular Cross-Section Conduits Running Full–Part 2: Orifice Plates*.

[3] ISO 5167-3:2003. *Measurement of Fluid Flow by Means of Pressure Differential Devices Inserted in Circular Cross-Section Conduits Running Full–Part 3: Nozzles and Venturi Nozzles*.

[4] ISO 5167-4:2003. *Measurement of Fluid Flow by Means of Pressure Differential Devices Inserted in Circular Cross-Section Conduits Running Full–Part 4: Venturi Tubes*.

[5] DSTU GOST 8.586.1: 2009 (ISO 5167-1:2003). *State system for ensuring the uniformity of measurements. Measurements of liquid and gas flow rate and quantity by means of orifice instruments. Part 1. Principle method of the of measurements general requirements*. (in Ukrainian)

[6] DSTU GOST 8.586.2: 2009 (ISO 5167-2:2003). *State system for ensuring the uniformity of measurements. Measurements of liquid and gas flow rate and quantity by means of orifice instruments. Part 2. Orifice plates. Technical requirements* (in Ukrainian).

[7] DSTU GOST 8.586.3: 2009 (ISO 5167-3:2003*). State system for ensuring the uniformity of measurements. Measurements of liquid and gas flow rate and quantity by means of orifice instruments Part 3. Nozzles and Venturi nozzles. Technical requirements* (in Ukrainian.

[8] DSTU GOST 8.586.4: 2009 (ISO 5167-4:2003). *State system for ensuring the uniformity of measurements. Measurements of liquid and gas flow rate and quantity by means of orifice instruments. Part 4. Venturi tubes. Technical requirements* (in Ukrainian).

[9] DSTU GOST 8.586.5: 2009. *State system for ensuring the uniformity of measurements. Measurements of liquid and gas flow rate and quantity by means of orifice instruments. Part 5. Measurement procedure*. (in Ukrainian)

[10] Pistun, Y. and Lesovoy, L. (2006) Normalization of Pressure Differential Flow Meters. Publishing House of Institute of Energy Audit and Energy Carrier Accounting, Lviv, 576 (in Ukrainian).

[11] Pistun, Y., Lesovoy, L., Matiko, F., Markovskyi, D. and Lesovoy, R. (2007) “RASKHOD-RU” CAD computer program. User manual. Publishing House of Institute of Energy Audit and Energy Carrier Accounting (www.ieoe.com.ua), Lviv, 128 (in Ukrainian).

[12] Fedoryshyn, R.; Lesovoi, L. & Pistun, Y. (2010). *“Raskhod-RU” CAD system for computer aided calculation and design of flowmeters for fluid energy carriers* (2010). 0557-0558, Annals of DAAAM for 2010 & Proceedings of the 21st International DAAAM Symposium, ISBN 978-3-901509-68-1, ISSN 1726-9679, pp. 347, Editor B. Katalinic, Published by DAAAM International, Vienna, Austria 2010.

Алгоритм розрахунку витрати плинного енергоносія для витратоміра на основі стандартного еліпсного сопла

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Анотація

Розроблено нове рівняння та алгоритм для безітераційного розрахунку витрат плинного енергоносія для витратоміра змінного перепаду тиску на основі еліпсного сопла. Це рівняння містить у неявному вигляді три вкладені ітераційні цикли обчислення витрат. За результатами порівняння значень витрат, отриманих за розробленим безітераційним алгоритмом, зі значеннями витрат, одержаними за стандартизованим ітераційним алгоритмом, встановлено, що запропонований безітераційний алгоритм забезпечує точність обчислення витрат, визначену вимогами стандарту ДСТУ ГОСТ 8.586.5:2009. Отже, запропоновані рівняння та алгоритм обчислення витрати можуть застосовуватись у витратомірах на основі стандартного еліпсного сопла як для технологічного, так і для комерційного обліку плинних енергоносіїв. Використання розробленого алгоритму дає можливість пришвидшити розрахунок витрати енергоносія за допомогою мікропроцесорних контролерів.

Ключові слова: витрата; метод змінного перепаду тиску; звужувальний пристрій; еліпсне сопло; алгоритм.