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DESIGN OF FLOWMETERS FOR FLUID ENERGY CARRIERS BY MEANS OF "RASKHOD-RU" CAD

Yevhen Pistun, Leonid Lesovoy and Roman Fedoryshyn
Lviv Polytechnic National University, Lviv, Ukraine
epistun@polynet.lviv.ua, lleo_cat@yahoo.com, romanfedoryshyn@yahoo.com

Abstract: A new methodology for designing differential pressure flowmeters for fluid energy carriers has been developed in order to provide the minimum uncertainty of flowrate measurement results. This methodology is implemented in "Raskhod-RU" CAD system for the computer aided design and calculation of pressure differential flowmeters. "Raskhod-RU" CAD meets the requirements of new Standards (DSTU GOST 8.586.1,2,3,4,5-2009 and GOST 8.586.1,2,3,4,5-2005).

Key words: energy carrier, flowrate, measurement, uncertainty, design.

1. Introduction

The world prices for the energy resources have been rising up, which is caused by world market trends and by other factors. In Ukraine the situation is complicated by the fact that the major part of the most important energy carriers (natural gas and oil) needs to be purchased abroad (from Russia and other countries). Such a state of things sets a very important task – the task of energy carrier saving.

Efficient energy consumption and saving is possible only if metering is carried out with high accuracy and on every step and branch of supply of energy carriers. The accuracy of such metering is defined by a technical base, normative base, metrological base and the professional level of personnel.

The present situation on the US gas market (when there is the surplus of gas and its price is low) does not diminish the importance of accurate metering of fluid energy carriers (natural gas in particular) especially for countries in other parts of the world.

2. Normative base for flowrate measurement

In order to control consumption of fluid energy carriers (natural gas, hot water, overheated steam etc.) a pressure differential method is applied. This method is used for the measurement of energy carrier flowrate and volume in pipes with the internal diameter of 50 mm and more.

Metering of fluid energy carriers by means of pressure differential devices in Europe is carried out according to the requirements of ISO 5167.1,2,3,4-2003 [1,2,3,4]. In CIS countries the new Intergovernmental Standard GOST 8.586.1,2,3,4,5-2005 [5,6,7,8,9] is in force. The first four parts of this Intergovernmental Standard were developed as modified versions of ISO 5167.1,2,3,4-2003 and the fifth part of GOST 8.586.5-2005 covers the requirements of CIS laws on the measurement of energy carrier flowrate and volume and normalizes the procedure for measurements.

The Intergovernmental Standard GOST 8.586.1,2,3,4,5-2005 was developed by authors of this paper together with scientists and specialists from "Ukrmetrteststandard" National Standardization Body (Ukraine) and with experts from "Gazmetrologia" Field Metrology Centre of "Gazprom" Joint-Stock Company (Russia). This Standard was implemented in Russia in 2007 as a national Standard. In 2010 this Standard was implemented in Ukraine as DSTU GOST 8.586.1,2,3,4,5-2009.

The most important thing here is that according to the analysis we have carried out we can state that the implementation of the new Standard will provide the improvement of the accuracy of energy carrier metering.

It should be mentioned that the new Standards in force (ISO 5167.1,2,3,4-2003 and GOST 8.586.1,2,3,4,5-2005) considerably differ from previous Standards. The most significant distinctions are new limitations for the application of the pressure differential method, new mathematical formulae for the main coefficients of a flowrate equation, new requirements to pipe straight lengths and fittings, new requirements to the application of flow straighteners and flow conditioners and finally a new methodology for assessment of the uncertainty of flowrate and volume measurement results. The detailed comparative analysis of various normative documents on fluid flowrate measurement by means of the pressure differential method was given in [10].

An important distinction between GOST 8.586.1,2,3,4,5-2005 and ISO 5167.1,2,3,4-2003 is that the first one covers a wider area of the application of the pressure differential method. In particular there is a possibility of taking into account the roughness of pipe internal diameter by introducing an appropriate correction coefficient into the flowrate equation. In a similar way there is a possibility of taking into account other influencing factors. Additionally there is the normalization of fluid volume measurement in pressure differential flowmeters as well as the normalization of the uncertainties of fluid flowrate and volume measurement in GOST 8.586.1,2,3,4,5-2005.

3. Peculiarities in implementation of new standards

Naturally, such significant distinctions between the new Standards and the previous ones cause considerable difficulties during implementation of the former. In particular, for every flowmeter at least the following tasks have to be accomplished:

- verification of conditions (constraints) for the application of the pressure differential method according to the requirements of the new Standards;
- verification of pipe straight lengths according to the requirements of the new Standards;
- calculation of parameters of a primary device, pipe straight lengths and a flowmeter in general according to the requirements of the new Standards;
- calculation of the uncertainty of the results of fluid flowrate and volume measurements according to the requirements of the new Standards.

On the basis of the obtained data it is necessary to carry out the design of a flowmeter (and of a whole metering system) that is optimal with respect to measuring accuracy, i.e. a flowmeter providing the minimum uncertainty of the fluid flowrate and volume measurement.

The methodology of the verifications mentioned above, the calculation and design of pressure differential flowmeters were not formalized even for previous Standards. Therefore, we have developed a new formalized methodology according to the new Standards.

4. Description of "Raskhod-RU" CAD

In order to simplify the accomplishment of the tasks and implementation of new Standards mentioned above (ISO 5167.1,2,3,4-2003 and GOST 8.586.1,2,3,4,5-2005) we propose to implement the developed methodology of flowmeter calculations and design by means of a specialized computer program: a system for the computer aided calculation and design of pressure differential flowmeters.

Such a system named "Raskhod-RU" CAD [11] has been developed in the Institute of Energy Audit and Energy Carrier Accounting (www.ieoe.com.ua). By means of this computer program all the tasks of the verifications, calculations and design of flowmeters mentioned above can be accomplished. "Raskhod-RU" CAD meets the requirements of new Standards and has been certified in Ukraine and in Russia.

"Raskhod-RU" CAD is intended for the design of flowmeters for 48 fluids including the following: natural gas, humid oil gas, overheated steam, dry saturated steam, water, air, nitrogen, argon, oxygen etc. All valid procedures for the calculation of an expansibility factor for natural gas (NX19 mod.; GERG-91 mod.; AGA8-92DC mod.; VNIC SMV; SD 7-2005) are implemented in the software.

Currently "Raskhod-RU" CAD is available in Ukrainian, Russian, Kazakh and English.

The following four different algorithms of the calculation of flowmeter parameters have been implemented in "Raskhod-RU" CAD:

- calculation of flowmeter parameters for the given upper limit of differential pressure measurement;
- calculation of flowmeter parameters for the given tolerable pressure loss across a primary device;
- calculation of flowmeter parameters that secure the minimum uncertainty of flowrate measurement;
- calculation of flowmeter parameters for the given specifications of the primary device and a pipe (the so called inverse calculation of flowmeter).

The first three types of calculation are applied at the initial stage of the pressure differential flowmeter design. Here in the second and third type of calculation the optimization problem is solved to minimize pressure losses across the primary device or to minimize the uncertainty of flowrate measurement respectively. And the fourth type of calculation is applied to determine the parameters of an existing flowmeter and the conditions of its application according to the requirements of new Standards (ISO 5167.1,2,3,4-2003 and GOST 8.586.1,2,3,4,5-2005).

When designing a flowmeter, "Raskhod-RU" CAD gives the possibility for choosing one of the three possible configurations (schemes) of the flowmeter:

- with the separate measurement of flow parameters;
- with a flowrate and volume calculator;
- with a measuring complex.

Here the software provides the possibility of choosing up to four measuring transducers (installed in series) in each channel of the measurement of any flow parameter (fluid pressure, temperature or differential pressure across the primary device). In order to provide a wider range of flowrate measurement there is the possibility of specifying the parameters of additional measuring transducers (installed in parallel) in the channels of differential pressure measurement and fluid pressure measurement. The example of the application of two differential pressure transducers in a flowmeter for widening the range of flowrate measurements with an uncertainty of no more than 3 % is given in Fig.1.

After choosing the type of the problem to be solved (the type of calculation) the following input data should be entered (see Fig. 2):

- parameters and characteristics of the fluid;
- parameters and characteristics of the primary device;
- parameters and characteristics of the pipe;

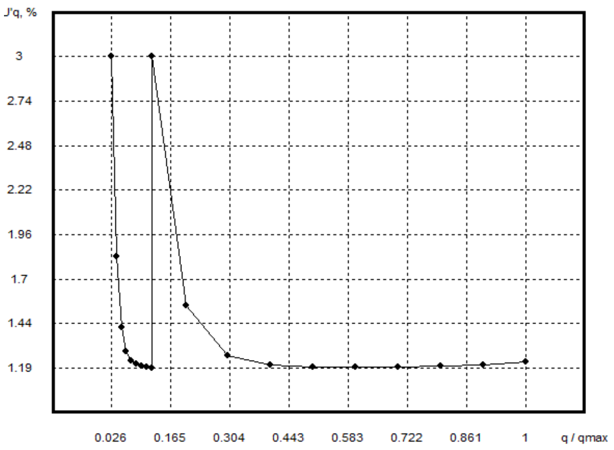


Fig. 1. The curve of relative expanded uncertainty of fluid flowrate measurement versus relative flowrate.

- parameters and characteristics of the pipe straight lengths and fittings;
- parameters and characteristics of the measuring and calculating instruments;
- parameters and characteristics of the flowmeter.

The part of the software for entering the parameters and characteristics of the fluid consists of the fields where the input data should be entered (the list of input parameters and characteristics is individual for each type of fluid). The parameters and characteristics for natural gas including the method for calculating the gas compressibility factor (GERG-91 mod.) are shown in Fig. 2.

The part of the software for entering the parameters and characteristics of the primary device (an orifice plate with corner pressure tappings in this example) is shown in Fig. 3. The list of the input parameters and characteristics is individual for each type of the primary device and pressure tappings. The drawing of the primary device appears in a dialog box after choosing the type of the primary device. All the types of standard primary devices according to ISO 5167.1,2,3,4-2003 are included in "Raskhod-RU" CAD. Similar dialog boxes have been implemented for other parameters and characteristics of the flowmeter.

It should be mentioned that the calculation and design of the differential pressure flowmeter is a multi-optional problem. "Raskhod-RU" CAD is an interactive program, which means that each action of a user is being analyzed and in case of a mistake or any wrong input data, the appropriate warnings, tips or recommendations are displayed by "Raskhod-RU" CAD. The most important tips are those concerning discrepancy between the input data and the requirements of new Standards. In this case "Raskhod-RU" CAD is like educational software for teaching the requirements of new Standards and for teaching the design of a pressure differential flowmeter.

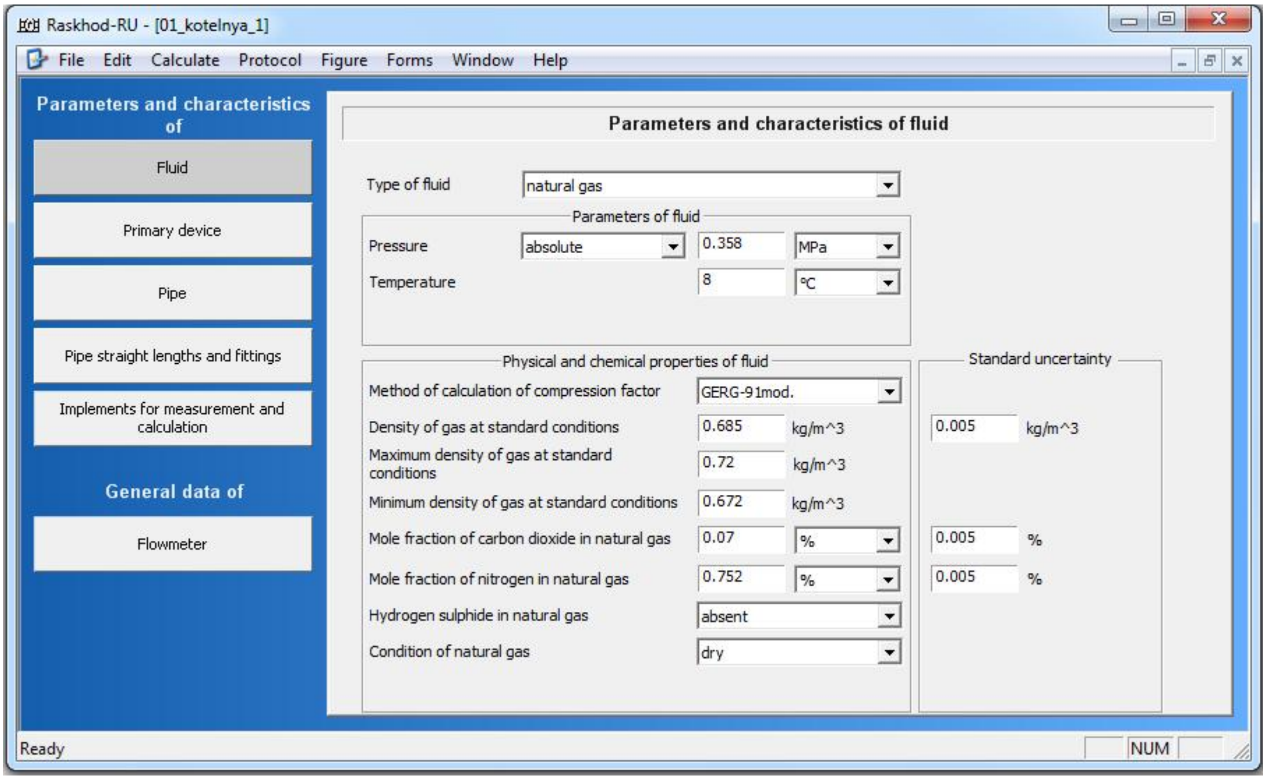


Fig. 2. The dialog box for entering the parameters and characteristics of the fluid (natural gas in this example).

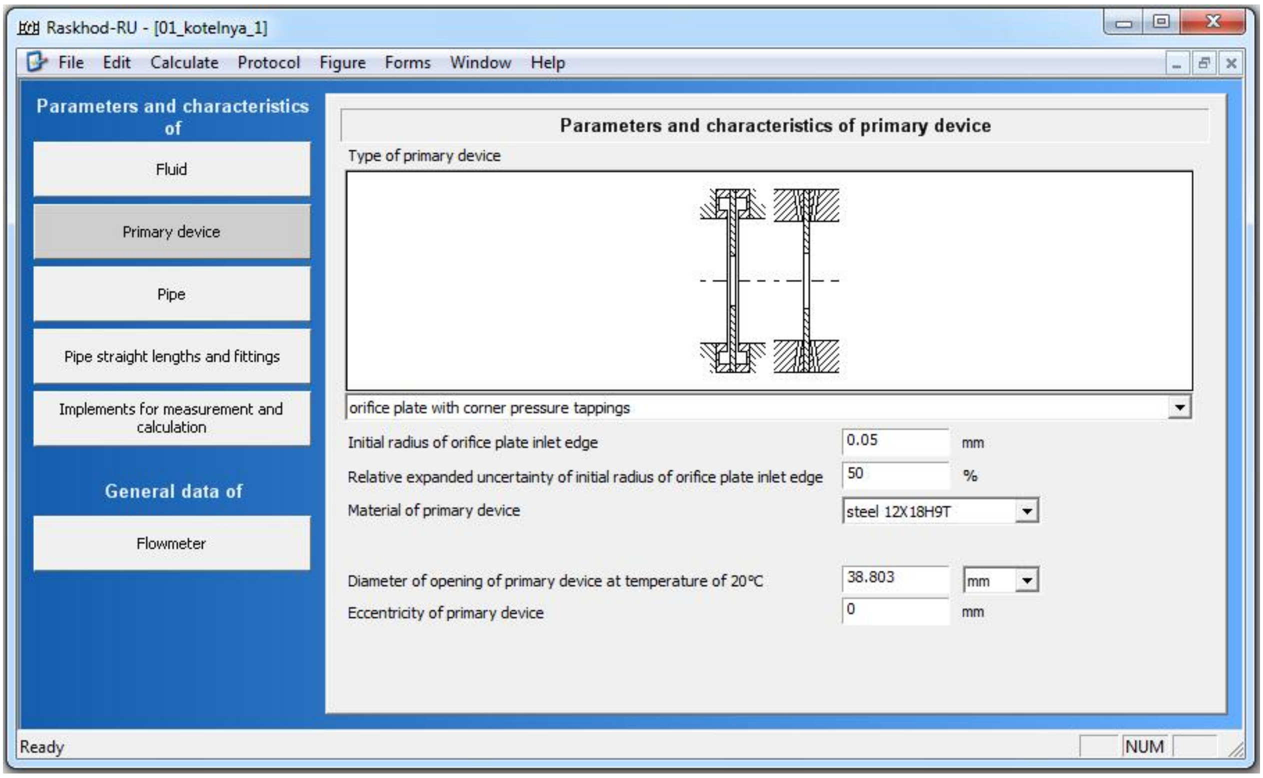


Fig. 3. The dialog box for entering the parameters and characteristics of the primary device (orifice plate in this example).

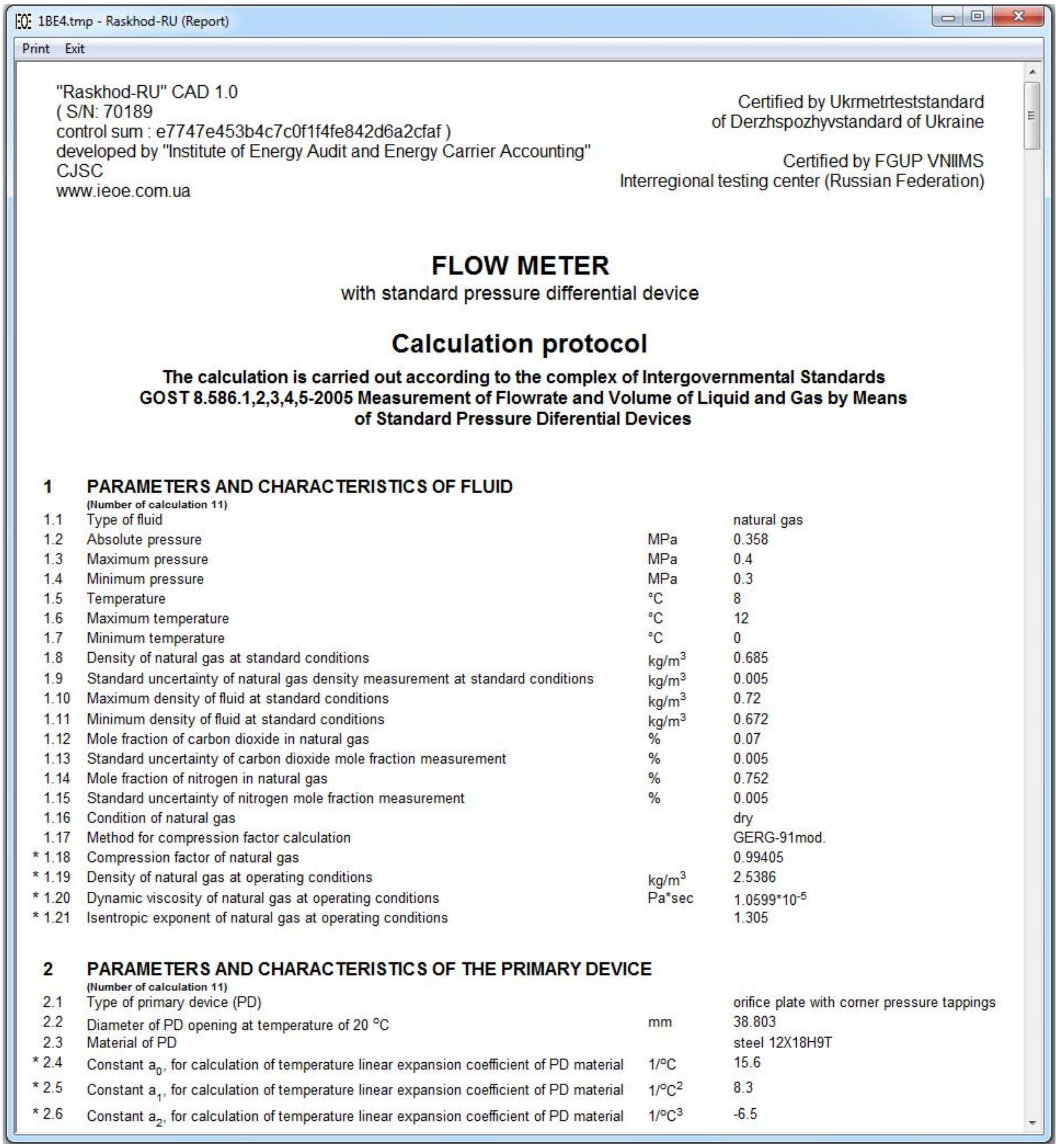
The interactive recommendations of "Raskhod-RU" CAD provide the possibility not only for designing a pressure differential flowmeter according to the requirements of new Standards but also for minimizing the uncertainty of flowrate measurements. Those recommendations should be taken into account by the user and the input data should be corrected according to them.

At the end of such an iterative process the calculation protocol for a differential pressure flowmeter which meets the requirements of the new Standards is returned by the software (see Fig. 4). We can get such a protocol without iterations if all the input data are correct. In any case "Raskhod-RU" CAD will not return the calculation protocol for a flowmeter which does not meet the requirements of the new Standards.

5. Advantages of "Raskhod-RU" CAD

The following advantages of "Raskhod-RU" CAD should be pointed out:

- the user friendly interface of the software providing quick and easy learning the possibilities of the software and using them to the maximum extent which is achieved by the logical and understandable distribution of input data among the dialogue boxes; the interface of the software has been developed in such a way that the dialog boxes are being changed during entering the input data (the fields for the unnecessary parameters and characteristics are taken away if not needed);
- an interactive shell for data input which is especially important for pipe straight lengths; in particular there is a possibility for using flow straighteners and flow conditioners in the pipe as well as various options for mounting the thermometer;
- the automatic control of dialogue boxes while entering the input data which makes it possible to avoid unexpected mistakes;
- a possibility for saving the input data files and no possibility for saving the calculation protocol (in order to prevent any distortions in the protocol);
- an impossibility for carrying out calculation and design and obtaining a calculation protocol for a flowmeter which does not meet the requirements of the new Standards;
- the display of warnings about additional component measurement errors and possible ways to eliminate those errors according to the requirements of new Standards;
- the high quality visualization of calculation results which simplifies the analysis and application of the results; there are curves of flowrate measurement uncertainty versus flowrate or other parameters; there are also drawings of primary devices, pipe straight lengths, fittings, etc.;
- reliable protection against the unauthorized use of the software.



1BE4.tmp - Raskhod-RU (Report)

Print Exit

"Raskhod-RU" CAD 1.0
(S/N: 70189
control sum : e7747e453b4c7c0f1f4fe842d6a2cfaf)
developed by "Institute of Energy Audit and Energy Carrier Accounting" CJSC
www.ieoe.com.ua

Certified by Ukrmetrteststandard
of Derzhspozhyvstandard of Ukraine

Certified by FGUP VNIIMS
Interregional testing center (Russian Federation)

FLOW METER
with standard pressure differential device

Calculation protocol

The calculation is carried out according to the complex of Intergovernmental Standards GOST 8.586.1,2,3,4,5-2005 Measurement of Flowrate and Volume of Liquid and Gas by Means of Standard Pressure Diferential Devices

1	**PARAMETERS AND CHARACTERISTICS OF FLUID** (Number of calculation 11)		
1.1	Type of fluid		natural gas
1.2	Absolute pressure	MPa	0.358
1.3	Maximum pressure	MPa	0.4
1.4	Minimum pressure	MPa	0.3
1.5	Temperature	°C	8
1.6	Maximum temperature	°C	12
1.7	Minimum temperature	°C	0
1.8	Density of natural gas at standard conditions	kg/m^3	0.685
1.9	Standard uncertainty of natural gas density measurement at standard conditions	kg/m^3	0.005
1.10	Maximum density of fluid at standard conditions	kg/m^3	0.72
1.11	Minimum density of fluid at standard conditions	kg/m^3	0.672
1.12	Mole fraction of carbon dioxide in natural gas	%	0.07
1.13	Standard uncertainty of carbon dioxide mole fraction measurement	%	0.005
1.14	Mole fraction of nitrogen in natural gas	%	0.752
1.15	Standard uncertainty of nitrogen mole fraction measurement	%	0.005
1.16	Condition of natural gas		dry
1.17	Method for compression factor calculation		GERG-91mod.
* 1.18	Compression factor of natural gas		0.99405
* 1.19	Density of natural gas at operating conditions	kg/m^3	2.5386
* 1.20	Dynamic viscosity of natural gas at operating conditions	Pa*sec	$1.0599*10^{-5}$
* 1.21	Isentropic exponent of natural gas at operating conditions		1.305
2	**PARAMETERS AND CHARACTERISTICS OF THE PRIMARY DEVICE** (Number of calculation 11)		
2.1	Type of primary device (PD)		orifice plate with corner pressure tappings
2.2	Diameter of PD opening at temperature of 20 °C	mm	38.803
2.3	Material of PD		steel 12X18H9T
* 2.4	Constant a_0, for calculation of temperature linear expansion coefficient of PD material	1/°C	15.6
* 2.5	Constant a_1, for calculation of temperature linear expansion coefficient of PD material	$1/°C^2$	8.3
* 2.6	Constant a_2, for calculation of temperature linear expansion coefficient of PD material	$1/°C^3$	-6.5

Fig. 4. Flowmeter calculation protocol.

6. Optimization criteria for the flowmeters

During the design of differential pressure flowmeters for fluid energy carriers both the structural and parametrical optimization can be applied. The first type of optimization includes the selection of the layout (scheme) of the system, types of the measuring implements and the primary device. The second type of optimization includes the selection of the parameters of the measuring implements and the dimensions of the primary device.

In general, during the design, the optimization criteria are chosen from a number of technical, economical or technological indexes. Such indexes for the differential pressure flowmeters can be: the accuracy or uncertainty of results of energy carrier flowrate measurement; speed, e.g. time constant for the measurement of one flowrate value; reliability; price; service costs etc. The optimization criterion can be chosen from the indexes listed above or as an *n*-dimensional vector consisting of those indexes. The vector should be reduced to a scalar by setting corresponding relations between its components (indexes).

Having analyzed various schemes of the flowmeters, we may conclude that only in the scheme with the separate measurement of flow parameters the following indexes become worse: reliability, price, service costs as well as speed. For other schemes those indexes do not change. Besides, the indexes listed above do not depend on the parameters of the primary device. Taking into account the information mentioned above, it is not rational to apply the listed above indexes as the optimization criteria during designing the differential pressure flowmeters.

Other indexes, such as the accuracy or uncertainty of the results of the energy carrier flowrate and volume measurement, depend significantly both on the scheme of the flowmeter and on the parameters of the primary device. That is why those indexes can be used as the optimization criteria while designing the differential pressure flowmeters.

Since the uncertainty of results of energy carrier flowrate and volume measurement depends on the value of the flowrate itself, the optimization criterion during the design of the differential pressure flowmeter should be taken as the value of the uncertainty at a specific value of the flowrate. Usually when making the assessment of the accuracy of the energy carrier flowmeter the value of the uncertainty at maximum flowrate is applied. So we shall take this uncertainty as the optimization criterion during the design of the differential pressure flowmeter:

$$F = U'_q \, (q_{\max}, b, \Delta p), \quad (1)$$

where U'_q is the relative expanded uncertainty of the results of the flowrate measurement; $q_{\max}$ is the maximum flowrate for a given flowmeter; b is the relative diameter of the primary device; Δp is the pressure difference at the primary device.

The following optimization problems can be solved for this criterion:

- to reach the minimum of the uncertainty:

$$\min(U'_q \, (q_{\max}, b, \Delta p)), \quad (2)$$

- to reach the minimum of the uncertainty with taking into account the pressure losses across the primary device:

$$\min(U'_q \, (q_{\max}, b, \Delta p)), \quad (3)$$

$$\Delta w(b, \Delta p) \le \Delta w_g ,$$

where Δw_g is the given value of pressure losses across the primary device.

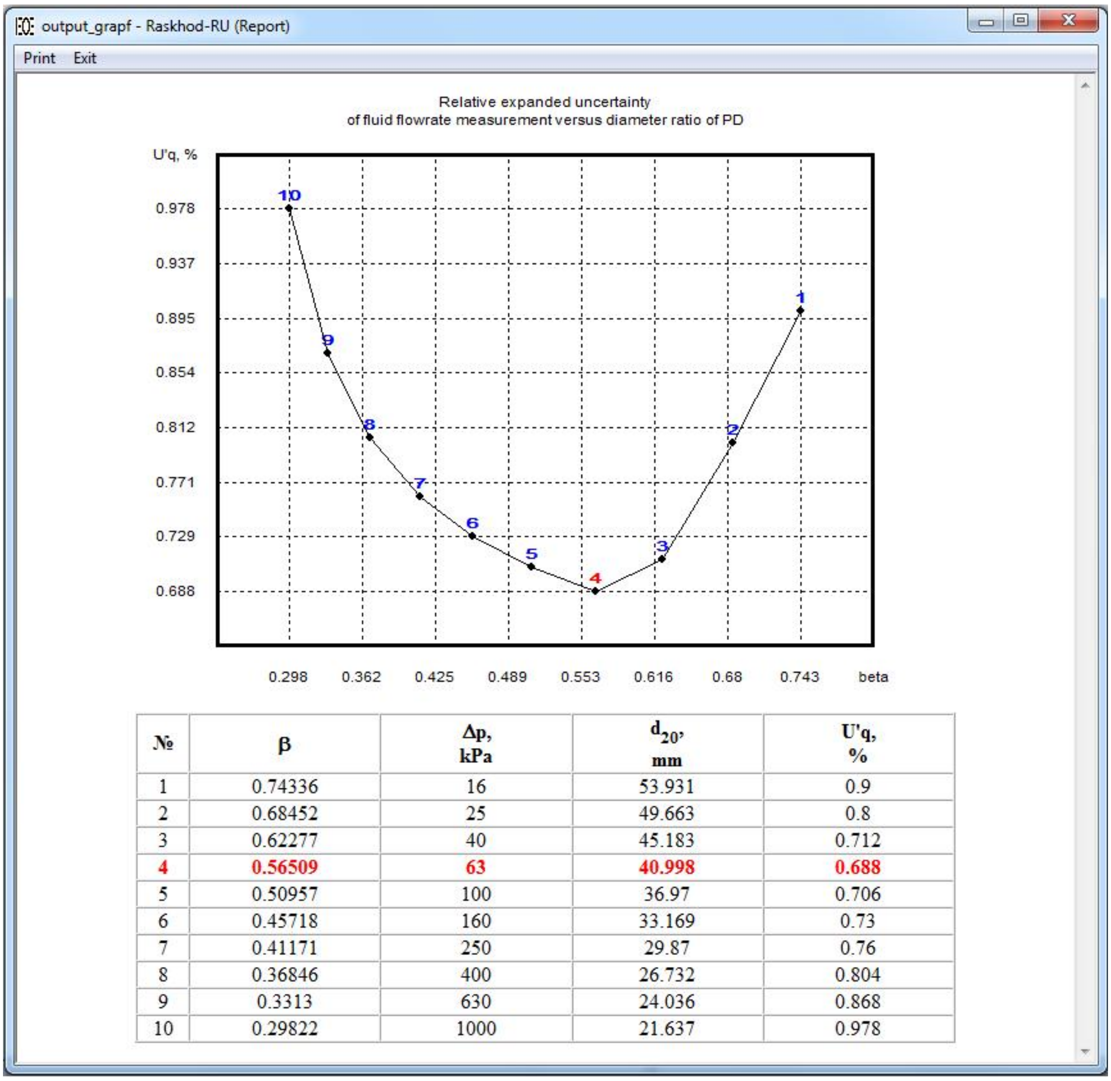
These particular optimization criteria have been taken and applied in “Raskhod-RU” CAD.

A significant advantage of “Raskhod-RU” CAD is the possibility for carrying out the design of a flowmeter with the optimal accuracy of the flowrate measurement. As an example, the curve of relative expanded uncertainty of fluid flowrate measurement versus the diameter ratio of a primary device is shown in Fig. 5. There is a table under the curve containing those values together with the upper limits of the differential pressure measurement and with the diameter of the opening of the primary device. Both the curve and the table demonstrate the possibility of obtaining the maximum accuracy of the flowrate measurement when designing the pressure differential flowmeter. In the given example the highest accuracy is obtained for flowmeter number four.

No matter what type of calculation is chosen by a user, the calculation results are returned in the following way. After all the input data being entered, the command “Design” should be selected in the top menu of the program (see Fig. 2, Fig. 3). Then the main calculation results are displayed in the same dialog box. After selecting “Protocol” in the top menu of the software, the calculation protocol with all the input parameters and characteristics together with calculation results and drawings is displayed in a separate window (see Fig. 4). After selecting “Figure”, the curve of the relative expanded uncertainty of the fluid flowrate measurement versus flowrate (or versus the diameter ratio of the primary device in the case of making the design of the flowmeter with the optimal accuracy of the flowrate measurement) is displayed in the same dialog box. The calculation results can be printed out.

7. Conclusion

The methodology for the calculation and design of pressure differential flowmeters has been developed by the authors according to the requirements of the new Standards (ISO 5167.1,2,3,4-2003 and GOST 8.586.1,2,3,4,5-2005). That methodology has been implemented in “Raskhod-RU” CAD which enables the computer aided calculation and design of the pressure differential flowmeters. At the same time the verification of conditions (constraints) for the application of the pressure differential method according to the requirements of the new Standards can be carried out by this computer program what significantly simplifies the process of the implementation and application of the new Standards. The application of flowmeters with the optimal accuracy of the flowrate measurement, proposed in “Raskhod-RU” CAD, will provide the improvement of the accuracy of fluid energy carrier metering.



№	β	Δp, kPa	d_{20}, mm	U'q, %
1	0.74336	16	53.931	0.9
2	0.68452	25	49.663	0.8
3	0.62277	40	45.183	0.712
4	**0.56509**	**63**	**40.998**	**0.688**
5	0.50957	100	36.97	0.706
6	0.45718	160	33.169	0.73
7	0.41171	250	29.87	0.76
8	0.36846	400	26.732	0.804
9	0.3313	630	24.036	0.868
10	0.29822	1000	21.637	0.978

Fig. 5. The curve of relative expanded uncertainty of fluid flowrate measurement versus diameter ratio of the primary device together with the table of the corresponding values.

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ПРОЕКТУВАННЯ ВИТРАТОМІРІВ ДЛЯ ПЛИННИХ ЕНЕРГОНОСІЇВ ЗА ДОПОМОГОЮ САПР "РАСХОД-РУ"

Євген Пістун, Леонід Лесовой, Роман Федоришин

Розроблено нову методологію проектування витратомірів змінного перепаду тиску, оптимальних за точністю вимірювання витрати, яка забезпечує мінімальну невизначеність результатів вимірювання витрати. Цю методологію реалізовано у системі автоматизованого проектування та розрахунку витратомірів змінного перепаду тиску САПР "Расход-РУ", яка відповідає вимогам нових стандартів (ДСТУ ГОСТ 8.586.1,2,3,4,5-2009).

Yevhen Pistun - Prof., D.Sc., The Head of the Department of Automation of Heat and Chemical Processes at Lviv Polytechnic National University, Ukraine. He obtained his degree of Doctor of Engineering Sciences in Instruments and Methods of Measurement of Mechanical Quantities in 1992. He has been working in Lviv Polytechnic National University since 1970 as a Teaching Assistant, Associate Professor, Professor, the Head of the Department. From 1992 to 2005he was Vice-Rector for research and production in Lviv Polytechnic National University. His research interests pertain to fluid flowrate measurements, mathematical modeling of flowmeters, automation of technological processes.

Leonid Lesovoy - D.Sc., Associate Professor of Department of Automation of Heat and Chemical Processes at Lviv Polytechnic National University, Ukraine. He obtained the degree of Doctor of Engineering Sciences in Instruments and Methods of Measurement of Mechanical Quantities in 2013. His research interests concentrate on the measurement of flowrate and volume of fluid energy carriers at steady and unsteady regimes, the simulation of flow regimes in pipelines, the design of microprocessor devices based on microcontroller series 8x51 and PIC18.

Roman Fedoryshyn - Ph.D. in Engineering Sciences, Associate Professor of the Department of Automation of Heat and Chemical Processes at Lviv Polytechnic National University, Ukraine. He obtained his Ph.D. degree in Instruments and Methods of Measurement of Mechanical Quantities in 2007.

His research interests are the measurement of flowrate and volume of natural gas, mathematical modeling of fluid flows, building algorithms and programs for flowmeters.