https://doi.org/10.30857/2786-5371.2022.2.1

УДК 681.121.8: 681.122

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ALGORITHM FOR SELECTING A FLOW METER WITH OPTIMAL PARAMETERS

Problems. *In many cases, the problem arises of choosing from a variety of alternatives to measuring instruments necessary for measuring the parameters of a technological process. So as that measuring instruments with different designs, operating principles and different technical and technological parameters are produced by different manufacturers. One of the important problems in the development of these systems is the selection of measuring instruments with optimal operational and metrological characteristics in accordance with the manufacturer's specifications and the terms of reference for the system design.*

Methodology. *Multiple criteria decision-making (MCDM) are used in order to solve problems related to several criteria. The high accuracy sensors ensure accurate readings, although there are several parameters involved in measuring process: flow rate; gas or gases used; temperature; operating pressure; pressure drop; price; accuracy; response time; warm-up time; stable measurement range (turndown) gas is selected.*

Findings. *Selection process of the optimal gas flow meter for information-measuring system is considered. Criteria for selection of the flow meters is studied, shown that the selection process is multi-criterial problem. Algorithm for selection of the gas flow meter is proposed. Proposed algorithm based on AHP method and TOPSIS. An idea of algorithm is following. İnitially experts select some alternatives, which meet all requirements for flow meters of different suppliers. At the next step the relative criteria of importance are calculated. After that decision matrixes are composed by which determine the preferences for the goals.*

Originality. *Better alternative or flow meter with optimal parameters is determined by ranking of all alternatives.*

Practical value. *Applying of the proposed algorithm increases reliability of the final decision and automates the selection process by using of the corresponding software.*

Keywords: *gas flow meter; selecting algorithm; multi-criteria; decision making.*

Introduction. The flow meters differ in the way of measuring the flow. A flow meter is measuring the flow either directly or indirectly. Results of this measurement may or may not depend on fluid properties. For example, one flow meter indicates mass flow calculated indirectly based on a differential pressure and given gas properties, and another flowmeter measures mass flow directly. In many cases, the problem arises of choosing from a variety of alternatives to measuring instruments necessary for measuring the parameters of a technological process. So as that measuring instruments with different designs, operating principles and different technical and technological parameters are produced by different manufacturers. One of these measuring instruments is a gas flow meter. At present, flow meters of various designs with a simple operating principle are used to measure and account for the flow (amount) of gas. The information and measurement systems to which these devices are connected can also be built on the basis of various concepts. Accurate measurements and metering of natural gas during production, transportation and distribution is very important in terms of optimizing these processes. One of the important problems in the development of these systems is the selection of measuring instruments with optimal operational and metrological characteristics in accordance with the manufacturer's specifications and the terms of reference for the system design.

Flow meter technologies. Naturally, such a choice is made using existing criteria and methods, based on information about the principle of operation of these devices, about the parameters that determine their design, about metrological indicators (accuracy and error, etc.), methods of receiving and transmitting information, about operating temperature and pressure, about the type of output signal and the functionality of measuring instruments [1].

Two primary thermal measuring methods of flow. The flow directly is measured by temperature sensors in each method. Measurements results in thermal method depend on gas properties, which depend on temperature of gas, so used gas tables that loaded into them [2].

The first method is the flow meter with the thermal bypass. It operates by following way. The small portion of the fluid directs to flow through a capillary tube which is wrapped by heating element with temperature sensors on the both sides. If there is no flow, temperature difference between the sensors is zero [3]. But the incoming flow passes the first sensor, then it heated as it passes the heating element, so second sensor indicates raised temperature. The temperature difference between these sensors will be directly proportional to the value of flow.

The second method uses of the thermal MEMS or CMOS for measuring of the flow. It operates on the differential temperature between the heated sensor and sensor that measures the flow temperature. If there is no flow, the difference between the temperature sensors is constant. A flow cools the flow temperature sensor, and to compensate for this change a heating current is increased. The value of this current will be proportional to the gas flow [4]. The largest advantages of instruments with MEMS sensor over thermal bypass devices are the small inertia and small size.

Another type of mass flow meters uses of the Coriolis principle to measure the mass flow independently of fluid properties. This sensor consists of one or two tubes, that are oscillated at the tube's resonant frequency by the special electromagnet. The mechanical waves of tubes are measured by sensors at different points along of the tube [5]. If there is no flow, the oscillates on the tube propagate symmetrically, and there is no phase shift between the measuring points. Twisting of the tube during the flow passes through it, causes a phase shift between the measuring points that is proportional to the mass flow rate. These measurements do not dependence on pressure. The only temperature influence will cause of changing of frequency of mechanical oscillations, that leads to zero shifts, which is smaller than other measurement methods [6].

In the laminar flowmeters measuring of the mass flow performed indirectly based on differential pressure. In these flowmeters contain of the elements that convert turbulent flow into laminar [7]. A sensor is carried out measurements of the pressure drop on these elements, and the flowmeter uses this data in Poiseuille equation to determination a volumetric flow rate. The flowmeter then converts of this measurement results to standardized mass flow using tables of gas properties that take into account of the temperature and pressure influence. The high accuracy sensors ensure accurate readings, although there are several parameters involved in measuring process. So as the mass flow value is different for each gas, for choosing a mass flow meter it is necessary to take into account following of the 10 parameters [8]:

1. Flow rate.
2. Gas or gases used.
3. Temperature.
4. Operating pressure.
5. Pressure drop.
6. Price.
7. Accuracy.
8. Response time.
9. Warm-up time.
10. Stable measurement range (turndown) gas is selected.

Research method. Multiple criteria decision-making [9] (MCDM) are used in order to solve problems related to several criteria. Multiple criteria decision-making are regrouped into two partssections AHP and TOPSIS applied in the field of this research. AHP method is an mostly applied MCDM technique. It provides a structural and hierarchical method for formulate software for the selection problems and used to carried out of calculation of the weights of selection criteria [18], and

TOPSIS technique is applied to ranking of the alternative based on the overall performance of them. The integrated methodology proposed above has some advantages compared to the techniques proposed in the literature, as follows: 1) it is suitable for the evaluation and selection of flowmeter regarding to preferences of the experts depending on their experiences; 2) the weights of multiple and conflicting criteria can be obtained by pair-wise comparisons according to decision-makers' preferences; and 3) the total ranking of the computed alternatives is ensured [10].

AHP method is the structuring process the decision hierarchy taking into account the goal of the studied problem [24] and determination of the criteria and sub-criteria and formulating a set of all estimations in the comparison matrix, where the set of elements is compared with another by using based on scale of pair-wise comparison [12].

TOPSIS method proposed in [14] for solving decision making problems with multiple criteria. the concept of this method based on the choosing alternative that should have the shortest distance to the positive ideal solution (A*) and the longest distance from the negative ideal solution (A−). For example, on the positive ideal solution the functionality is maximized and the cost is minimized, meanwhile on the negative ideal solution the cost is maximized and the functionality is minimized [11]. In the solution process by TOPSIS, the performance ratings of studied object and the weights of the criteria should be given as exact values [16]. Recently, several interesting studies have focused on the TOPSIS technique and applied it in many fields, including supplier selection, tourism destination evaluation, financial performance evaluation, location selection, company evaluation, and ranking the carrier alternatives. Examples of those studies are described in the literature: ERP software selection [13], design process of the customer-driven product [18], open-source for EMR software packages [33]. Let us consider development of TOPSIS model.

Statement of the problem**.** This multi-criterion decision-making problem contains different and conflicting criteria. [15] Therefore, after analyzing the necessary parameters of the flow meters included in the set for selection, these flow meters were selected finally by experts according to four main criteria: C_1-accuracy, C_2-reliability, C_3-survivability, C_4-price and cost of maintenance. Next, we solve the problem of selecting a flow meter from the resulting series with alternatives (A, B, C, D) [17].

The relative importance between the two criteria for selecting of the gas flow meter is measured on a numerical scale from 1 to 9, as represented in Table 1.

Table 1

Relative importance

Value	**Interpretation**
1	j and k equally important
3	j is slightly more important than k
5	j is strongly more important than k
7	j is very strongly more important than k
9	j is absolutely strongly more important than k

Table 2 shows the ratings of linguistic performances according to various criteria.

Table 2

Linguistic performance rating

Criteria	C_1	C_2	C_3	C_4
C_1	1	1/5	1/3	5
C_2	5	1	5	1/7
C_3	3	1/5	1	3
C_4	1/5	7	1/3	1

Pair wise comparisons are not required if the items being compared are expressed in the same units and using an appropriate precision meter. The answer to the question of how important one item is over another is presented as a simple combination of the dimensions of all items [19].

So, let's solve the problem of choosing a gas flow meter for an information-measuring system according to many criteria using an algorithm proposed below.

Solutions of the problem**.** This algorithm is a combination of the AHP (Analytical Hierarchy Process) and TOPSIS methods. AHP, proposed by Saaty, is a multi-criterial decision-making method used to assess and determine the importance of relative weights for decision criteria [20].

It is widely used to analyze and structure complex decision-making problems. The decision-making process is initially divided into various criteria. The AHP method can be applied to make decision in calculating weights for each criterion and evaluating them by pairwise comparison. AHP has attracted the interest of many researchers, mainly because of the excellent mathematical properties of the method and the ease of obtaining the required input data. The AHP method is a stable and flexible decision-making tool in a multi-criteria environment for solving complex decision-making problems. This method separates a complex system into a system of hierarchical elements, usually consisting of goals, evaluation criteria and alternatives. The assessment criteria level can be composed of various assessment criteria, which can be extended to a multi-level structure. There are following main steps of the AHP methodology [21]:

Step 1: Formation of the decision matrix. The rows of the decision matrix contain the alternatives that are given priority, and the columns contain the criteria used in making decisions. This matrix is the original matrix created by the decision maker. The decision matrix is displayed as follows:

$$A_{ij} = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{m1} & a_{m2} & \dots & a_{mn} \end{bmatrix}. \quad (1)$$

where *m* is the number of alternatives; *n* is the number of evaluation factors – criteria.

Step 2: Formation of the standard decision matrix R. The standard decision matrix is calculated using the elements of the matrix A by the following formula [23]:

$$r_{ij} = \frac{a_{ij}}{\sqrt{\sum_{k=1}^{m} a_{kj}^2}}. \quad (2)$$

The R matrix looks like this:

$$R_{ij} = \begin{bmatrix} r_{11} & r_{12} & \dots & r_{1n} \\ r_{21} & r_{22} & \dots & r_{2n} \\ \dots & \dots & \dots & \dots \\ r_{m1} & r_{m2} & \dots & r_{mn} \end{bmatrix}. \quad (3)$$

Step 3: Formation of the standard weighted decision matrix (V).

$$V_{ij} = \begin{bmatrix} w_1 r_{11} & w_2 r_{12} & \dots & w_n r_{1n} \\ w_1 r_{21} & w_2 r_{22} & \dots & w_n r_{2n} \\ \dots & \dots & \dots & \dots \\ w_1 r_{m1} & w_2 r_{m2} & \dots & w_n r_{mn} \end{bmatrix}. \quad (4)$$

Step 4: Ranking of the scenario, which is done by sorting the total points in descending order.

One of the multi-criteria decision-making models is the TOPSIS [22]. This method was developed to solve the problem of multi-criteria decision-making based on the concept that the chosen alternative is at the shortest distance from the positive ideal solution (A^*) and the largest distance from the negative ideal solution (A^-) [25]. The TOPSIS method is used to obtain the final rating. Some of the advantages of this method are simplicity, rationality, good understanding, good computational efficiency, and the ability to measure the relative capabilities of each alternative in a simple mathematical way. The chosen alternative should be located at the shortest distance from the positive ideal solution and at the greatest distance from the negative ideal solution [27].

The main stages of multi-criteria decision-making are as follows [30]:

Step 1: Formation of a normalized decision matrix that transforms properties of different dimensions into dimensionless properties, allowing you to compare properties using formula (2).

Step 2: Formation of a weighted normalized decision matrix using formula (4).

Step 3: Calculate the positive ideal (A^*) and negative ideal (A^-) solutions. The TOPSIS method assumes that each factor - assessment criterion has a monotonically increasing or decreasing character [26]. Calculation of the set of ideal solutions by the following formula:

$$\begin{aligned} A^* &= \left\{ \left(\max_i v_{ij} \middle| j \in J \right), \left(\min_i v_{ij} \middle| j \in J \right) \right\} \\ A^* &= \left\{ v_1^*, v_2^*, \dots, v_n^* \right\} \end{aligned} \quad (5)$$

Step 4: The set of negative ideal solutions chooses the largest of the values in the columns of the matrix V (the largest when the corresponding criterion is maximized). The set of negative ideal solutions is calculated using the following formula:

$$\begin{aligned} A^- &= \left\{ \left(\min_i v_{ij} \middle| j \in J \right), \left(\max_i v_{ij} \middle| j \in J \right) \right\} \\ A^- &= \left\{ v_1^-, v_2^-, \dots, v_n^- \right\} \end{aligned}. \quad (6)$$

Step 5: Calculating distance values. Distance from positive ideal solution

$$S_i^* = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^* \right)^2}. \quad (7)$$

Distance from negative ideal solution

$$S_i^- = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^- \right)^2}. \quad (8)$$

Step 6: Determination of the relative closeness to the ideal solution.

$$C_i^* = \frac{S_i^-}{S_i^- + S_i^*}. \quad (9)$$

Step 7. Priority row ranking: Alternatives C can be ranked in descending order.

Considering the steps described above we solve problem of the selection of the gas flow meter [31].

It is recommended to investigate the properties of the comparison matrix during accurate measurements. A pairwise comparison matrix is a consistent matrix for accurately comparing any number of items.

AHP is a powerful method and can be used to make decisions during many conflicting criteria and both qualitative and quantitative aspects of the decision are considered. AHP allows to pairwise comparison of complex solutions [32].

First, using formula (2), we determine the preferences for the goals shown in Tables 1 and 2, and the weights calculated for these goals [28].

$$C_{11} = \frac{1}{\left(1+5+3+\frac{1}{5}\right)} = 0{,}11.$$

Average weight for

$$C_1 = \frac{(0{,}11+0{,}06+0{,}04+0{,}55)}{4} = 0{,}18.$$

Other calculated weights (average)

$$C_2 = 0{,}36;\; C_3 = 0{,}21;\; C_4 = 0{,}25$$

Table 3

Weights for criteria

Criteria	C_1	C_2	C_3	C_4	**Average**
C_1	0.11	0.06	0.04	0.55	0.18
C_2	0.54	0.12	0.75	0.015	0.36
C_3	0.33	0.02	0.15	0.33	0.21
C_4	0.02	0.83	0.05	0.11	0.25

At the next stage, we define for each alternative different relative criterion. The relative values of properties and functionality were calculated as examples and are presented in Table 4.

Table 4

Property and functionality values

C_1	A	B	C	D	
A	1	1/3	5	1/3	
B	3	1	1/3	1/3	
C	1/5	3	1	5	
D	3	3	1/5	1	
C_1	A	B	C	D	**Average**
A	0.14	0.05	0.76	0.05	0.25
B	0.42	0.14	0.05	0.05	0.34
C	0.03	0.41	0.15	0.75	0.34
D	0.42	0.41	0.08	0.15	0.27

In the same way, we determine the relative values for other alternatives and results shown in table 4.

Table 5

Relative values for alternatives

Criteria	A	B	C	D
C_1	0.25	0.34	0.34	0.27
C_2	0.05	0.44	0.31	0.25
C_3	0.21	0.38	0.36	0.40
C_4	0.51	0.01	0.29	0.19

Finally, we calculate the weights for the alternatives (Table 3) and rank them according to the relative values for every alternative (Table 4):

$$A = 0{,}25 \cdot 0{,}18 + 0{,}05 \cdot 0{,}36 + 0{,}21 \cdot 0{,}21 + 0{,}51 \cdot 0{,}25 =$$
$$= 0{,}045 + 0{,}018 + 0{,}044 + 0{,}127 = 0{,}23;$$
$$B = 0{,}34 \cdot 0{,}18 + 0{,}44 \cdot 0{,}36 + 0{,}38 \cdot 0{,}21 + 0{,}01 \cdot 0{,}25 =$$
$$= 0{,}061 + 0{,}0158 + 0{,}08 + 0{,}0025 = 0{,}25;$$
$$C = 0{,}34 \cdot 0{,}18 + 0{,}31 \cdot 0{,}36 + 0{,}36 \cdot 0{,}21 + 0{,}29 \cdot 0{,}25 =$$
$$= 0{,}061 + 0{,}011 + 0{,}075 + 0{,}11 = 0{,}25;$$
$$D = 0{,}27 \cdot 0{,}18 + 0{,}25 \cdot 0{,}36 + 0{,}40 \cdot 0{,}21 + 0{,}19 \cdot 0{,}25 =$$
$$= 0{,}049 + 0{,}09 + 0{,}084 + 0{,}047 = 0{,}27.$$

After ranking the alternatives, we determine that alternative D is better than the other alternatives.

The TOPSIS is used to decide by computer, and the best alternative chosen would be the shortest distance from the positive and the longest distance from the negative ideal solution. After forming the normalized and weighted normalized matrix (table 6), we determine the ideal and negative ideal solutions by formulas (5) and (6) [28]:

Table 6

Weight Normalized Matrix

	C_1	C_2	C_3	C_4
A	0.25	0.05	0.21	0.51
B	0.34	0.44	0.38	0.01
C	0.34	0.31	0.36	0.29
D	0.27	0.25	0.40	0.19

At the next stage, the distance from the ideal solution and the distance from the negative ideal solution are calculated by using formulas (7) and (8). Thus, for alternative A will have got:

$$S_A^* = \sqrt{\sum_{j=1}^{4}\left(A_{ij} - A^*\right)^2} = (0{,}25 - 0{,}34) + (0{,}05 - 0{,}44) + (0{,}21 - 0{,}40) + (0{,}51 - 0{,}51) = 0{,}41$$

$$S_A^- = \sqrt{\sum_{j=1}^{4}\left(A_{ij} - A^-\right)^2} = (0{,}25 - 0{,}25) + (0{,}05 - 0{,}05) + (0{,}21 - 0{,}21) + (0{,}51 - 0{,}01) = 0{,}5$$

Relative closeness to ideal solution

$$C_A^* = \frac{S_A^-}{S_A^- + S_A^*} = \frac{0{,}5}{(0{,}41 + 0{,}5)} = 0{,}54$$

For other alternatives

$$C_B^* = \frac{S_B^-}{S_B^- + S_B^*} = \frac{0,43}{(0,50 + 0,43)} = 0,46;$$

$$C_C^* = \frac{S_C^-}{S_C^- + S_C^*} = \frac{0,42}{(0,29 + 0,42)} = 0,59;$$

$$C_D^* = \frac{S_D^-}{S_D^- + S_D^*} = \frac{0,33}{(0,10 + 0,32)} = 0,78.$$

After ranking the alternatives, we find that alternative D is superior to the other alternatives.

Thus, considering the opinion of an expert or experts, using the AHP and TOPSIS methods, based on the selection criteria, we refine the decision on choosing a flow meter among alternatives, which is superior in parameters and indicators [29].

CONCLUSIONS

Selecting the flowmeter with optimal parameters for an application is not complicated, if knowing what parameters are important and how does take into account. This way will be doing order makes the decision much easy. For the significantly narrowing of choosing area it is necessary by first ensuring requirements for flow rate, temperature and gas properties are met. Then, take into account of the controlled parameters: an operating pressure and pressure drop. After this, analysis budget and specific parameters of application. It is concerned such as accuracy, warm-up and response time, dynamic range of some controlled parameters. All steps and these recommendations, will help choosing of the optimal mass flowmeter based on solution by taking into account of the requirements of a proposed methodology.

Proposed algorithm consisted of two methods uses initial information about selection of the required measurement device with optimal parameters.

Initial information prepared by experts, who study all technical and metrology parameters of the device and prepares information about alternative devices. This information is processed in the next stage for find optimal device by proposed algorithm, that allows automate decision making above mention process.

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АЛГОРИТМ ВИБОРУ ВИТРАТОМІРУ З ОПТИМАЛЬНИМИ ПАРАМЕТРАМИ

Проблеми. *У багатьох випадках виникає проблема вибору з безлічі альтернатив засобів вимірювальної техніки, необхідних для вимірювання параметрів технологічного процесу. Тому вимірювальні прилади з різними конструкціями, принципами роботи та різними техніко-технологічними параметрами випускаються різними виробниками. Однією з важливих проблем при розробці цих систем є вибір засобів вимірювальної техніки з оптимальними експлуатаційними та метрологічними характеристиками відповідно до технічних умов виробника та технічного завдання на проектування системи.*

Методика. *Прийняття рішень за кількома критеріями використовуються для вирішення проблем, пов'язаних з кількома критеріями. Датчики високої точності забезпечують точні показання, хоча в процесі вимірювання беруть участь кілька параметрів: швидкість потоку; газ або використані гази; температура; робочий тиск; перепад тиску; ціна; точність; час реакції; час розігріву; вибрано стабільний діапазон вимірювання (зниження) газу.*

Результати. *Розглянуто процес вибору оптимального витратоміра газу для інформаційно-вимірювальної системи. Досліджено критерії вибору витратомірів, показано, що процес відбору є багатокритеріальним завданням. Запропоновано алгоритм вибору витратоміра газу. Запропонований алгоритм на основі методу AHP та TOPSIS. Ідея алгоритму наступна. Спочатку експерти вибирають кілька альтернатив, які відповідають усім вимогам до витратомірів різних постачальників. На наступному кроці розраховуються відносні критерії важливості. Після цього формуються матриці рішень, за якими визначаються переваги до цілей.*

Наукова новизна. *Краща альтернатива або витратомір з оптимальними параметрами визначається ранжуванням усіх альтернатив.*

Практична значимість. *Застосування запропонованого алгоритму підвищує надійність остаточного рішення та автоматизує процес відбору за допомогою відповідного програмного забезпечення.*

Ключові слова: *витратомір газу; алгоритм вибору; багатокритеріальний; прийняття рішення.*

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АЛГОРИТМ ПОДБОРА РАСХОДОМЕРА С ОПТИМАЛЬНЫМИ ПАРАМЕТРАМИ

Проблемы. *Во многих случаях возникает проблема выбора из множества альтернатив средств измерений, необходимых для измерения параметров технологического процесса. Так как средства измерений с различной конструкцией, принципом действия и разными технико-технологическими параметрами выпускаются разными производителями. Одной из важных проблем при разработке этих систем является выбор средств измерений с оптимальными эксплуатационными и метрологическими характеристиками в соответствии с техническими условиями производителя и техническим заданием на проектирование системы.*

Методика. *Принятие решений по нескольким критериям используется для решения проблем, связанных с несколькими критериями. Датчики высокой точности обеспечивают точные показания, хотя в процессе измерения участвуют несколько параметров: скорость потока; используемый газ или газы; температура; рабочее давление; падение давления; цена; точность; время отклика; время прогрева; выбран стабильный диапазон измерения (диапазон) газа.*

Результаты. *Рассмотрен процесс выбора оптимального расходомера газа для информационно-измерительной системы. Изучены критерии выбора расходомеров, показано, что процесс выбора является многокритериальной задачей. Предложен алгоритм выбора расходомера газа. Предлагаемый алгоритм основан на методе AHP и TOPSIS. Идея алгоритма следующая. Первоначально специалисты отбирают несколько вариантов, отвечающих всем требованиям, предъявляемым к расходомерам различных поставщиков. На следующем шаге рассчитываются относительные критерии важности. После этого составляются матрицы решений, по которым определяются предпочтения по целям.*

Научная новизна. *Лучшая альтернатива или расходомер с оптимальными параметрами определяется ранжированием всех альтернатив.*

Практическая значимость. *Применение предложенного алгоритма повышает достоверность окончательного решения и автоматизирует процесс выбора за счет использования соответствующего программного обеспечения.*

Ключевые слова: *расходомер газа, алгоритм выбора, многокритериальность, принятие решения.*