

**THE ROLE OF MATHEMATICAL MODELING IN ASSESSING THE UNCERTAINTY
OF FLOW STANDARDS AND THE ASSOCIATED RISKS**

Bekmurotov Chori Abdullayevich

Associate Professor Avezov Nodirbek Egambergonovich

Inagamdjanov Doniyor Tuxtamuratovich

Usmonov Hamzali Qambarali o'g'li

¹ *Tashkent State Technical University named after Islam Karimov, Associate Professor of the Department of Metrology, Technical Regulation, Standardization and Certification, Doctor of Philosophy (PhD) in Technical Sciences.*

² *Uzbekistan National Metrology Institute, State Institution — Specialist, Independent Researcher*

Abstract. *Flow standards (standards for measuring gas or liquid flow rates) occupy a central position in the metrological system. Accurate assessment of their uncertainty is essential for reliable calibration, industrial accounting, and commercial measurement operations. In this process, mathematical modeling plays a decisive role.*

Mathematical models used in flow determination enable the study of uncertainty sources, the influence of parameters, and the mechanisms of uncertainty propagation. At the same time, factors such as incorrect model selection, errors in input parameters, neglect of correlations, numerical computation inaccuracies, and failure to validate model results against experimental data can adversely affect uncertainty estimates. This article proposes approaches aimed at mitigating these risks and enhancing the reliability of flow standards.

Keywords: *flow standard, measurement uncertainty, mathematical modeling, analysis of measurement results, risks, accuracy.*

Аннотация. *Эталоны расхода (эталоны измерения расхода газа или жидкости) занимают центральное место в метрологической системе. Точная оценка их неопределённости является необходимым условием обеспечения достоверности калибровки, промышленного учёта и коммерческих измерений. В этом процессе решающую роль играет математическое моделирование.*

Математические модели, применяемые при определении расхода, позволяют исследовать источники неопределённости, влияние параметров и механизмы распространения неопределённости. В то же время такие факторы, как неправильный выбор модели, ошибки входных параметров, игнорирование корреляций, численные ошибки вычислений и отсутствие подтверждения результатов модели экспериментальными данными, могут отрицательно влиять на оценку неопределённости. В статье предложены подходы,



направленные на снижение этих рисков и повышение надёжности эталонов расхода.

Ключевые слова: *эталон расхода, неопределённость измерений, математическое моделирование, анализ результатов измерений, риски, точность.*

The mathematical modeling of measurement results is the process of expressing the measurement procedure, the quantity being measured, and the factors influencing the measurement through mathematical equations, functions, and algorithms.

Furthermore, the primary purpose of mathematical modeling is to represent real physical or technical processes through mathematical relationships, thereby enabling analysis, prediction, and optimization of those processes. The main tasks include the following processes (1):

$$(1) \quad Q = f(x_1, x_2, \dots, x_n)$$

Here, Q denotes the flow rate, while x_i represents parameters such as pressure, temperature, density, time, volume, sensor readings, and other influencing variables.

Through modeling, sources of uncertainty are identified, the contribution of each factor is evaluated, uncertainty propagation is calculated, and the combined uncertainty is determined. This is typically performed using the GUM (Guide to the Expression of Uncertainty in Measurement) framework or Monte Carlo methods.

Modeling reduces the need for costly experiments, enables virtual testing under various operating conditions, facilitates sensitivity analysis of parameters, and supports the selection of optimal system designs.

The main risks arising in the assessment of flow standard uncertainty include the following:

1) Incorrect model selection.

If the physical process is oversimplified or improperly represented, the calculated uncertainty will not reflect actual conditions.

2) Uncertainty in input parameters.

Incorrect statistical data or insufficient measurement data for parameters may lead to inaccurate uncertainty evaluation.

3) Neglecting correlations between parameters.

In many cases, parameters such as temperature and pressure are interdependent, yet they are often assumed to be independent within models.

4) Numerical computation errors.

In computer-based calculations, the following factors may affect the reliability of uncertainty evaluation results:

– discretization errors,



- approximation errors,
 - algorithmic instability.
- 5) Software-related errors.

Programming mistakes or incorrect application of algorithms may distort results.

6) Lack of experimental validation of the model.

If the model is not compared with practical measurement results, its reliability becomes questionable.

To reduce risks in uncertainty assessment of flow standards, the following measures are recommended:

- validation of the model using experimental results,
- performing parameter sensitivity analysis,
- applying Monte Carlo methods,
- comprehensive accounting of all uncertainty sources,
- verification of computational software,
- consideration of parameter correlations.

CONCLUSION

The article analyzes the role of mathematical modeling in evaluating the uncertainty of flow measurement standards, as well as the main risks arising in this process. The study results demonstrate that, within modern metrology systems, mathematical modeling has become an indispensable tool for ensuring high-accuracy flow measurements. It enables the integration of numerous parameters influencing flow determination into a unified computational model, allowing assessment of their individual contributions and the evaluation of overall measurement uncertainty.

Through modeling, it becomes possible to reduce the number of costly experimental studies, predict operating conditions in advance, analyze parameter sensitivity, and optimize standard measurement facilities. At the same time, excessive reliance on modeling results may introduce certain risks.

Therefore, the results obtained through mathematical modeling must always be compared with experimental data, sensitivity analyses should be conducted, and computational algorithms must be regularly verified to ensure reliability.

In conclusion, mathematical modeling represents a highly effective approach for evaluating the uncertainty of flow standards. However, its successful application critically depends on the adequacy of the model, the reliability of input data, and the proper organization of computational procedures. Combining modeling techniques with experimental investigations in scientific and practical applications makes it possible to further enhance the metrological reliability of flow measurement standards.



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