positions, velocities and accelerations. Software implementation in Pascal (`assur` module) confirms the correctness of the model. Further research may include consideration of dynamic factors (friction, inertia) and extension of the model to analyse multi-link systems.

Prospects of application of the developed model:

– Optimisation of motor and pump designs

– creation of digital twin mechanisms for industrial monitoring.

The developed mathematical model can be used as a basis for engineering solutions in the field of energy efficiency and reliability of machines.

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METHODS FOR DETERMINING THE MASS FRACTION OF CRUDE FIBRE WITH CONSIDERATION OF MEASUREMENT UNCERTAINTY

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Accurate measurement of crude fibre content is essential for product quality control, regulatory compliance and ensuring efficient feed utilization. However, the results of analyses can be subject to various sources of uncertainty that need to be considered to improve the reliability of the data. This article discusses methods for determining the mass fraction of crude fibre, their features, and approaches to estimating measurement uncertainties.

Objective of the study**.** The aim of this study is to investigate methods for determining the mass fraction of crude fibre, taking into account factors affecting the accuracy of the analysis, such as equipment errors, analysis conditions and human factors. Particular attention is paid to the calculation of measurement uncertainties to ensure the reliability of the results.

Material and methods. The work is based on the results of analysis of scientific and technical information, normative documents (GOST 13496.2-91) and researches devoted to methods of determination of crude fibre, its physical and chemical properties and application of modern technologies.

Results and their discussion. Classification of methods for determining the mass fraction of crude fibre was performed. On the basis of the analysis, the methods of determination of crude fibre content can be divided into the following groups:

1) **Classical methods**:

– gravimetric method – based on treatment of the sample with weak acids and alkalis, subsequent precipitation and drying of the insoluble residue;

– Weindaus method – involves the use of special reagents for fibre extraction.

2) **Modern methods**:

– NIR spectroscopy – analysing the spectral characteristics of the sample;

– machine learning methods – prediction of fibre content based on input parameters.

As a result of the analysis, common characteristics of the methods are highlighted. All methods considered are aimed at quantitative determination of crude fibre content, but differ in principle of operation, speed of analysis, cost and destructiveness.

Precision of methods according to GOST 13496.2-91 is assessed through repeatability and reproducibility of results. For example, for the gravimetric method, the allowable differences between the results of parallel determinations depend on the mass fraction of crude fibre:

– less than 5%: ±0.5%;
– 5-15%: ±1%;
– over 15%: ±2%.

Formula for calculating crude fibre content for the gravimetric method:

$$C = \frac{m_2 - m_0}{m_1} \cdot 100, \quad (1)$$

Where:

C – mass fraction of crude fibre (%);
m_0 – mass of empty crucible (g);
m_1 – mass of the initial sample (g);
m_2 – mass of crucible with residue after treatment (g).

To account for these factors, formulae for calculating Type A and B standard uncertainty, as well as total and expanded uncertainties, were used. For example, for the gravimetric method, the total uncertainty u_c was calculated as:

$$u_c = \sqrt{u_A^2 + u_B^2}, \quad (2)$$

where u_A is the Type A standard uncertainty, u_B is the Type B standard uncertainty.

Example of determination of crude fibre content with regard to measurement uncertainty, if known: $u_A = 0.003\%$, $u_B = 0.005\%$, then:

$$u_c = \sqrt{(0.003)^2 + (0.005)^2} = \sqrt{0.000009 + 0.000025} = 0.0058\%.$$

Expanded uncertainty: U

$$U = k \cdot u_c = 2 \cdot 0.0058 = 0.0116\%.$$

Conclusion. Based on this analysis, it can be concluded that the choice of method for determining the mass fraction of crude fibre depends on the type of product, required accuracy, equipment availability and budget. While classical methods remain relevant for small laboratories, modern technologies such as spectroscopy and machine learning offer new opportunities for automation and improved accuracy. Accounting for measurement uncertainties can improve the reliability of results and ensure regulatory compliance.

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