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CONDITIONALITY EXAMINATION OF THE NEW TESTING ALGORITHMS FOR COAL-WATER SLURRIES MOISTURE MEASUREMENT

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ПЕРЕВІРКА ЗУМОВЛЕНОСТІ НОВИХ ТЕСТОВИХ АЛГОРИТМІВ ДЛЯ ВИМІРЮВАННЯ ВМІСТУ ВОЛОГИ ВОДНО-ВУГІЛЬНИХ ЕМУЛЬСІЙ

Purpose. To inspect the ability of the new testing algorithms of coal-water slurries moisture calculation to retain stability when working with experimental results that have natural random variation.

Methodology. Symmetric variation has been artificially introduced into the values of binary material-water slurry dielectric permittivity, applied in appropriate testing algorithm of moisture calculation. Inspection of the testing algorithm ability to retain the calculated water content values stability have been done for the conditions, when each value of dielectric permittivity that enters the testing algorithm takes maximum or minimum inside the symmetric variation range. Results of such an inspection allowed detecting some negative features of the existing testing algorithms and producing a new testing algorithm with sufficient stability for the calculated moisture values of material-water slurries.

Findings. When inspecting two testing algorithms for the calculated water content values conditionality, it was detected, in spite of our expectations, that variation of dielectric permittivity values in a rather small range of 0.1 % gives a significant dispersion of calculated moister values. This situation signified low conditionality for both testing algorithms. It caused the authors to generate the modified testing algorithm, able to provide a sufficient stability for the calculated binary coal-water system moisture values according to the results of its comparison with modern analogues with a help of Pyrson's test.

Originality. Testing algorithms inspection for the calculated moisture values conditionality allowed generating more relevant testing algorithm of moisture calculating in binary systems and, as a result, increasing the accuracy of coal-water slurries moisture measurement.

Practical value. Application of the two additive, two multiplicative and two additional test influences on the substance under consideration in a new testing algorithm allowed increasing moisture measurement accuracy for capacitance moisture meters by several times. It is provided at the expense of small testing algorithm sensitivity to the substance's variation of physicochemical structure and due to the conditionality increase for the calculated values of moisture.

Keywords: *moisture content control, capacitance moisture meter, dielectric permittivity, coal-water slurries*

Introduction. Application of different coal slurries like COS (coal-oil slurry), CWS (coal-water slurry), COWS (coal-oil-water slurry), CMWS (coal-methanol-water slurry) is a way of further development for the coal-water suspension technologies [1, 2].

The idea of CWS application instead of traditional oil products became widespread in the early 70s of the 20th century. Now the biggest range of CWS research studies can be seen in Japan and China [3]. As for Chinese megalopolises, it is forbidden to build and exploit boiler stations with solid coal. Besides, there is a state program to substitute traditional oil and gas fuel into CWS.

CWS usually contains 60–80 % of specially grained coal, 20–40 % of water and approximately 1 % of chemical plasticizers, where moisture is an important parameter to control. Currently the capacitance method for moisture control prevails over others [4]. Its advantages are simple architecture, possibility of momentary measurements, satisfactory accuracy level and others. One of the main negative features of capacitance moisture me-

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ters is presence of the so-called “type uncertainty”. It can be directly associated with a fact, that different dielectric materials under research have different dielectric permittivity values in a dehydrated stage.

Analysis of the recent research and publications. If we follow the reference [4], we can see that there are a lot of ways to solve the “type uncertainty” problem. Par example, such modern devices as Wile-55, Grain Master, Farmpoint, Multi Grain and Kett series, GAC500, are provided with calibrating tabular forms for the group of certain materials. As we claim to create a moisture meter for CWS moisture control to be universal for the wide range of coals, it is necessary to reduce the influence of “type uncertainty” as much as possible directly in a capacitance instrument transducer.

One of the perspective directions was detected for that purpose. The idea was to use special test methods that allow increasing the accuracy of measurements. Essentiality of these methods consists in determining the parameters of a static function for the transducer with the help of additional tests, functionally connected with an object under control. For the moisture control purposes test actions should be formed as a number of water injections into the substance under consideration. Using the values of dielectric permittivity after each of test actions it is possible to calculate the initial moisture of the CWS [5].

The authors explored various testing algorithms and detected a perspective combination, consisting of independent additive and multiplicative tests. Functional circuit of such a measuring system is illustrated below (Fig. 1).

According to Fig. 1, the measurement cycle consists of three steps. At the first step keys K1 and K2 are opened and key K3 is closed. Input parameter X is directly connected to the input of the meter M. At the second step keys K1 and K3 are closed, key K2 remains opened. Such a position for three keys forms an additive test action like $X + \Delta X$.

At the third step key K3 is opened and K2 is closed, which provides a multiplicative test $k \cdot X$.

Implementing such steps for our purposes, we can get a system of three equations (1)

$$\begin{cases} C_1 = \varepsilon_s \left(1 + 3W\right) \cdot g \\ C_2 = \varepsilon_s \left(1 + 3\left(W + \Delta W\right)\right) \cdot g \\ C_3 = k \cdot \varepsilon_s \left(1 + 3W\right) \cdot g \end{cases}, \qquad (1)$$

where ε_s is the dielectric permittivity of CWS; g is the space characteristic of the electric field inside the capacitance instrument transducer gap between electrodes, g = 10 m; ΔW is portion of water to get an additive test, ΔW = 0.1 (10 % from the total volume of CWS); $k = 2$ is the coefficient for the multiplicative test, C_1, C_2, C_3 are electric capacitances of the transducer.

After the system (1) solvation we can get an equation that allows moisture calculation (the first testing algorithm)

$$W = \frac{\Delta W \left(C_3 - C_1\right)}{\left(k - 1\right)\left(C_2 - C_1\right)}.$$

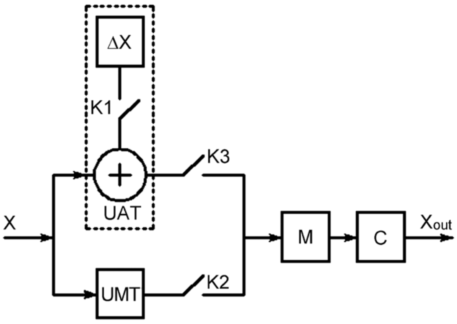

Fig. 1. Block diagram of a measuring system with additive and multiplicative tests and three keys:
UAT – unit of additive test; UMT – unit of multiplicative test; M – meter; C – calculator; K – key

In accordance with [5], after one more additive and multiplicative tests had been applied, a modified testing algorithm appeared

$$\frac{W_1 + W}{W_1 - W} = \frac{\dfrac{\Delta W^{/}\left(C_3^{/} - C_1\right)}{\left(k^{/} - 1\right)\left(C_2^{/} - C_1\right)} + \dfrac{\Delta W\left(C_3 - C_1\right)}{\left(k - 1\right)\left(C_2 - C_1\right)}}{\dfrac{\Delta W^{/}\left(C_3^{/} - C_1\right)}{\left(k^{/} - 1\right)\left(C_2^{/} - C_1\right)} - \dfrac{\Delta W\left(C_3 - C_1\right)}{\left(k - 1\right)\left(C_2 - C_1\right)}}, \qquad (2)$$

where $C_2^{/} = \varepsilon\left(1 + 3\left(W + \Delta W^{/}\right)\right)g$; $C_3^{/} = k^{/}\varepsilon \times \left(1 + 3W\right)g$; $\Delta W^{/} = 0.2$; $k^{/} = 4$ is the coefficient for the multiplicative test. Theoretical research studies on the test algorithm (2) show good results for the calculated moisture values W when applying theoretical deterministic values $C_1, C_2, C_3, C_2^{/}, C_3^{/}$. But during the real CWS moisture control parameters of instrument transducer will not be deterministic and will have natural random variation. The task is to check how this fact will influence ability of the testing algorithm (2) to retain stability for the calculated values of moisture.

Objectives of the article. The main purpose of our research is to check the ability of the new testing algorithm for CWS moisture calculation to retain stability when working with experimental results that have natural random variation. A need for such a study is conditioned with a fact that values of electric capacitances taken from instrument transducer will not be ideal deterministic values used in [5] to check the testing algorithm effectiveness, but will be the results of measurements that always have some random variation. The level of random variation (capacitance measurement uncertainty) will directly influence the calculated moisture values conditionality: measurement uncertainty growth will decrease the calculated moisture values conditionality up to the moment when testing algorithm becomes irrelevant.

Scientific results. Symmetric variation, introduced into the values of binary material-water slurry dielectric permittivity, was calculated according to the universal Wiener equation [6]. Ranges of variation were set after metrological performance analysis for modern electric capacitance meters had been carried out: 0.05, 0.1, 0.2, 0.3 % from the values of dielectric permittivity.

Calculated values of dielectric permittivity are shown in Tables 1–4 (initial values of dielectric permittivity

Table 1

Values of dielectric permittivity ε_s with 0.05 % variation for different moisture values *W*

W, %	ε_s											
	2_-	**2**	2_+	2.5_-	**2.5**	2.5_+	3_-	**3**	3_+	3.5_-	**3.5**	3.5_+
0	1.999	**2.0**	2.001	2.499	**2.5**	2.501	2.998	**3.0**	3.002	3.498	**3.5**	3.502
10	2.613	**2.614**	2.615	3.250	**3.252**	3.254	3.883	**3.885**	3.887	4.510	**4.512**	4.514
20	3.366	**3.368**	3.370	4.171	**4.173**	4.175	4.961	**4.963**	4.965	5.738	**5.741**	5.744
30	4.315	**4.317**	4.319	5.321	**5.324**	5.327	6.302	**6.305**	6.308	7.258	**7.262**	7.266
40	5.542	**5.545**	5.548	6.803	**6.806**	6.809	8.018	**8.022**	8.026	9.192	**9.197**	9.202
50	7.196	**7.2**	7.204	8.780	**8.784**	8.788	10.290	**10.295**	10.300	11.732	**11.738**	11.744
60	9.543	**9.548**	9.553	11.558	**11.558**	11.564	13.470	**13.477**	13.484	15.258	**15.226**	15.274

Table 2

Values of dielectric permittivity ε_s with 0.1 % variation for different moisture values *W*

W, %	ε_s											
	2_-	**2**	2_+	2.5_-	**2.5**	2.5_+	3_-	**3**	3_+	3.5_-	**3.5**	3.5_+
0	1.998	**2.0**	2.002	2.498	**2.5**	2.502	2.997	**3.0**	3.003	3.497	**3.5**	3.503
10	2.611	**2.614**	2.617	3.249	**3.252**	3.255	3.881	**3.885**	3.889	4.507	**4.512**	4.517
20	3.365	**3.368**	3.371	4.169	**4.173**	4.177	4.958	**4.963**	4.968	5.735	**5.741**	5.747
30	4.313	**4.317**	4.321	5.319	**5.324**	5.329	6.299	**6.305**	6.311	7.255	**7.262**	7.269
40	5.539	**5.545**	5.551	6.799	**6.806**	6.813	8.014	**8.022**	8.030	9.188	**9.197**	9.206
50	7.193	**7.2**	7.207	8.775	**8.784**	8.793	10.285	**10.295**	10.305	11.726	**11.738**	11.750
60	9.538	**9.548**	9.558	11.546	**11.558**	11.570	13.464	**13.477**	13.490	15.251	**15.226**	15.281

Table 3

Values of dielectric permittivity ε_s with 0.2 % variation for different moisture values *W*

W, %	ε_s											
	2_-	2	2_+	2.5_-	2.5	2.5_+	3_-	3	3_+	3.5_-	3.5	3.5_+
0	1.996	2.0	2.004	2.495	**2.5**	2.505	2.994	**3.0**	3.006	3.493	**3.5**	3.507
10	2.609	**2.614**	2.619	3.245	**3.252**	3.259	3.877	**3.885**	3.893	4.503	**4.512**	4.521
20	3.361	**3.368**	3.375	4.165	**4.173**	4.181	4.953	**4.963**	4.973	5.730	**5.741**	5.752
30	4.308	**4.317**	4.326	5.313	**5.324**	5.335	6.292	**6.305**	6.318	7.247	**7.262**	7.277
40	5.534	**5.545**	5.556	6.792	**6.806**	6.820	8.006	**8.022**	8.038	9.179	**9.197**	9.215
50	7.186	**7.2**	7.214	8.766	**8.784**	8.802	10.274	**10.295**	10.316	11.715	**11.738**	11.761
60	9.529	**9.548**	9.567	11.535	**11.558**	11.581	13.450	**13.477**	13.504	15.235	**15.226**	15.297

Table 4

Values of dielectric permittivity ε_s with 0.3 % variation for different moisture values *W*

W, %	ε_s											
	2_-	**2**	2_+	2.5_-	**2.5**	2.5_+	3_-	**3**	3_+	3.5_-	**3.5**	3.5_+
0	1.994	**2.0**	2.006	2.493	**2.5**	2.507	2.991	**3.0**	3.009	3.490	**3.5**	3.511
10	2.606	**2.614**	2.622	3.242	**3.252**	3.262	3.873	**3.885**	3.897	4.498	**4.512**	4.526
20	3.358	**3.368**	3.378	4.160	**4.173**	4.186	4.948	**4.963**	4.978	5.724	**5.741**	5.758
30	4.304	**4.317**	4.330	5.308	**5.324**	5.340	6.286	**6.305**	6.324	7.240	**7.262**	7.284
40	5.528	**5.545**	5.562	6.786	**6.806**	6.826	7.998	**8.022**	8.046	9.169	**9.197**	9.225
50	7.178	**7.2**	7.222	8.758	**8.784**	8.810	10.264	**10.295**	10.326	11.703	**11.738**	11.773
60	9.519	**9.548**	9.577	11.523	**11.558**	11.593	13.437	**13.477**	13.517	15.220	**15.226**	15.312

calculated in accordance with universal Wiener equation are marked with bold print).

As mentioned before, inspection of the water content values conditionality was done for the conditions, when each value of dielectric permittivity that enters the testing algorithm takes maximum or minimum inside the symmetric variation range. Further the signs "+" and "–" will mean the maximum and minimal value, correspondingly, of dielectric permittivity ε_1, ε_2 or ε_3. As we have three parameters under control, eight different combinations will be possible (Table 5). Par example, designation like "+–+" means that dielectric permittivities ε_1 and ε_3 take maximal values and ε_2 is minimal. Let us check testing algorithm (2) for the calculated moisture values stability.

As we can see from Table 5, testing algorithm (2) has low conditionality for moisture points 0, 10 and 20 % even with 0.05 % variation. That is why the next attempt to create testing algorithm had been undertaken in accordance with a measuring system from Fig. 2.

Applying the block diagram in Fig. 2 we can get one more test $K(X + \Delta X)$ and system of equations (3)

$$\begin{cases} C_1 = \varepsilon_s\left(1+3W\right)\cdot g \\ C_2 = \varepsilon_s\left(1+3\left(W+\Delta W\right)\right)\cdot g \\ C_3 = k\cdot\varepsilon_s\left(1+3W\right)\cdot g \\ C_4 = k\cdot\varepsilon_s\left(1+3\left(W+\Delta W\right)\right)\cdot g \end{cases}. \qquad (3)$$

In comparison with (1) this system will have one more equation. The solution of (3) gives us another equation for moisture calculation

$$W = \frac{\left(C_3 - C_1\right)\Delta W}{\left(C_4 - C_2\right) - \left(C_3 - C_1\right)}.$$

Acting in accordance with [5] after generating one more additive, multiplicative and complementary tests another modified testing algorithm appeared (4)

$$W = \frac{\dfrac{\left(C_3' - C_1\right)\Delta W'}{\left(C_4' - C_2'\right) - \left(C_3' - C_1\right)} + \dfrac{\left(C_3 - C_1\right)\Delta W}{\left(C_4 - C_2\right) - \left(C_3 - C_1\right)}}{\dfrac{\left(C_3' - C_1\right)\Delta W'}{\left(C_4' - C_2'\right) - \left(C_3' - C_1\right)} - \dfrac{\left(C_3 - C_1\right)\Delta W}{\left(C_4 - C_2\right) - \left(C_3 - C_1\right)}}. \qquad (4)$$

However, after conditionality inspection in a way illustrated in Table 5, it appeared that testing algorithm (4) and testing algorithm (2) have similar problems in moisture points 0 and 10 %.

The decision was to pay more attention to the testing algorithm (2) denominator after some modification (5)

$$W = \left[\left|\left(\frac{\Delta W'\left(C_3' - C_1\right)}{\left(k' - 1\right)\left(C_2' - C_1\right)} - \frac{\Delta W\left(C_3 - C_1\right)}{\left(k - 1\right)\left(C_2 - C_1\right)}\right)\right| - 0.033\right]\times$$
$$\times 1600. \qquad (5)$$

Inspection results for the testing algorithm (5) are placed in Table 6. There we can see results of the 0.3 % variation from the values of dielectric permittivity as most

Table 5

Moisture values *W* with 0.05 % variation according to (2)

ε_s	W_n, %	W_{+++}	W_{---}	W_{-+-}	W_{+-+}	W_{++-}	W_{+--}	W_{-++}	W_{--+}
2.0	0	1.969	0.892	-1.603	4.262	-0.208	2.212	0.645	3.007
2.0	10	11.068	11.905	8.793	13.997	9.688	12.732	10.206	13.199
2.0	20	20.751	20.342	18.429	22.534	19.526	21.382	19.695	21.533
2.0	30	30.448	30.518	28.948	31.935	29.563	31.102	29.852	31.369
2.0	40	39.619	39.658	38.593	40.637	39.073	40.118	39.151	40.188
2.5	0	0.881	1.966	-2.136	4.706	-0.966	3.034	-0.239	3.681
2.5	10	10.672	10.088	7.378	13.158	8.912	11.523	9.210	11.788
2.5	20	20.360	20.791	18.388	22.623	19.315	21.656	19.463	21.784
2.5	30	30.096	29.900	28.537	31.385	29.331	30.658	29.325	30.647
2.5	40	39.463	39.683	38.767	40.351	39.178	40.079	39.057	39.960
3.0	0	0.227	0.218	-3.447	3.600	-1.391	2.117	-1.752	1.770
3.0	10	10.512	10.001	7.652	12.691	8.977	11.252	9.240	11.489
3.0	20	20.138	20.217	18.083	22.142	18.902	20.988	19.350	21.400
3.0	30	29.662	29.709	28.082	31.199	28.795	30.385	28.971	30.544
3.0	40	40.414	40.358	39.364	41.362	39.840	40.815	39.950	40.917
3.5	0	0.355	-0.361	-3.641	3.348	-1.806	1.348	-1.388	1.722
3.5	10	9.329	9.431	6.200	12.309	7.428	10.565	8.162	11.228
3.5	20	19.838	19.904	17.299	22.251	18.425	20.949	18.761	21.249
3.5	30	29.267	29.307	27.421	31.034	28.302	30.134	28.418	30.234
3.5	40	40.444	40.389	39.291	41.486	39.838	40.912	39.912	40.977

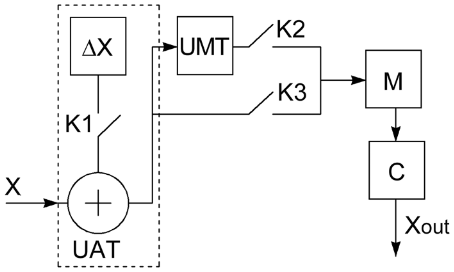

Fig. 2. Block diagram of a measuring system with additive, multiplicative and complementary tests

informative. Intermediate calculations for variation of 0.05, 0.1 and 0.2 % are absent in the article.

We can notice that bad conditionality of moisture results occurs for the combinations: W_{-+-}, W_{++-} and W_{-++}.

The next step of our research was to explore the modified denominator of the testing algorithm (4)

$$W=\left|\frac{\left(C_3^{/}-C_1\right)\Delta W^{/}}{\left(C_4^{/}-C_2^{/}\right)-\left(C_3^{/}-C_1\right)}-\frac{\left(C_3-C_1\right)\Delta W}{\left(C_4-C_2\right)-\left(C_3-C_1\right)}+\right.$$

$$\left.+0.033\right|\cdot 1666. \qquad (6)$$

Results for the testing algorithm (6) can be found in Table 7 and again only variation of 0.3 % is represented. Analyzing the results we can see that combinations W_{-+-}, W_{++-} and W_{-++} for the 0 % moisture point give us moisture values, close to the testing algorithm (5) but with the opposite sign. This circumstance means that some average testing algorithm between (5, 6) would satisfy the purpose of the research and have good conditionality (7), Table 8.

$$W=\left|\frac{\left(C_3^{/}-C_1\right)\Delta W^{/}}{\left(C_4^{/}-C_2^{/}\right)-\left(C_3^{/}-C_1\right)}-\frac{\left(C_3-C_1\right)\Delta W}{\left(C_4-C_2\right)-\left(C_3-C_1\right)}+0.033\right|\cdot 833+\left[\left|\left(\frac{\Delta W^{/}\left(C_3^{/}-C_1\right)}{\left(k^{/}-1\right)\left(C_2^{/}-C_1\right)}-\frac{\Delta W\left(C_3-C_1\right)}{\left(k-1\right)\left(C_2-C_1\right)}\right)\right|-0.033\right]\cdot 800. \qquad (7)$$

Analyzing the data from Table 8, we can see that maximal conditionality decrease takes place for the 0.3 % variation in a 40 % moisture point and dielectric permittivity $\varepsilon_s = 3.5$. However, if we compare these results with existing analogues, it is possible to make a conclusion that conditionality of moisture values, calculated with a help of testing algorithm (7), is satisfactory.

Experimental results. The first task was to create material-water samples with necessary percentage of water to provide test influences on the material under research. Air-oven reference method was used for that purpose [7]. To prepare our samples it was necessary to dry them up to the complete water extraction. Probes of different materials with a mass of 500 g were placed into gage tanks and weighed on the top-loading balance. After that gage tanks with opened lids were loaded into an oven, heated up to 120 °C, for 1.5 hours to dry samples inside gage tanks. For that purposes SNUG II-60 ana-

Table 6

Moisture values W with 0.3 % variation according to (5)

ε_s	W_n, %	W_{+++}	W_{---}	W_{-+-}	W_{+-+}	W_{++-}	W_{+--}	W_{-++}	W_{--+}
2.0	0	0.367	0.707	-0.575	0.262	-1.554	0.340	-1.815	0.467
2.0	10	10.879	10.549	8.185	11.959	9.286	11.365	9.591	10.956
2.0	20	19.986	19.960	16.768	21.927	18.159	21.100	18.407	20.599
2.0	30	30.423	30.594	27.388	32.382	29.021	31.980	28.614	30.820
2.0	40	39.999	40.011	38.088	40.595	39.501	41.098	38.437	39.360
2.5	0	0.677	1.190	-0.661	1.133	-0.839	0.618	-1.311	1.539
2.5	10	9.719	10.105	7.458	12.074	7.863	11.217	8.202	10.764
2.5	20	20.187	20.060	16.337	22.740	18.381	21.934	17.943	20.666
2.5	30	29.717	29.478	26.337	31.622	28.225	31.130	27.647	29.789
2.5	40	39.467	39.372	37.226	40.283	38.638	40.454	37.901	39.047
3.0	0	0.342	0.710	-1.663	1.402	-1.224	0.836	-0.879	1.094
3.0	10	10.180	10.029	7.622	12.644	8.007	11.471	8.342	10.992
3.0	20	19.721	19.755	15.414	22.912	17.468	21.659	17.458	20.798
3.0	30	29.129	29.015	24.993	31.977	27.171	31.020	26.754	29.776
3.0	40	41.219	41.374	38.334	43.002	40.236	43.019	39.155	41.195
3.5	0	0.649	1.258	-1.714	2.350	-1.033	1.668	-0.220	1.752
3.5	10	9.858	9.284	6.556	12.540	7.344	11.026	7.734	10.574
3.5	20	19.466	19.624	23.664	23.390	16.740	21.665	17.089	21.128
3.5	30	28.390	28.606	31.680	32.228	26.165	31.003	25.680	29.622
3.5	40	41.510	41.251	44.950	43.874	40.068	43.431	38.950	41.513

Table 7

Moisture values W with 0.3 % variation according to (6)

ε_s	W_n, %	W_{+++}	W_{---}	W_{-+-}	W_{+-+}	W_{++-}	W_{+--}	W_{-++}	W_{--+}
2.0	0	0.382	0.736	0.973	0.262	1.824	0.340	0.855	1.467
2.0	10	11.328	10.984	12.094	11.959	8.421	12.365	10.739	12.956
2.0	20	20.810	20.784	20.965	21.927	18.661	22.100	19.919	22.599
2.0	30	31.678	31.856	32.023	32.382	28.970	32.980	30.547	32.820
2.0	40	41.649	41.662	43.164	40.595	39.883	42.098	40.775	41.360
2.5	0	0.704	1.239	1.183	1.758	2.121	0.932	0.130	2.891
2.5	10	10.120	10.522	12.683	12.074	7.940	12.968	9.292	13.497
2.5	20	21.020	20.888	21.516	22.740	17.892	21.128	19.436	23.807
2.5	30	30.943	30.694	32.228	33.504	28.142	33.703	29.540	33.306
2.5	40	41.092	40.996	43.267	40.283	38.984	42.412	40.217	42.946
3.0	0	0.356	0.739	1.827	1.858	2.522	1.160	0.994	1.428
3.0	10	10.600	10.442	12.853	13.743	7.090	13.233	9.438	12.734
3.0	20	20.534	20.570	21.655	22.935	16.941	21.842	18.930	23.045
3.0	30	30.330	30.212	33.529	33.874	28.045	33.988	28.610	32.293
3.0	40	42.920	43.080	43.920	42.354	40.648	43.082	40.522	44.183
3.5	0	0.676	1.310	2.280	2.025	3.323	1.426	0.634	1.113
3.5	10	10.265	9.667	12.827	12.635	7.400	13.770	8.806	13.299
3.5	20	20.269	20.433	22.691	23.132	17.183	22.247	18.547	23.289
3.5	30	29.561	29.786	32.745	34.135	27.997	34.170	28.492	33.133
3.5	40	42.842	42.952	44.747	43.261	38.473	43.512	39.309	44.514

Table 8

Moisture values W with 0.3 % variation according to (7)

ε_s	W_n, %	W_{+++}	W_{---}	W_{-+-}	W_{+-+}	W_{++-}	W_{+--}	W_{-++}	W_{--+}
2.0	0	0.375	0.713	0.199	0.556	0.135	0.492	-0.480	1.121
2.0	10	11.104	10.767	10.140	12.495	8.854	11.744	10.165	11.326
2.0	20	20.398	20.372	18.867	22.668	20.294	21.680	19.163	21.169
2.0	30	31.051	31.225	29.706	32.839	28.996	32.284	29.581	31.600
2.0	40	40.280	40.837	40.626	41.720	39.692	42.090	39.606	40.317
2.5	0	0.691	1.215	0.261	1.446	0.641	0.775	-0.591	2.225
2.5	10	9.920	10.314	10.071	12.612	7.902	12.093	8.747	12.131
2.5	20	20.694	20.474	18.927	23.498	18.367	21.531	18.465	22.237
2.5	30	30.330	30.086	29.283	32.563	28.184	32.417	28.594	31.548
2.5	40	40.280	40.184	40.247	41.403	38.811	41.433	39.059	40.997
3.0	0	0.349	0.725	0.082	1.630	0.649	0.998	0.058	1.261
3.0	10	10.390	10.236	10.238	13.194	7.549	12.352	8.845	11.863
3.0	20	20.128	20.163	18.535	22.924	17.205	21.751	18.194	21.922
3.0	30	29.730	29.614	29.261	32.926	27.608	32.504	27.682	31.035
3.0	40	42.070	42.227	41.127	42.678	40.442	43.051	39.854	42.689
3.5	0	0.663	1.284	0.283	2.188	1.145	1.547	0.217	1.433
3.5	10	10.062	9.476	9.692	12.588	7.372	12.398	8.270	11.937
3.5	20	19.868	20.029	23.178	23.261	16.962	21.956	17.817	22.209
3.5	30	28.976	29.196	32.213	33.182	27.081	32.587	27.086	31.378
3.5	40	42.176	42.102	44.849	43.568	39.271	43.472	39.130	43.014

lytic top-loading balance and TBV-2000 thermal vacuum chamber were used.

After being heated gage tanks were covered with lids, cooled down to +20 °C temperature and weighed with ± 0.01 g accuracy. Cycles of drying should be continued till the mass of gage tank become stable. That will provide complete moisture deletion.

Samples taken for the research were represented with wheat, barley, pearl barley, poppy-seed, crushed pea and sand – dry materials with rather different values of dielectric permittivity and grain-size composition.

It should be clear that each of six probes in dehydrated state is a sample with 0 % of moisture. Next sample with 10 % of moisture can be created by adding 50 g of water in accordance with [7]. Third sample – 100 g (20 %), fourth – 150 g (30 %), etc.

Two capacitance instrument transducers T1 and T2 with different plates shape were used to measure dielectric permittivity of the prepared samples (Fig. 3).

T1 instrument transducer consists of two parallel teflon-covered plates, assembled on a polytetra-fluorethylene disk with a capacitance in empty state equal to 7 pF. Top of T1 transducer has two clamps to connect the capacitance meter. T2 instrument transducer contains a system of flat plates that form nine electric capacitances connected in parallel and coated with epoxy varnish. Electric capacitance of T2 instrument transducer in empty state is equal to 47 pF. System of flat plates is assembled inside two polytetra-fluorethylene rings with tang slots. Dielectric coat of both instrument transducers is necessary to prevent the electrical short-circuit of electrodes when the sample under research moisture value overcomes 10 %. Two instrument transducers application allowed two groups of independent results to be obtained with an ability to be compared.

Unfortunately, all list of RLC and capacitance meters, portable and bench multimeter instruments as well as three types of Q-meters we had at our disposal failed to measure electric capacitances of both instrument transducers correctly because of strong dielectric losses in moisture samples. That is why original capacitance –pulse duration – voltage secondary transducer had been developed (Fig. 4).

Mentioned above capacitance-voltage transducer is based on two 555 or 777 timers (Fig. 5), where the left one is connected as a multivibrator circuit and generates meander pulses on its output. The right one, where instrument transducer with moisture sample C_{x1} is connected, works as a one-shot multivibrator, and pulses duration on its output is in straight proportion with a capacitance of the instrument transducer. Low-pass filter R_4C_4 works as pulse duration into d. c. voltage transducer in a range of 0.000–2.000 volts.


a *b*

Fig. 3. Capacitance instrument transducers:
a – T1 with two teflon-coated plates; b – T2 with multiple epoxy-varnished plates

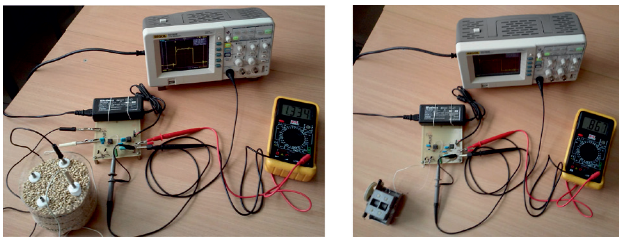
a *b*

Fig. 4. Laboratory setup for capacitance measurement:
a – with moisture sample; b – with variable air capacitor instead moisture sample

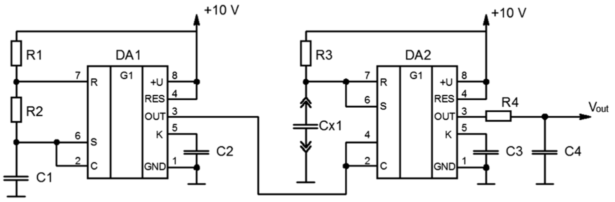

Fig. 5. Electric circuit of a capacitance-voltage transducer

Measurement process included several steps. At the first step instrument transducer filled with a prepared sample were connected to the secondary transducer. Oscilloscope was used to control the form and duration of output pulses and the task of a digital multimeter was to measure output d. c. voltage of the circuit. D. c. voltage value was fixed by the operator. At the second step instrument transducer with a sample was disconnected form the circuit and substituted with variable air capacitor (Fig. 4, *b*) able to change its capacitance in a range of 5–760 pF. Capacitance of the air capacitor in accordance with a substitution method of measurement was slowly increased till the output voltage value was equal to the value, fixed by the operator. Then air capacitor was disconnected from the circuit and its capacitance was measured with high accuracy.

Average values for ten results of capacitance measurement are shown in Tables 9, 10 (for both instrument transducers).

Such a number of samples were necessary to cover the moisture range from 0 up to 30 % what is enough for CWS moisture control.

Substituting these results into equation (7) we were able to get experimental values of moisture, placed in Tables 11 and 12.

Conclusion. As we can see, experimental results of moisture measurement are close to the nominal moisture points, which means that testing algorithm (7) can be applied with experimental results of measurement and retains a good conditionality of calculated moisture values. Besides, we can see that testing algorithm (7) demonstrates good results in solving the “type uncertainty”

Table 9

Values of capacitance for T1 instrument transducer

	C, pF					
W, %	0	10	20	30	40	50
Wheat	28.0	36.2	45.7	57.7	72.3	91.8
Barley	22.4	29.2	37.1	47.2	59.5	76.2
Pearl barley	26.4	34.5	43.9	55.8	68.7	87.4
Poppy-seed	25.2	32.7	41.4	52.5	66.0	84.1
Crushed pea	23.1	30.1	38.2	48.5	61.1	78.2
Sand	14.0	18.3	23.3	29.8	38.8	50.4

Table 10

Values of capacitance for T2 instrument transducer

	C, pF					
W, %	0	10	20	30	40	50
Wheat	188.1	241.7	306.2	386.0	485.7	616.6
Barley	150.3	194.3	248.2	316.5	399.1	511.1
Pearl barley	178.5	229.8	291.7	368.7	464.3	590.7
Poppy-seed	169.1	218.0	277.1	351.0	442.9	564.7
Crushed pea	155.1	200.3	255.3	324.5	410.2	524.7
Sand	94.1	122.5	158.5	205.9	260.6	338.4

Table 11

Experimental values of moisture for T1 transducer

W, %	0	10	20	30
Wheat	0.388	9.763	19.921	30.041
Barley	0.419	9.481	19.802	29.738
Pearl barley	0.401	9.605	19.731	29.701
Poppy-seed	0.237	10.000	20.114	30.254
Crushed pea	0.084	9.835	19.967	30.126
Sand	0.000	9.786	19.872	29.917

Table 12

Experimental values of moisture for T2 transducer

W, %	0	10	20	30
Wheat	0.397	9.881	19.885	29.844
Barley	0.472	10.000	20.351	30.436
Pearl barley	0.272	9.893	20.191	30.210
Poppy-seed	0.000	9.842	19.793	29.710
Crushed pea	0.011	9.679	19.699	29.672
Sand	0.366	9.594	19.701	29.843

problem because moister values of different materials are close to each other.

Testing algorithms inspection for the calculated moisture values conditionality allowed generating more relevant testing algorithm of moisture calculating in binary systems and, as a result, increasing the accuracy of coal-water slurries moisture measurement.

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Мета. Перевірка здатності нових тестових алгоритмів розрахунку вмісту вологи водно-вугільних емульсій зберігати зумовленість обчислених рішень під час роботи з експериментальними даними, що мають природну варіацію.

Методика. У значення діелектричних проникностей бінарної суміші матеріал – вода, за якими здійснюється розрахунок вмісту вологи за обраним тестовим алгоритмом, штучно вводиться симетрична варіація. Здійснена перевірка здатності тестового алгоритму зберігати стабільність розрахункових значень вмісту вологи в умовах, коли кожна з діелектричних проникностей бінарної суміші, що входять у тестовий алгоритм, приймає максимальне або мінімальне значення в межах заданої варіації. Результати перевірки дозволили виявити недоліки запропонованих раніше тестових алгоритмів і синтезувати новий, що має достатній рівень зумовленості розрахункових значень вмісту вологи.

Результати. Унаслідок перевірки на зумовленість двох розглянутих тестових алгоритмів виявилось, що, всупереч очікуванням, уже за наявності варіації значень діелектричних проникностей на рівні 0,1 % спостерігається значне розсіювання розрахункових значень вмісту вологи, що свідчить про погану зумовленість отриманих рішень. Це викликало необхідність синтезу ще одного тестового алгоритму, який забезпечує задовільну зумовленість розрахункових значень вмісту вологи в результаті його порівняння з аналогами за допомогою критерію узгодженості Пірсона.

Наукова новизна. Перевірка відомих тестових алгоритмів на зумовленість отриманих рішень дозволила синтезувати більш досконалий тестовий алгоритм розрахунку вмісту вологи бінарних систем, і, як наслідок, підвищити точність вимірювання вмісту вологи водно-вугільних емульсій.

Практична значимість. Використання двох адитивних, двох мультиплікативних і двох додаткових тестових впливів на досліджувану речовину в новому тестовому алгоритмі дозволило в декілька разів підвищити точність вимірювання вмісту вологи ємнісними вологомірами. Це вдалося забезпечити як за рахунок низької чутливості тестового алгоритму до зміни фізико-хімічного складу досліджуваної речовини, так і за рахунок підвищення зумовленості розрахункових значень вмісту вологи.

Ключові слова: *контроль вмісту вологи, ємнісний вимірювач вологості, діелектрична проникність, водно-вугільна емульсія*

Цель. Проверка способности новых тестовых алгоритмов расчета влагосодержания водно-угольных эмульсий сохранять обусловленность получаемых решений при работе с экспериментальными данными, имеющими природную вариацию.

Методика. В значения диэлектрических проницаемостей бинарной смеси материал – вода, на основании которых производится расчет влагосодержания по выбранному тестовому алгоритму, искусственно вводится симметричная вариация. Осуществлена проверка способности тестового алгоритма сохранять стабильность расчетных значений влагосодержания в условиях, когда каждая из диэлектрических проницаемостей бинарной смеси, входящих в тестовый алгоритм, принимает максимальное или минимальное значение в пределах заданной вариации. Результаты проверки позволили выявить недостатки предложенных ранее тестовых алгоритмов и синтезировать новый, имеющий достаточную степень обусловленности расчетных значений влагосодержания.

Результаты. В результате проверки на обусловленность двух рассмотренных тестовых алгоритмов оказалось, что, вопреки ожиданиям, уже при вариации значений диэлектрических проницаемостей на уровне 0,1% наблюдается значительный разброс расчетных значений влагосодержания, что говорит о плохой обусловленности получаемых решений. Это вызвало необходимость синтезировать еще один тестовый алгоритм, обеспечивающий удовлетворительную обусловленность расчетных значений влагосодержания по результатам его сравнения с аналогами при помощи критерия согласия Пирсона.

Научная новизна. Проверка известных тестовых алгоритмов на обусловленность получаемых решений позволила синтезировать более совершенный тестовый алгоритм расчета влагосодержания бинарных систем, и, как следствие, повысить точность измерения влагосодержания водно-угольных эмульсий.

Практическая значимость. Применение двух аддитивных, двух мультипликативных и двух дополнительных тестовых воздействий на исследуемое вещество в новом тестовом алгоритме позволило в несколько раз повысить точность измерения влагосодержания емкостными влагомерами. Это обеспечивается как за счет слабой чувствительности тестового алгоритма к изменению физико-химического состава исследуемого вещества, так и за счет повышения обусловленности расчетных значений влагосодержания.

Ключевые слова: *контроль влагосодержания, емкостный измеритель влажности, диэлектрическая проницаемость, водно-угольная эмульсия*

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