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Evaluation of Rock Porosity Measurement Accuracy with a Helium Porosimeter

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Abstract

Results of an interlaboratory experiment, lying in determining the accuracy (trueness and precision) of rock porosity measurements with a helium porosimeter, are presented in the paper, taking into account foundations of metrology, theory of uncertainty and measurement errors. The experiments were carried out in three different petrophysical laboratories related with oil mining in a different span of time. The research material was composed of 20 rock samples of varying porosity coefficient, ranging from about 1 to about 23%.

In the course of the analysis, the measurement accuracy was assessed in the conditions of repeatability and reconstructibility of experiments, taking into account interlaboratory and intralaboratory variability of the results.

***Key words**: Rock **P**orosity, **H**elium **P**orosimeter*

Introduction

In the years 1993-94, major changes took place in metrology and the related branches of science and technology. They resulted from the introduction of a basic and general notion of uncertainty in measurement. The changes were spurred by the publication of the Guide to the Expression of Uncertainty in Measurement by the International Organization for Standarization – ISO in 1993, a result of co-operation of a number of international institutions and recommendations on uncertainty in measurements. In 1994 the standard ISO 5725:1986 Precision of test methods – Determination of repeatability and reproducibility for a standard test method by interlaboratory tests was replaced by a standard published in six parts under the common title Accuracy (trueness and precision) of measurement methods and results.

The Polish counterparts of these documents are published by:

- Central Office of Measurements in 1999 (A Guide to the Expression of Uncertainty in Measurement [10];
- Polish Committee of Standarization in 2002 in six parts, standard PN-ISO 5725 Accuracy (trueness and precision) of measurement methods and results (part I – [8]).

Evaluation of a rock porosity measurement method with a helium porosimeter

The newest and most perfect laboratory method of determining rock porosity coefficient values is the helium porosimeter. Measurement devices, i.e. helium porosimeters act in line with the gas (helium) expansion law, following the Boyle Law. Practical implementation of a reliable method for determining rock porosity values, especially calibration of devices, may create certain problems [3]. They may eventually result in imprecise results of measurements of rock porosity, systematic errors in particular.

To empirically verify the above theory, an interlaboratory experiment was carried out. It tackled the problem of evaluation of inaccuracies (trueness and precision) of rock porosity measurements with a helium porosimeter. Experiments were carried out in various spans of time and at various petroleum laboratories (denoted as *A*, *B* and *C*.) The population of n=20 rock samples (experiment units) varied in their porosity coefficient values ϕ from ca. 1 to ca. 23%. Laboratories *A* and *C* had only helium porosimeters of HGP100 type at their disposal [4], whereas laboratory *B* – a helium porosimeter of CORELAB type [1].

The results of porosity measurements performed within the described interlaboratory experiment are presented in table 1. At the first stage of the experiment, three series of measurements were performed, one in each of the laboratories. The obtained results denoted as ϕ^A, ϕ^B i ϕ^C are put in columns 2, 3 and 4, respectively, in table 1. It is evident that the results obtained in laboratories *A* and *B* are similar, whereas those from laboratory *C* are much

lower (differences on the level of ca. 4% porosity). This can be confirmed by the results of significance tests on differences between measurement results from the laboratories with the use of the method described by the standard [6]. Discrepancies between porosity values from measurements carried out in laboratories *A* and *C* as well as *B* and *C* are evident and are systematic in character. This shows to the presence of systematic measurement errors. The differences between the results obtained in laboratories *A* and *B* are small, but

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significant at the test significance level α=0.05. This speaks for the principal role of random components in the observed differences.

Tab. 1 Results of porosity measurements within the interlaboratory experiment

Sample No.	ϕ^A, %	ϕ^B, %	ϕ^C, %	ϕ^{C1}, %	ϕ_{sr} (A,B,C), %	ϕ^{IN}, %
1	2	3	4	5	6	7
1	20.27	20.59	16.41	16.38	19.09	–
2	14.60	16.19	11.87	12.01	14.22	–
3	17.61	18.02	13.75	13.76	16.46	–
4	5.39	5.34	1.00	1.04	3.91	0.49 ± 1.30
5	14.72	14.94	10.64	10.71	13.43	–
6	16.72	17.40	12.83	12.85	15.65	–
7	14.35	14.85	10.94	10.82	13.38	10.85 ± 1.20
8	10.52	10.68	6.72	6.81	9.31	–
9	21.80	22.51	17.21	17.20	20.51	17.20 ± 1.10
10	11.29	11.39	7.42	7.25	10.03	–
11	8.52	8.76	4.30	4.53	7.19	–
12	14.46	15.30	10.57	9.95	13.44	–
13	12.52	12.88	8.62	8.03	11.34	–
14	8.76	9.25	4.81	4.23	7.61	–
15	8.96	9.96	6.18	5.53	8.37	–
16	16.10	16.28	11.38	11.37	14.59	–
17	7.97	8.08	3.81	3.75	6.62	–
18	18.68	19.09	14.33	14.44	17.37	–
19	18.31	18.88	14.45	13.87	17.21	–
20	14.14	13.91	9.45	10.15	12.50	–
$\overline{\phi}$	13.78	14.22	9.83	9.73	12.61	–

To check the correctness of measurements performed in laboratory *C,* the whole series of measurements were re-made, with the fulfilled conditions of measurement repeatability. The obtained results, denoted as ϕ^{C1} in table 1, are very close to the results from the first measurement series (ϕ^C). Testing differences between porosity values in both measurement series has shown that they are insignificant at the test significance level α=0.05. Therefore, the results of measurements obtained in laboratory *C* in both measurement series in repeatability conditions, were used for the characteristic of the applied measurement method [9].

The following can be assessed for the helium porosimetry method with reference to the measured porosity values in the fulfilled repeatability conditions:

- standard deviation (absolute value) $S \approx 0.07\%$,
- variability coefficient (relative standard deviation) $\hat{v} \approx 0{,}0073$ (i.e. 0.73%).

This signifies that helium porosimeters are highly precise devices in the repeatability conditions, with a low value of random error of measurement results. Similar results were obtained in [2, 3].

Having assumed the equality and trueness of hypothetical results of rock porosity measurements obtained in laboratories *A*, *B* and *C* (regardless systematic errors), the assumed reference values for the specific samples are arithmetic means of the obtained results:

$$\phi_{sr}(A,B,C) = \tfrac{1}{3}(\phi^A + \phi^B + \phi^C) \tag{1}$$

They are presented in the sixth column of table 1.

At such assumptions, the evaluated load $\hat{\Delta}$ of the specific laboratories *A, B* and *C* would be:

- absolute values: ca. +1.17%, +1.61% and –2.78%;
- relative values: ca. +9.3%, +12.8% and –22.1%,

standard deviation of repeatability $\hat{S}_R$ (measurement repeatability conditions fulfilled):

- absolute values: ca. 0.83%, 1.14% and 2.00%;
- relative values: ca. 85%, 11.6% and 20.5%, respectively.

To explain the trueness of measurement results obtained in laboratories *A*, *B* and *C* (some of which (ϕ^A and ϕ^B or ϕ^C) are burdened with evident systematic errors), verification porosity measurements were carried out for selected rock samples. Accredited measurements with the use of a helium porosimeter, were carried out at the Laboratory of Geophysical Parameters of Rock and Formation Fluids, Institute of Oil and Gas, Cracow, following own procedures, thanks to which "true" values (i.e., close to the unknown actual ones) can be obtained. Three selected rock samples of strongly varied porosity qualities were measured. The results of measurements, along with uncertainties corresponding to the probability *P*=95% (statistically, this corresponds to 95% confidence intervals) are presented in table 1 (column 7). The following can be inferred from the results:

- results of measurements in laboratory *C* are in practice accurate (true);
- results of measurements in laboratories *A* and *B* are far from the true ones (the so-called "outstanding" values), therefore should be either rejected or corrected;
- approximated loads $\hat{\Delta}$ of the specific laboratories *A*, *B* and *C* are:
  - absolute values: ca. 4.33%; 4.72% and 0.19%;
  - relative values: ca. 44.3%; 48.3% and 1.94%, respectively.

In the light of the above data, laboratories A and B should be considered as "outstanding" [9]. They have a too high systematic error of the results, therefore must be rejected. Accordingly, the measurement procedures applied in the laboratories should be modified and corrected.

Conclusions

The most recent fundamental changes in metrology, caused by the introduction of the notion of uncertainty in measurement, necessitate the use of a number of notions and terms (new ones or reinterpreted) in science and technology for a quantitative characterization of measurement methods and elaboration of the results. This mainly applies to the notions of accuracy, trueness, load, precision, repeatability and reproducibility [5, 7÷10].

The presented example of evaluation of rock porosity measurement with a helium porosimeter exhibits typical metrological problems encountered in the research practice. The results of the conducted experiments prove that the helium porosimeters provide the repeatability of measurements, high precision and small random error of the obtained results in the repeatability conditions. The basic problems may arise in reference to the methods and calibration procedures, deciding about the correctness of the results and level of systematic errors (laboratory loading).

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