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# Jury Member Report – Doctor of Philosophy thesis.

**Name of Candidate:** Maksim Zhmaev

**PhD Program:** Petroleum Engineering

**Title of Thesis:** Experimental evaluation of filtration properties of cryolithozone rocks under conditions of formation and decomposition of gas hydrates

**Supervisor:** Dr. Evgeny Chuvilin

**Name of the Reviewer: Dmitrii Sergeev**

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| I confirm the absence of any conflict of interest | **Date: 15-11-2024** |

*The purpose of this report is to obtain an independent review from the members of PhD defense Jury before the thesis defense. The members of PhD defense Jury are asked to submit signed copy of the report at least 30 days prior the thesis defense. The Reviewers are asked to bring a copy of the completed report to the thesis defense and to discuss the contents of each report with each other before the thesis defense.*

*If the reviewers have any queries about the thesis which they wish to raise in advance, please contact the Chair of the Jury.*

**Reviewer's Report**

Reviewers report should contain the following items:

- Brief evaluation of the thesis quality and overall structure of the dissertation.
- The relevance of the topic of dissertation work to its actual content
- The relevance of the methods used in the dissertation
- The scientific significance of the results obtained and their compliance with the international level and current state of the art
- The relevance of the obtained results to applications (if applicable)
- The quality of publications

The summary of issues to be addressed before/during the thesis defense

The presented manuscript is characterized by a classical structure. It includes sections with the formulation of the research hypothesis and the defended topics. A review of the literature on the properties of gas hydrates and their distribution is given. The study of gas-dynamic processes in frozen deposits, permeability and capacitive properties of ice-bearing and hydrate-bearing deposits is also considered. The main methods for determining the porosity of sediments in laboratory conditions are described. A special chapter contains the methodology for migration testing in ice-bearing and hydrate-bearing deposits under various thermobaric conditions. The data from experimental modeling of gas migration in ice-bearing rocks with various pressure gradients are presented. A special section shows the effect of nitrogen injection on the change in the gas permeability of a hydrate-bearing sample under dissociation with a constant negative temperature. The interpretation of the data obtained is given. The clear conclusions are formulated that allow assessing the novelty of the study.

The content of the work corresponds to its title.

The methods used for the study correspond to the specifics of the object and the current level of knowledge. The author developed well-known laboratory research methods and implemented his own version of the laboratory installation, which includes a core holder with a comprehensive compression system. An original sequence of tests is also proposed.

The scientific significance of the investigation is due to the obtaining of quantitative indicators of the permeability of natural and artificial samples in the considered pressure and temperature ranges. The effect of structural-phase transformations on gas filtration in ice-bearing rocks was estimated by used visual analysis and microtomographic studies. The founded effect of the transfer of a significant amount of pore moisture during gas migration is important. It has also been found that in the process of replacing the $CH_4$-$CO_2$ hydrate by injecting $CO_2$ or flue gas into a hydrate-containing sample, its gas permeability is reduced due to the additional formation of $CO_2$ hydrates from the residual pore water. The scientific value is a conceptual model of the porous medium of hydrate-containing rocks. The use of this model helps to interpret the obtained particular phenomenal dependencies. At the stage of dissociation of pore hydrates under conditions of negative temperature and constant axial pressure, a multidirectional nature of gas permeability and the increase in the first half hour with the exponential drop during the day were revealed. The effect of injection of an inhibitor gas ($N_2$) on gas permeability in hydrate-saturated sand under conditions of dissociation at constant negative temperature was also established.

The conclusions can be directly taken into account in the practice of gas production. The difficulties of field determination of porosity characteristics under conditions of abrupt changes in pressure and/or temperature can be overcome by applying the laboratory characteristics obtained by the author in the range of parameters of salinity, temperatures, pressures and gas content studied by the author. It is important for practice to know that an increase in the compression pressure on hydrate-saturated samples from 4 to 10 MPa can lead to a decrease in gas permeability by almost 40%, which will be accompanied by an increase in relative linear deformation. For ice-containing rocks, critical temperatures have been determined and pressures at which gas can break through the thickness of frozen rocks have been estimated.

The quality of the author's presentation of the material is quite high. The work as a whole is written in understandable language and has correct internal references to illustrative material. The material is presented in high detail and attention to the features of conducting experiments. This justifies the relatively large volume of the manuscript. The review of Russian and foreign literature includes 312 titles.

When formulating the conclusions, the author does not always link the obtained patterns with his own conceptual explanation of their causes. In particular, conclusion 3.1 on page 201 is of the nature of a statement without explaining the nature and causes of the observed effect. It should be explained what the found dependence is connected with.

Conclusion 5.4 (p. 202) should be clarified and commented on. Is the decrease in longitudinal wave velocities an unambiguous characteristic of the content of unfrozen water and evidence of changes in permeability? Is the permeability of the medium unambiguously related to the water content in the liquid phase? Probably, this is also due to the nature of the pores and deformations of the sample (Figs. 11 and 17).

Attention is drawn to some inconvenience in the perception of figures when the illustration and the caption are broken (Figures 10, 15, 23, 44, 48, 49). Similarly, the inconvenience is linked with the tearing the header of the table and its content (Tables 5, 8, 13, 38). Parts of Figure 7 do not have the designations "a" and "b".

It is also recommended to adhere to a single style of writing formulas. Either write in words or in mathematical symbols (p. 61 and following).

**Provisional Recommendation**

*I recommend that the candidate should defend the thesis by means of a formal thesis defense*

*I recommend that the candidate should defend the thesis by means of a formal thesis defense only after appropriate changes would be introduced in candidate's thesis according to the recommendations of the present report*

*The thesis is not acceptable and I recommend that the candidate be exempt from the formal thesis defense*