MIKOVINY SÁMUEL DOCTORAL SCHOOL OF EARTH SCIENCES

Theses of doctoral dissertation

Production of artificially consolidated core samples and studies of their suitability for filtration test of drilling fluids

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I. SCIENTIFIC BACKGROUND AND AIMS

Filtration during the drilling of a well can have a profound effect on hydrocarbon recovery, i.e. the production capacity of the well, as the skin zone created by drilling reduces the initial permeability of the reservoir. The same phenomenon affects the feasibility of drilling operations and determines the impact of the drilling mud on the environment. Overbalanced drilling conditions cannot eliminate the filtration process, but only reduce it. This implies that it is a process that is bound to occur, and the aim is to minimise the harmful effects of the fluid and solid particles that are filtered out during the work process. In conclusion, the phenomenon of filtration is a complex issue that has a fundamental influence on the development of the economic, environmental and technical processes both in newly drilled wells and in some workover well programs.

The commonly used filtration test, as recommended by the API (American Petroleum Institute), is performed on filter paper and/or ceramic discs. However, it should be noted that the tests performed on these do not have the characteristics that are typical of a reservoir, so in such cases the test results may be misleading because the filter medium does not adequately simulate the reservoir conditions. Tests that are more reliable are carried out on core samples, but such measurements are not widespread because a rock core can only be used once, due to the specificity of the measurement. This is due to a permanent change in the initial petrophysical parameters, so that the qualitative and quantitative criteria for the core samples required for the measurement series are generally not guaranteed.

In this respect, one of the objectives of my research was to produce a new type of model material that can replace natural sandstone samples in fluid loss testing.

One of the objectives was to establish a set of criteria which, when considered during the research, would greatly facilitate the efficient development of a technological process to make these new types of model materials, i.e. artificially consolidated core samples, as close as possible to natural sandstones in as many properties as possible. Primarily, these specimens had to be physically stable in structure and water-wet, while meeting the expected petrophysical parameters (e.g. porosity, permeability). It was also useful to establish a general sequence of operations in order to ensure the reproducibility of the new types of core samples.

I planned to modify an existing OFITE 17-50-1 measuring equipment to carry out the fluid loss measurements on natural and artificially consolidated core samples. The measuring instrument can only be used with filter paper or ceramic discs in its factory condition, and it is not possible to perform such experiments on core samples. My aim was to make the measurement set-up suitable for experiments on core samples, where tests at different temperatures and differential

II. ACCOMPLISHED INVESTIGATION

In the first part of my research, I presented the possible ways of producing artificially consolidated core samples based on the relevant literature. The first attempts to produce artificially consolidated specimens for the oil industry date back several decades (Jishun, 2004), where skeleton and binder materials are required in all cases. I used the skeleton material from the selected Hungarian reservoir as the reservoir base material and the skeletal grain from the open pit mine as the non-reservoir based binder material. Both are characterised by a high quartz content, which is consistent with the skeletal base materials used in much of the literature (Holt és Kenter, 1992; Den Brok és társai, 1997; David és társai, 1998; Holt, 2001; Al-Homadhi és Hamada, 2003; Saidi és társai; 2003). I chose industrial cement as binder material, mainly because of its wettability (Viksne és társai, 1961; Saidi és társai, 2003; Chen és Zhang, 2014; Rios és társai, 2014; Younessi és társai, 2013; Marco és társai, 2018). As a result, I have demonstrated through laboratory tests that, thanks to the new cement-based procedure, artificially consolidated core samples can be produced from both reservoir and non-reservoir based raw materials with designable petrophysical parameters and adequate mechanical stability. I have demonstrated that a wide range of porosity and permeability can be achieved by varying the sand-cement-water ratio, the particle size range and the application of appropriate compressive forces. The petrophysical parameters of the artificially consolidated rock samples were also successfully influenced by the application of different environmental conditions. In this way, the mean porethroat size and the ratio of micro- to macro pores could be altered by CO2 flooding for different durations and at different curing periods. Through further measurements, I have demonstrated that the use of additives could be another way to influence the desired parameters. Therefore, by using different amounts of salts during the manufacturing process, I have successfully influenced the pore structure, which also affects porosity and permeability.

In developing the core sample consolidation method, I have shown that the absolute permeability of the resulting core samples can be predicted early in the production process. As early as the second day of the several-week-long production process, a reliable prediction of the absolute permeability of the final product can be made. The reason for this is that the apparent permeability results obtained from the measurements performed are in good agreement with the API recommended absolute permeability values, regardless of the type of skeletal particles used and the method of production.

In the second half of my paper, the aim was to investigate whether these artificially consolidated core samples, which can be produced in a reproducible way, are suitable for fluid loss tests. To establish this, the OFITE 17-50-1 measuring equipment has been successfully retrofitted with customised high-pressure cells. Comparative measurements on the core samples were carried out at different temperatures, using different types of drilling mud and rock groups with different petrophysical parameters. Through tests, I have established that the filtration curves of the artificially consolidated rock samples and the natural rock samples have the same slope when using the drilling mud employed. Since the trends of the mud curves are similar, it can be demonstrated that artificially consolidated rock samples can be used as a substitute for natural rock samples in the permeability ranges studied to observe the filtrate formation characteristics of the given drilling mud. By further related measurements, I have shown that the rate of effective permeability degradation in the artificially consolidated cores is similar to that of natural cores. Thus, these types of rock samples can also be used as a substitute for natural core samples for the determination of return permeability.

III. NEW SCIENTIFIC RESULTS

1. Thesis

I have demonstrated the effect of sand-cement-water ratio and also the effect of the applied compression force and compaction time on petrophysical properties of the artificially consolidated core samples in laboratory tests. On the basis of the results these samples can be produced from both reservoir (drilled core material) and surface (construction sand, etc.) source materials. The studies have demonstrated that the petrophysical properties of core samples can be reliably designed using appropriate sand fractions, experimentally proven sand-cement-water ratios, and different compressive forces.

2. Thesis

I have shown that the petrophysical parameters changing is possible with different applied environmental effects in curing period. I have found that core samples prepared from non-reservoir sand, in curing period the effect of CO2 gas results a small increase in porosity and a significant decrease in absolute and effective permeability compared to the samples kept in a high moisture chamber.

3. Thesis

According to the experimental results it can be stated that besides mechanical compaction, different additives (such as sodium chloride, potassium chloride and calcium chloride) can be used to modify the porosity and also the absolute and effective permeability of artificially consolidated core samples effectively. As I have shown an increase in porosity is obtained by adding 1 and 3 % by volume of additives to the binding material (in the same production conditions), moreover a significant change in the pore system can be obtained, which also affects the permeabilities significantly.

4. Thesis

Based on the experimental results, I have noticed that the artificially consolidated core samples, obtained by the new method, can be considered homogeneous in petrophysics terms. Based on Mercury Injection Capillary Pressure measurements I have demonstrated that the core samples formed to a length of 6.98 cm (2.75 in) ± 0.1 cm (0.039 in) show only negligible differences in porosity and micro-macropore structure. These results confirm that the new type of porous core samples can serve as suitable model for the study of fluid losses and flooding tests.

5. Thesis

A major advantage of the newly developed artificially consolidated cores process is that absolute permeability can be predicted well in the initial phase of the curing period. Based on my measurement results, I have found that the apparent permeability results, obtained during the curing period, fit well with the absolute permeability results measured according to API Standard. The best predictions are shown in the range above 2000 mD and below 1000 mD, where the average deviation is below 10%.

6. Thesis

I have developed a new measurement system for fluid losses tests through modifying the OFITE 17-50-1 measurement device. Due to the newly designed accessories, the measurement device has become suitable for fluid losses tests both on natural and artificially consolidated core samples under static conditions, where the overpressure rate and also the test temperature can be varied.

7. Thesis

Based on my measurement results, I have found that in case of filtration tests on cores, the intrusion should be at least 50% of the water porosity of the core sample. Through the applied laboratory and drill-in fluids I have found that if the cumulative amount of filtrate volume is less than this before mentioned calculated value (50%), the results of the second effective permeability measurements show a slight improvement trend in the effective permeability. Thus, the formation damage effect of these drilling fluids could be regenerated.

Furthermore, I have shown that the fluid losses curves of the artificially consolidated core samples and the natural core samples have the similar shape of curve at the laboratory temperature. Thus, it is demonstrated that taking into account/considering fluid losses characteristics of the used drilling fluids, it is proven that the artificially consolidated core samples can substitute for the natural core samples in the investigated permeability ranges. Based on the experimental results, I have found that the effective permeability decrease of the artificially consolidated core samples is also similar to the same parameter of natural sandstone. These artificially consolidated core samples are suitable for determining the return permeability in fluid filtration testing.

IV. PUTTING THE RESULTS INTO PRACTICE

Based on the tests carried out, a number of practical applications are possible with the rock samples prepared in this novel way, as well as with the new measurement setup for fluid loss.

Firstly, the poroperm values of artificially consolidated specimens can be preselected over a wide range. This makes it possible to produce core samples typical of many sandstone reservoirs. A further positive outcome is that the poroperm values of the specimens obtained under a given composition and production condition are within a narrow range, so that the procedure developed can be used to produce replicable samples. If necessary, the mean pore size can also be influenced by the additives used or the environmental conditions affecting the specimen.

Even at the initial stage of the several-week-long core sample production process, the absolute permeability of the specimen that will be produced can be well predicted. From a technological point of view, this means that the time needed to develop a core sample type can be reduced. The possibility to intervene quickly minimises the number of non-compliant specimens, the workload of the measuring equipment and the number of person-hours needed to perform the measurements. From a practical point of view, even with small amounts of skeletal particles or binder materials available, the manufacturing process can be successful.

The scientific results obtained suggest that artificially consolidated core samples could be useful model materials in higher education. One advantage of these samples is that they can be easily replaced (if the raw materials are available). Thus, if the poroperm values are determined on such specimens, for example in the context of practice classes or during the preparation of a thesis, there is no need to worry about a possible damage or deterioration of natural rock cores. These model materials can also be used for test measurements or for the post-maintenance calibration of an equipment. The same applies to the installation of a new measuring instrument.

On the other hand, fluid loss tests have demonstrated that the high-pressure cell and the associated core holder can be successfully integrated into the factory equipment to form a functional unit with it. The resulting new, modified measuring instrument proved to be reliable under different operating conditions of pressure and temperature. As a result of this development, a measuring instrument is now available that works well on both natural and artificially consolidated rock samples, where measurements can be made under static and dynamic conditions. This can make the research and development of advanced drilling muds more successful than using filter paper or ceramic disc model materials.

Practical use is greatly facilitated by the fact that the geometrical shape of the rock samples is the same for routine measurements and, thanks to its thoughtful design, for fluid loss tests. Therefore, there is no need to make additional measurements or calculations, and neither to correct or reinterpret the data. Furthermore, this measurement method can be used to determine the permeability degradation of the rock samples compared to their initial condition after a filtration test was performed on them, thus providing a better and more thorough understanding of the filtration phenomenon.

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