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A SIMPLE METHOD TO CALIBRATE THE TEMPERATURE EFFECT FOR THE CALCULATION OF GAS PERMEABILITY

by

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Temperature plays an important role in the gas permeability test. A small temperature variation still exists in the experimental process since the temperature control device cannot strictly maintain a constant temperature. This can further affect the accuracy of the gas permeability. To solve this problem, a simple method based on the ideal gas equation of state is introduced to calibrate the gas pressure variation because of the temperature effect. We verified the calibration results through several examples, and the results proved the feasibility and effectiveness of the method. In particular, this method is particularly effective for low permeability materials in long-term gas permeation tests.
Key words: *gas permeability, temperature effect, pressure calibration*

Introduction

Temperature is an important factor for the gas permeability test. Many researchers have indicated that gas permeability tests are performed in air-conditioned rooms at a constant temperature [1-10]. However, the temperature control device cannot strictly maintain a constant temperature. A small temperature variation remains in the experimental process. The temperature variation will cause gas pressure variation and further affect gas permeability. This effect is particularly obvious for low permeability materials because of the long time required. We cannot determine whether the pressure variation is due to the temperature effect or the seepage property of the material. To avoid the temperature effect, a modified gas permeability calculation model was proposed.

Calibration of the gas permeability calculation

Figure 1 shows a schematic diagram of the gas permeability test that is commonly performed in many laboratories. The sample is jacketed in a protective Viton™ membrane and

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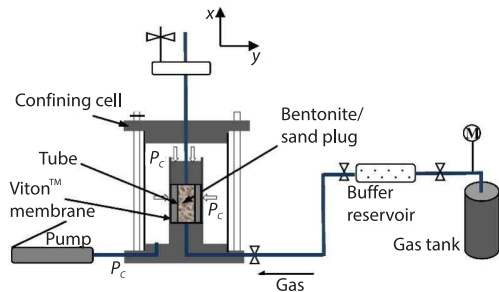THERMAL SCIENCE: Year 2021, Vol. 25, No. 6B, pp. 4605-4610

Figure 1. Schematic diagram of the experimental set-up (triaxial cell and gas panel) [3]

placed into a triaxial cell. A confining pressure, P_c, is applied and controlled by a servo pump. Gas is injected through a buffer reservoir to the upstream side of the sample at a pressure P_1, whereas the other side is maintained at atmospheric pressure, P_0. The gas-flows through the sample (along the *x*-axis) because of the pressure gradient. During this period, the time variation, Δt, is recorded when the upstream gas pressure decreases from P_1 to $P_1 - \Delta P$. Therefore, the average gas pressure, P_{mean}, in the buffer reservoir is $P_{mean} = (P_1 + P_1 - \Delta P)/2 = (P_1 - \Delta P)/2$. According to Darcy's law [11], the gas permeability is expressed:

$$k_{eff} = \frac{\mu_g v_0}{A} \frac{2h\Delta P}{(P_{mean}^2 - P_0^2)\Delta t} \tag{1}$$

where μ_g is the viscosity of the gas, v_0 – the volume of a gas tank, A – the cross-sectional area of the sample, h – the sample height, and k_{eff} – the effective gas permeability. More details can be found in these studies [3, 12].

When the gas pressure decreases from P_1 to P_2 (*e.g.*, $P_1 - \Delta P$), we should know whether this pressure change is due to the gas passes through the sample or the temperature changes. According to the ideal gas state equation [13], we have:

$$PV = nRT \tag{2}$$

where *n* is the number of moles of a substance, R – the ideal gas constant, and T – the absolute temperature. For a buffer reservoir, the volume is constant, and all valves are closed. When the temperature changes from T_1 to T_2, the corresponding pressure changes from $P_1^{T_1}$ to $P_2^{T_2}$. This pressure change is purely caused by the temperature change. Thus, there exists:

$$P_1^{T_1}V = nRT_1 \tag{3}$$

$$P_1^{T_2}V = nRT_2 \tag{4}$$

where $P_1^{T_1}$ and $P_1^{T_2}$ are the corresponding pressures at time T_1 and T_2.

Then, we can get:

$$P_1^{T_2} = P_1^{T_1} \frac{T_2}{T_1} \tag{5}$$

Generally, the experimental temperature was set at 20 °C (*i.e.*, 293.15 K). Therefore, the actual pressure at 20 °C:

$$P_1^{T_2} = P_1^{T_1} \frac{293.15}{T_1} \tag{6}$$

With this method, all the pressure should be calibrated before gas permeability calculation [14]. Now, we give several examples to explain how to calculate gas permeability according to the calibration pressure.

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Examples

Bentonite

Figure 2(a) gives an example of water-saturated bentonite. The entire gas permeability test lasted nearly 90 hours. It can be found that the temperature changes from 19-24 °C during the gas permeability test. As a result, the pressure fluctuates with the temperature change (between 10.5 bar and 10.8 bar). If the temperature is constant, the gas pressure should gradually decrease with time. However, without the calibration, the gas pressure appears to increase at certain moments. After the calibration using our method, we find that the gas pressure gradually decreases after the calibration, fig. 2(a).
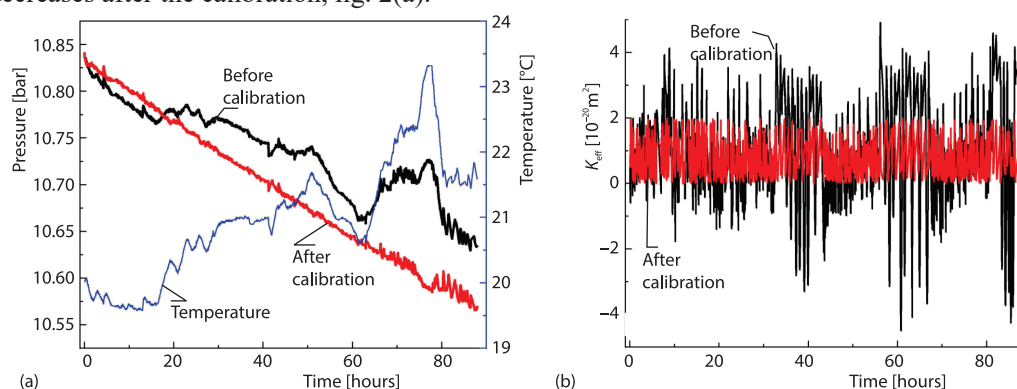

Figure 2. (a) Pressure changes over time: calibrated value *vs.* without calibration (water-saturated bentonite) and (b) evolution of the gas permeability with time: calibrated value *vs.* without calibration

The gas permeability was calculated according to the pressure evolution (before calibration *vs*. after calibration), see fig. 2(b). The gas permeability calculated with the measured pressure (without calibration) significantly fluctuates and is even negative in a certain period. This is mainly because the increase in pressure in the cylinder caused by the increase in temperature exceeds the pressure drop caused by gas permeation. After the calibration, we find that the range of fluctuation of the permeability decreases, and the overall trend tends to be stable. Therefore, the actual permeability can be obtained with this simple calibration method. However, most published results overlooked this phenomenon.

Hydrate sediments

For gas hydrates, we found that the gas permeability test lasted nearly 12 hours, shown in fig. 3(a). During the gas permeability test, the pressure drop was about 1.0 bar, and the temperature fluctuation range was around 2.7 °C. Further, it can be found that the gas pressure has an upward trend in the periods of 3.0~3.2 hours, 4.5~5.0 hours, and 10.5~11.8 hours before the temperature calibration. This is obviously due to temperature fluctuations. After using the aforementioned calibration method, it can be found that the pressure drop curve becomes smooth.

For the gas permeability test, we also found that the gas permeability values were highly fluctuating before the temperature calibration, fig. 3(b). Similarly, the calculation results of gas permeability even showed negative values at some stages. After calibration, the fluctuation in gas permeability is relatively small. However, the calibration effect is not as good as the calibration result of the bentonite. This is mainly because that the gas permeability test of bentonite lasts for a long time and the temperature fluctuation is relatively large. Therefore, the calibration effect is better.
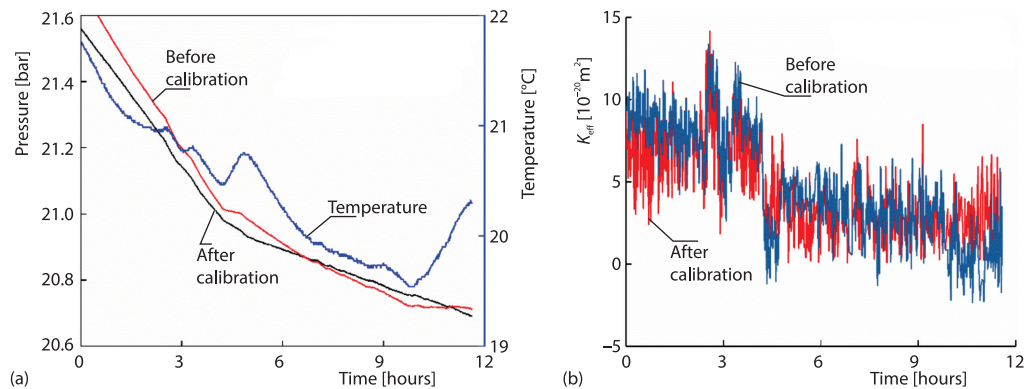
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Figure 3. (a) Pressure changes over time: calibrated value *vs.* without calibration (3.2. hydrate sediments) and (b) evolution of the gas permeability with time: calibrated value *vs.* without calibration

Cracked bentonite

Finally, we will show an example of an initially cracked bentonite. After full water saturation, we performed a gas permeability test. The pressure and temperature evolution curves are shown in fig. 4(a). The gas permeability test lasted for approximately 65 hours. During the test, the pressure dropped by about 0.4 bar and the temperature fluctuation range was 3.7 °C. Similarly, we found that gas permeation did not cause a drop in pressure due to temperature fluctuations during a certain period. After calibration, the pressure rise phenomenon is almost eliminated.

The calibration results of gas permeability show that the gas permeability before calibration is highly variable, see fig. 4(b). After calibration, it can be found that the fluctuation range of the gas permeability is greatly reduced. By comparing the test results of the bentonite (with/without cracks) and natural gas hydrate, it can be found that the method has a better calibration effect for the gas permeability test considering the creep effect for a long time. For the gas permeability test with a shorter duration, the calibration effect is not very obvious because the temperature change is not very obvious.
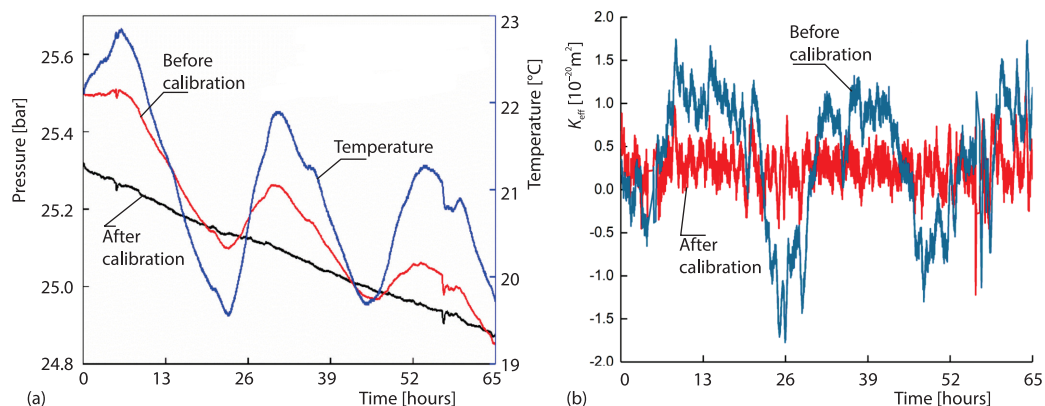

Figure 4. (a) Pressure changes over time: calibrated value *vs.* without calibration (initially cracked bentonite) and (b) evolution of the gas permeability with time: calibrated value *vs.* without calibration

Discussion

The feasibility of this temperature calibration method can be verified by the previous three calibration tests. In general, the accuracy of the calculation of gas permeability has been improved to varying degrees after calibration. However, the effectiveness of the method also depends on the specific circumstances of the test. For the gas permeability test of low permeability materials considering the time effect, the calibration effect is better. This is because, for low permeability media, the pressure fluctuations caused by gas permeation are small. As a result, temperature fluctuations cause pressure changes, which in turn lead to more obvious changes in gas permeability. For highly permeable materials, the gas permeation time is relatively short due to the faster gas pressure drop. Therefore, compared with the pressure fluctuation caused by gas permeation, the pressure fluctuation caused by temperature is not very obvious, and the influence on the calculation result of gas permeability is also limited.

In addition, this method also has high requirements for test instruments. Pressure sensors should be able to simultaneously record pressure and temperature evolution, *i.e.* pressure evolution should correspond to temperature evolution. In this way, the reliability of the calibration results is relatively high. The calibration method is simple and easy to understand. At present, even air-conditioned rooms cannot guarantee absolute constant temperature when conducting gas permeability experiments. However, temperature fluctuation has an obvious influence on the calculation of gas permeability of a low permeability medium.This method can effectively overcome the shortcoming of temperature influence, and the calibration process is also very simple.

Conclusions

Gas permeability measurement is notably important in many areas, *e.g*., storage of high level radioactive waste, storage of CO_2 and coal bed methane extraction, *etc*. When one measures the gas permeability, the temperature effect is a notably important factor that troubles many researchers. This effect is particularly pronounced for long-term permeability evolution tests of low permeability materials. To overcome this effect, we propose a simple calibration method. The method is based on pressure and temperature evolution data. The pressure evolution data at different temperatures are corrected according to the ideal gas equation.

To verify the effectiveness of the method, we have calibrated and verified the gas permeability results for different materials. The results show that the calibration effect is better and can effectively overcome the influence of temperature change on gas permeability calculation. However, we have also found that this method has limited calibration effects on high permeability materials. The effect of temperature on pressure changes is limited when compared to pressure changes due to permeation. Overall, the effect of temperature on gas permeability cannot be ignored. This method can effectively avoid the influence of temperature and can be further applied in similar experiments.

Acknowledgment

Nomenclature

A – cross-sectional area of the sample, $[m^2]$
h – sample height, $[m]$
k_{eff} – effective gas permeability, $[m^2]$
n – number of moles of a substance, $[mol]$
P – gas pressure, $[MPa]$
P_c – confining pressure, $[MPa]$
P_{mean} – average gas pressure, $[MPa]$
P_0 – atmospheric pressure, $[MPa]$
ΔP – pressure variation, $[MPa]$
$P_1^{T_1}$, $P_1^{T_2}$ – gas pressure when the temperature
is T_1/T_2, $[MPa]$

R – ideal gas constant, $[Jmol^{-1}K^{-1}]$
T – absolute temperature, $[K]$
T_1, T_2 – temperature at different time, $[K]$
Δt – time variation, $[s]$
v_0 – volume of the gas tank, $[m^3]$

Greek symbol

μ_g – viscosity of gas, $[Nsm^{-2}]$

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