FIRST NON-CONTACT MINI-PERMEAMETER

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ABSTRACT

Minipermeameters are gaining an increased interest in the petroleum industry due to being the main tools for non-destructive, fast and relatively cheap permeability measurement on core samples. This paper discusses a recently patented novel technique development for measuring permeability based on the pressure-decay technique but without touching the core sample. The exact range of permeability that the device would be able to measure is still under study. The non-contact mini-permeameter has been tested in both synthetic and real rock samples and compared with the latest commercially available mini-permeameter. The results are by far more accurate, precise and faster than current available mini-permeameters. The measurement time for each point is approximately 5 ms with a distance 0.04 mm between measured points compare to few minutes measurement time and 0.1 mm at best in other pressure-decay mini-permeameters. This makes the non-contact permeameter over 12,000 times faster. This allows permeability maps to be generated on slabbed core in a matter of hours instead of days or months. The concern of breaking a core sample while sealing the mini-permeameter probe to take a measurement is eliminated. The fact that no contact is required with the core sample allows the measurement to be made on any rock surface as long as 5 mm^2 area is available below the probe. The new device is small and can be used on site geological surveys. This new development of a non-contact sensing permeameter is part of a bigger routine core analysis system that aims at measuring almost all rock properties in a non-contact non-destructive fashion before and after core cleaning and with minimum core slabbing.

INTRODUCTION

In the petrophysics laboratories, measuring permeability on core samples is normally done by transmitting either liquids or gases through rock samples. A measurement can be either destructive or non-destructive, depending on whether a permanent alteration occurs to the sample's physical, chemical or mechanical properties. Permeability measurements can be divided into two types depending on the principle of operation used [1], steady-state devices and unsteady-state devices. The measurement using both operation principles can be made on whole core or core plugs. The core samples (whole or plug) are normally placed inside a pressure cell, except in the case when mini-permeameters are used to measure permeability. In this case, the core sample is placed on the profiling apparatus in ambient conditions. The standard devices that currently use the steady-state principle to measure permeability on whole core placed inside a pressure cell are transverse and radial steady-state devices. The standard devices that currently use the steady-state principle to measure permeability on the plug core placed inside a pressure cell are axial flow steady-state devices that operate at low, medium and high pressures [1]. The standard devices that currently use the unsteady-state principle to measure permeability on the plug core placed inside a pressure cell are axial flow pressure falloff and axial flow pulse-decay devices. The standard devices that are used to measure permeability on both whole and plug samples under ambient conditions are steady-state mini-permeameters and pressure-decay (unsteady-state) mini-permeameters. This paper will concentrate on these two types of mini-permeameters only, as one of the objectives of this project is to develop a non-contact mini-permeameter that is faster and more accurate. A detailed description of their principle of operation, calibration, advantages and disadvantages will be discussed later in the paper.

NON-CONTACT MINIPERMEAMETER PRINCIPLE OF OPERATION

The principle of the new method is called "apparent gas-distance". The premise is that gas issuing from a nozzle fixed at a constant but small distance above the surface of a porous medium whose permeability is to be measured can flow in two directions (see Figure 1), one into the porous medium (Q2), and the other out through the gap between the nozzle and the surface (Q3), as shown in Figure 1. The more permeable the porous medium the greater the relative volume of gas that will flow into the medium. Thus if the nozzle can be held at a constant distance and the relative values of the two gas flows (Q2 and Q3) are measured, a measure of the permeability would be achieved. One way to measure the relative volumes is to use the pressure difference created between the inner injection nozzle and an outer concentric tube. The concentric tube also focuses on the gas flow, thus increasing the depth of investigation. If the permeability is high, more gas will go into the sample, which means less gas is flowing across the surface and the gas distance sensor. Despite having the distance constant between the nozzle and the surface, the actual distance measured by the nozzle is larger, owing to high permeability. This difference between the nozzle constant distance and actual distance measured, which will be referred to hereafter as the "apparent distance", is directly related to permeability. The larger the apparent distance, the higher the permeability. Finding this direct relation (empirically) would make it possible to calculate the gas permeability of a porous medium using gas distance sensor.

CALIBRATION

Before establishing a relationship between apparent distance and permeability, a distance sensor is required to measure the actual distance between the nozzle and sample surface. A laser distance sensor is used for this propose. The apparent distance is computed as the difference between the physical distance of the nozzle above the surface of a sample and that measured by the gas distance sensor. Since the core sample's surface cannot be perfectly flat and given the very sensitive nature of the gas distance sensor, a laser distance sensor is used to measure the physical distance between the gas distance sensor and the sample surface. The laser and gas sensors were mounted on a computer automotive 3-axis table. This allowed the distance between the gas distance sensor and the sample surface to remain fixed by moving the gas sensor up and down automatically based on the laser distance sensor feedback. This apparatus made it possible to scan samples of any shape as the laser distance sensor will maintain the height of the gas distance sensor above sample surface. To calibrate apparent distance to permeability, ideally samples of fix increment steps (0.01, 0.1, 1, 10, 100, 1000, 10000 mD) are required. Lack of API standards for permeability calibration made this one of the biggest challenges designing this non-contact mini-permeameter. To overcome this problem, synthetic ceramic base samples were used. These synthetic samples are normally used as filters in water treatment facilities hence are homogenous with relatively constant permeability. Two synthetic samples were available for this study, with mean permeability of 1900 and 2700 mD. Another calibration concern is finding a tool that can measure permeability in similar volume to establish a meaning full relationship between apparent distance and permeability [2]. To overcome this issue, each of the synthetic sample's permeability were measured using unsteady-state mini-permeameter with probe size equal to that of the nozzle used on the gas distance sensor. In order to avoid edge effects, two lines (a) & (b) were selected in the middle of each synthetic sample. To assist precision (repeatability) of the gas distance sensor, each line was measured 5 times (Figure 2). The repeatability between first (assumed reference) and the other four measurements made on the line was found to be 98%. The variance of the data is narrow as expected in homogenous synthetic sample. Furthermore, the shape of the apparent distance distribution is similar to that of permeability measure by the unsteady state mini-permeameter (Figure 3 & 4). This observation confirmed the concept on which non-contact mini-permeameter was developed, the higher the permeability, the higher apparent distance measured. This confirmed that a linear empirical relationship can be developed between apparent distance and permeability measured by the unsteady-state mini-permeameter.

$$P = a*D \tag{1}$$

Where P is permeability in mD

D is the apparent distance in mm

a is a constant

The constant "a" was found empirically to be 5000. This equation was applied to apparent distance measurement in synthetic samples and compared with unsteady state mini-permeameter (Table 1). The results show that the gas distance sensor has lower variance than unsteady state especially in the 2700 mD synthetic sample. Later, the equation was applied to real rock with similar success.

DISCUSSION

Measurement made on real rock samples by non-contact mini-permeameter have revealed several limitations based on the current hardware. For the measurement to be valued, Q3 (see Figure 1) needs to be equal on both sides. This is true only if a 2 mm^2 flat area is below the 1 mm diameter nozzle of the gas distance sensor. In case of coarse grain samples > 0.5 mm, it was found the gas distance sensor is mapping grains and the permeability measurement is not accurate. This is a common problem with any type of mini-permeameter [2] and can be addressed by using a larger size probe. Another issue is related to unconsolidated and dusty samples. The fact that the outer cylinder of the gas distance sensor sucks air, it acts as a micro vacuum cleaner. Dust and loose fine grains are sucked into the sensor resulting in damage to it. To reduce this effect, samples measured were vacuumed before being measured by the gas distance sensor. Another issue was identified related to crystallized grains which affect distance measurement of the laser distance sensor as it becomes noisy due to scattering. Hence, this will affect apparent distance measurement. Smoothing and noise filtering techniques were used to minimize this effect. Based on several empirical studies on real rock samples, it was found that the current gas distance sensor used in this study has a confident permeability range from 400 – 15,000 mD. Both limits can be improved by redesigning the gas distance sensor for core analysis applications. Despite all these limitations, the non contact mini-permeameters have several advantages over current commercially available steady and unsteady state mini-permeameters. The fact it is non contact allows measurements to be made on broken samples and cuttings. It also allows permeability measurement on fragile samples where normal mini-permeameters could break the sample while sealing. Most importantly, being non contact makes it much faster, with a 5 ms response time compared to a few minutes in case of unsteady state and over 10 minutes in case of steady mini-permeameters. The repeatability is much higher (98%) than unsteady state which has poor repeatability (80% at best). The last two features make it possible to generate permeability maps within a few hours (see Figure 5) that would take months with normal mini-permeameters.

CONCLUSION

The first non-contact mini-permeameter was designed based on the "apparent gas-distance" method where a simple linear relationship can be used to estimate permeability.

The non-contact permeameter is much faster (over 12,000 times) than top of the line unsteady state commercial mini-permeameters. The high resolution (up to 0.0125 mm), repeatability (over 98%) and accuracy (over 90%) make it possible to generate permeability maps on rock samples of any shape within hours. The current range of permeability measured by the first prototype is from 400 – 15000 mD. Both limits can be extended further by customizing a gas distance sensor. In addition, an industry standard calibration kit for mini-permeameters is required as the repeatability of current commercially available reference tools are poor compared to the non-contact mini-permeameter, hence cannot be used to calibrate it. Grain size distribution can be estimated using a laser distance sensor in conjunction with the gas distance sensor. Both measurements can be part of a large non-contact non-destructive routine core analysis system that is capable of measuring all properties before and after cleaning. The measurement generated by such a system will redefine the importance of understanding the cleaning effect on core analysis and ultimately reservoir characterization.

REFERENCES

1. American Petroleum Institute, "*Recommended Practices for Core Analysis*," Second Edition : American Petroleum Institute, Washington DC, (1998), page 6/18 – 6/42.
2. Anggraeni S., Bowen D., Corbett P., "The Use of the Probe Permeameter in Carbonates Addressing the Problems of Permeability Support and Stationarity," *Society of Professional Well Log Analysts*, (1999) **Vol. 40**, No 5, page 316-326.

Table 1: Show summary of results measured by unsteady state mini-permeameter and gas apparent distance permeability using equation 1 on two synthetic samples.

Synthetic Sample No	line	Unsteady State dominant value (mD)	Unsteady State variance (mD)	Apparent distance dominant (mm)	Apparent distance variance (mm)	Estimated dominant permeability (mD)	Estimated permeability variance (mD)
1	a	1900	500	0.38	0.06	1900	300
1	b	1800	450	0.38	0.08	1900	400
2	a	2700	400	0.55	0.05	2760	250
2	b	3000	500	0.56	0.04	2800	200

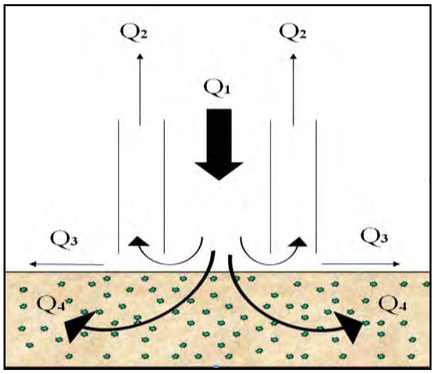

Figure 1. Shows 2-D section of the gas-distance sensor nozzle which consists of two cylinders, inner blowing air Q_1 and outer sucking air Q_2

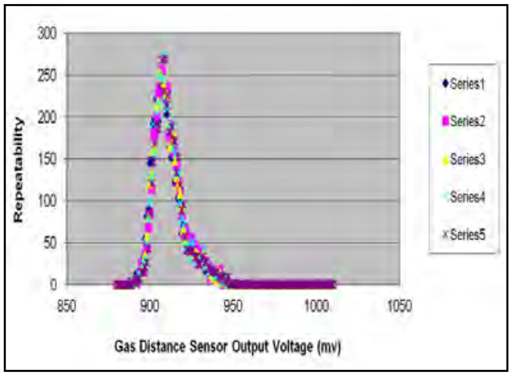

Figure 2. Shows measurement made by the gas distance sensor repeated 5 times over line "a" on synthetic sample.

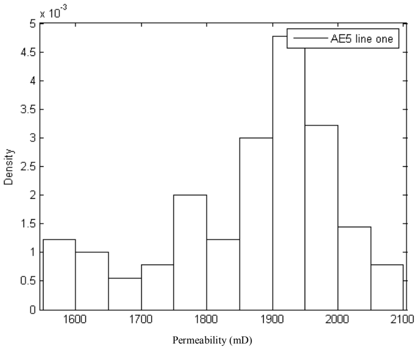

Figure 4. Distribution of permeabilities (mD) measured by unsteady-State mini-permeameter on synthetic sample No.1 (line a).

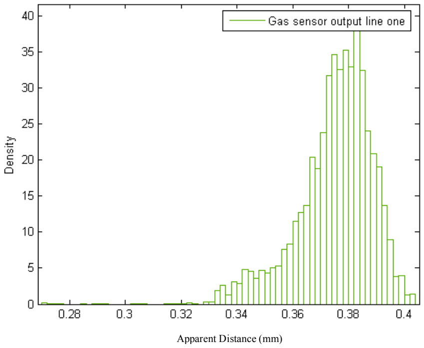

Figure 5. Distribution of apparent distance measured by gas distance sensor (mm) on synthetic sample No.1 (line a).

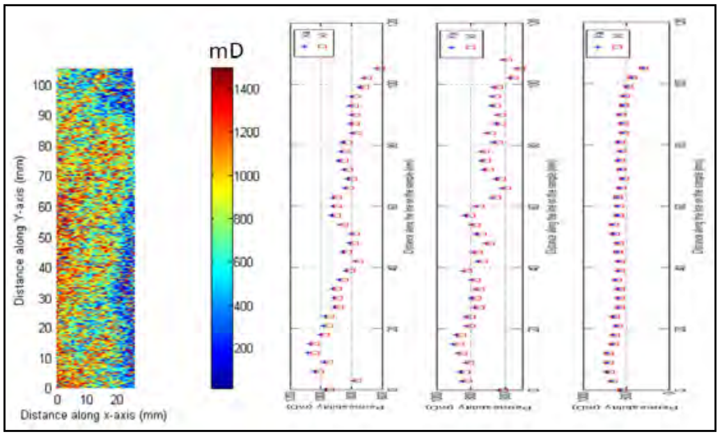

Figure 6: Permeability distribution map (measured at 0.0125 mm resolution) made by gas apparent distance method on real sample (26 x 110) mm and three lines measured by unsteady state mini-permeameter (measured every 1 mm). Note that both tools show that permeability reducing in the sample as you move from left to right.