UNIVERSITY OF NEVADA/RENO/5-7 JUNE 1995

Rock Mechanics Proceedings of the 35th U.S. Symposium

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A.A. BALKEMA / ROTTERDAM / BROOKFIELD / 1995

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The effect of drying and re-saturation on the gas permeability of coal

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ABSTRACT: Predictions of potential gas production from coal seam reservoirs rely on accurate measurements of porosity and permeability of coal samples. We have performed gas flow measurements on two coal samples from the San Juan Basin to examine the effect of drying and resaturation on flow rates. Gas flow rates were measured as a function of hydrostatic pressure, gas inlet pressure, and gas type (methane, helium, nitrogen) for samples under three different conditions: (1) 'un-disturbed', (2) dried, and (3) resaturated after drying. Drying the samples increased the flow rate by as much as two-orders of magnitude. The magnitude of the increase in flow caused by drying depended on the initial permeability of the sample and on the hydrostatic confining pressure. Resaturating the dried samples decreased the flow rate, but did not restore flow rates to the values obtained on the 'undisturbed' samples. Drying of coal samples results in permanent damage to the coal and thus greatly influences gas permeability.

1 INTRODUCTION

Coal seams contain some of the richest known reservoirs of potentially recoverable natural gas. Determination of the production potential of a coal seam reservoir relies on accurate measurement of the porosity and permeability of natural fractures, known as cleats, that occur in coal. Standard core measurement techniques for determining cleat porosity often involve weighing a sample, then drying out the coal, and re-weighing it. The sample is dried by vacuuming or heating. Changes in the moisture and volatile contents of coal can produce differential shrinkage and/or swelling, resulting in internal stresses that cause disintegrative weathering of the rock (Nelson, 1989). These internal stresses caused by differential volume changes in the coal may result in the formation of new cracks, and/or the interlinking of existing cracks. Because coal has a low permeability, gas flow rates are sensitive to the number of cracks and their interconnectivity. Any change induced in the coal by mechanical/thermal disturbances will therefore have a significant impact on the flow properties. A 100,000-fold increase in permeability on drying a coal sample was reported by (Rose and Foh, 1984). In this paper, we present the results of an investigation on the effect of drying and subsequent resaturation on gas flow rates for coal.

Table 1. Sample Number, core length, core diameter and approximate depth for the two coal samples tested

Sample Number	Length (cm)	Diameter (cm)	Approx Depth (m)
IC11	9.75	9.18	551
IC13	8.32	9.19	552

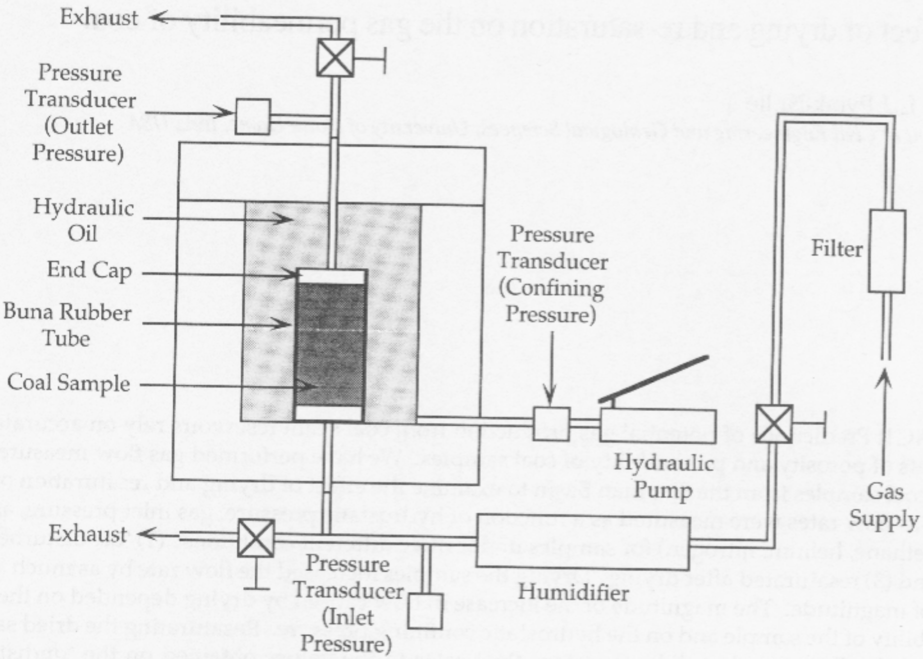

Figure 1. Experimental Setup used for measuring fluid flow rate through coal as a function of hydrostatic stress

2 EXPERIMENTAL PROCEDURE

Coal samples from the Intermediate Fruitland Formation, Valencia Canyon, San Juan Basin, La Plata County, Colorado were used in this study. Table I gives the sample location, approximate depth (Ertekin et. al., 1991), and the dimensions of the coal samples. Because well-cleated coal drill-core samples are generally friable, sample preparation involved coating the circumference of the coal drill core with an 0.8 mm thick layer of epoxy resin to help maintain the integrity of the sample, as well as sealed or otherwise filled in surface fractures and discontinuities. In addition, it was necessary to "size-out" the samples because the diameter of the competent coal was not uniform along the length of the core.

The experimental setup is shown in Figure 1. A sample is placed between endcaps and jacketed with buna rubber to prevent exposure to hydraulic oil. The jacketed sample is placed in the hydrostatic pressure vessel. Flow measurements were made for a range of confining pressures (0.5 MPa - 7.0 MPa) and pore pressures (0.137 MPa - to 0.548 MPa) using nitrogen, helium, and methane. Because coal is relatively impermeable, a finite volume technique was used to determine gas flow rates through the sample. The build-up in pressure with time was measured for a finite volume on the outlet using electronic pressure transducers with a sensitivity of (0.02 MPa/mv). Boyle's Law ($PV = n$*constant, where P is pressure, V is volume, and n the number of molecules) is then used to determine the volumetric flow rate from the pressure build-up data. This is calculated by determining the change in volume with time to produce the observed increase in pressure with time.

After measuring the fluid flow rate through the initial 'un-disturbed' samples, the samples were dried in an oven with circulating argon. An inert environment of argon was used to reduce oxidation of the samples during drying. The samples were maintained at 104°C for 24 hours.

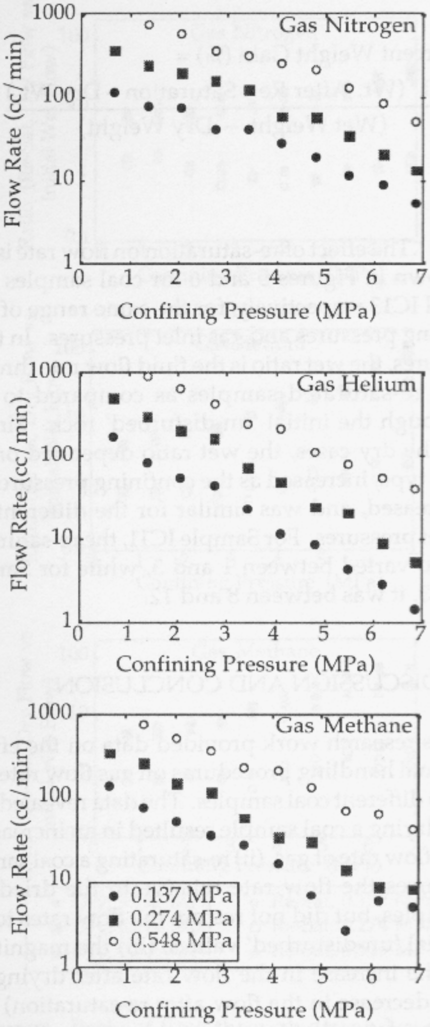

Figure 2. Flow rate as a function of confining pressure through initial 'un-disturbed sample IC11 for 3 different gases

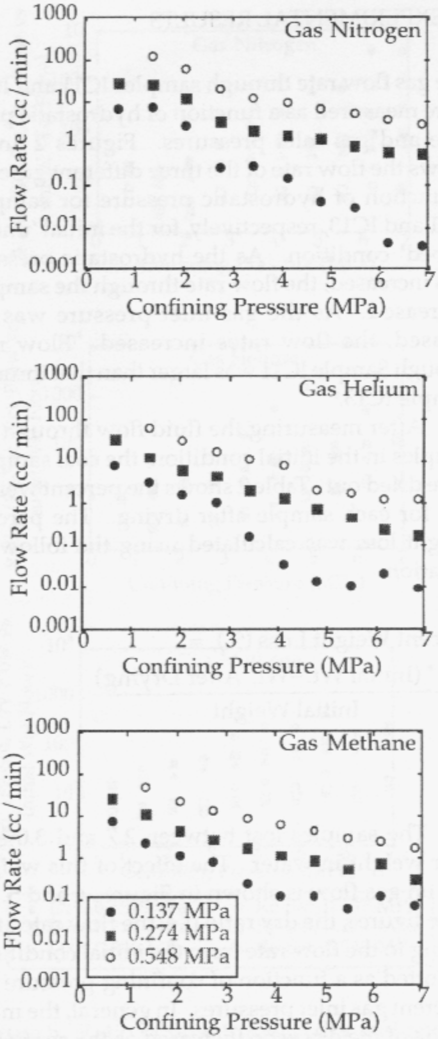

Figure 3. Flow rate as a function of confining pressure through initial 'un-disturbed sample IC13 for 3 different gases

After drying, gas flow rates through the samples were measured for same hydrostatic pressures, gas inlet pressure, and gas types. After the measurements, the samples were re-saturated over a period of about 6 weeks through imbibition of water. The rate of water ingress into the sample was monitored as a function of time. Finally, after the weight of the samples had reached a more or less steady value, the gas flow rate through the re-saturated rocks were measured.

As mentioned, three different gases, nitrogen, helium and methane, were used in this investigation. Humidified gas was used for the flow rate measurements for the initial 'un-disturbed' and the final re-saturated samples to minimize water migration in or out of the coal during the fluid flow experiments.. Dry gas was used for the dried samples.

3 EXPERIMENTAL RESULTS

The gas flow rate through samples IC11 and IC13 were measured as a function of hydrostatic pressure and gas inlet pressures. Figures 2 and 3 shows the flow rate of the three different gases as a function of hydrostatic pressure for samples IC11 and IC13, respectively, for the initial 'undisturbed' condition. As the hydrostatic pressure was increased, the flow rate through the samples decreased. As the gas inlet pressure was increased, the flow rates increased. Flow rate through Sample IC11 was larger than that through Sample IC13.

After measuring the fluid flow through the samples in the initial condition, the coal samples were dried out. Table 2 shows the percent weight loss for each sample after drying. The percent weight loss was calculated using the following equation:

$$\text{Percent Weight Loss (\%)} = \frac{100 * (\text{Initial Wt.} - \text{Wt. After Drying})}{\text{Initial Weight}} \tag{1}$$

The samples lost between 2.7 and 3.0% of their weight in water. The effect of this weight loss on gas flow is shown in Figures 4 and 5. In these figures, the dry ratio (i.e. the flow rate after drying to the flow rate from the initial condition) is plotted as a function of confining pressure for different gas inlet pressures. In general, the magnitude of the dry ratio increased as the confining pressure was increased, depended on gas type, and was similar for the different gas inlet pressures.

After measuring the fluid flow through the samples in the dry condition, the coal samples were re-saturated over a period of about month and a half through imbibition of water. Figure 6 shows the increase in sample weight over time plotted as the ratio of weight gained during re-saturation to weight loss during drying. Table 2 lists the initial weight, the dry weight, and the final re-saturated weight for the two samples tested. The percent weight gain upon re-saturation shown in Figure 6 is based on the following calculation:

$$\text{Percent Weight Gain (\%)} = \frac{100 * (\text{Wt. After Re} - \text{Saturation} - \text{Dry Wt.})}{(\text{Wet Weight} - \text{Dry Weight})} \tag{2}$$

The effect of re-saturation on flow rate is also shown in Figures 5 and 6 for coal samples IC11 and IC13 respectively, for the same range of confining pressures and gas inlet pressures. In these figures, the wet ratio is the fluid flow rate through the re-saturated samples as compared to that through the initial 'un-disturbed' rock. Similar to the dry cases, the wet ratio depended on the gas type, increased as the confining pressure was increased, and was similar for the different gas inlet pressures. For Sample IC11, the re-saturated ratio varied between 1 and 3, while for Sample IC13, it was between 8 and 12.

4 DISCUSSION AND CONCLUSION

This research work provided data on the effects of coal handling procedures on gas flow rates for two different coal samples. The data revealed that (i) drying a coal sample resulted in an increase in the flow rate of gas, (ii) re-saturating a coal sample reduces the flow rate relative to the dried-out samples, but did not restore the flow rates to the initial 'un-disturbed' values, (iii) the magnitude of the increase in the flow rate after drying (or the decrease in the flow after re-saturation) was stress-dependent, and (iv) the lower the flow rate through the initial 'un-disturbed' sample, the larger the wet ratio was indicating that the changes induced were the largest for low permeability samples.

Prediction of the gas production potential of a reservoir based on laboratory measurements of flow rates must take into account changes that may have been induced in the core from handling techniques. If the initial permeability of the core is low, a significant error in permeability will be produced by drying the samples.

CAT-scans of the samples taken prior to drying, and after re-saturation did not reveal any significant change in the micro-structure of the samples. However, because the magnitude of the changes observed in the flow rate was observed

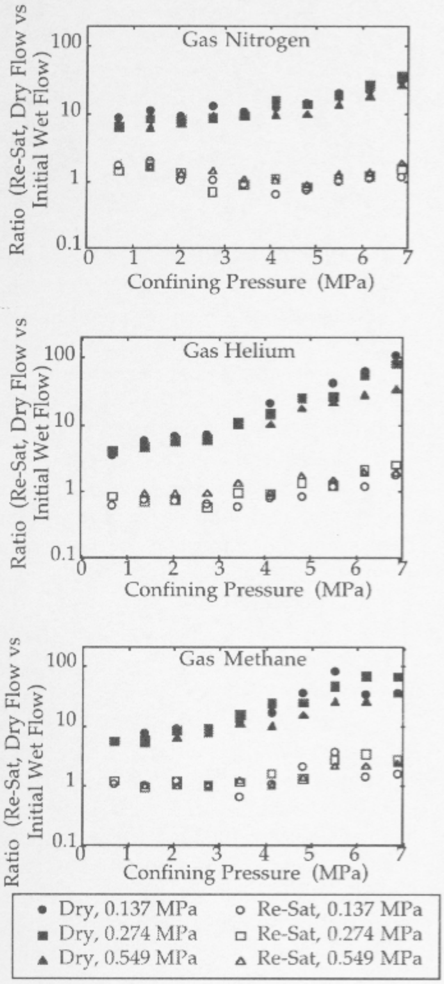

Figure 4. Ratio of flow through dry and re-saturated rock as a function of confining pressure-Sample IC11 for 3 different gases

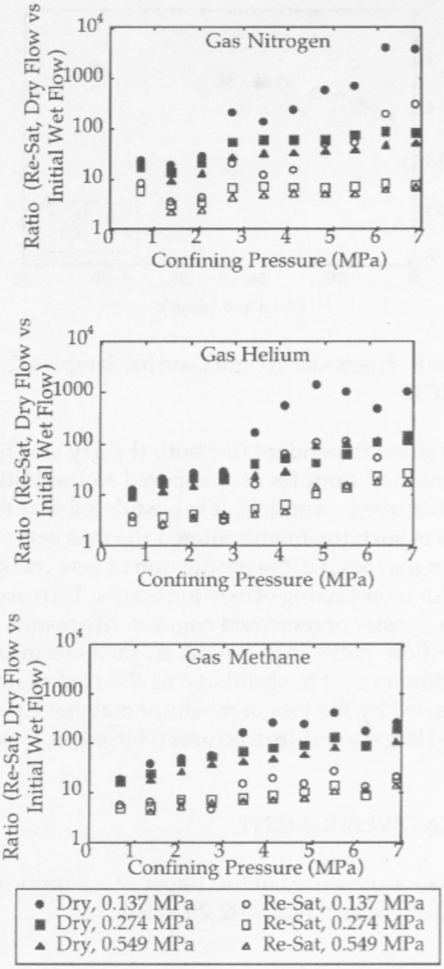

Figure 5. Ratio of flow through dry and re-saturated rock as a function of confining pressure-Sample IC13 for 3 different gases

Table 2. Initial Weights, Dry Weights, and Re-Saturated Weights for the two coal samples tested

Sample Number	Wt. Before Drying (g)	Wt. After Drying (g)	Weight Loss (%)	Wt. After Re-Sat. (g)	Weight Gain (g)	Weight Gain (%)
IC11	959.61	932.07	2.9	953.95	21.88	79.4
IC13	759.26	736.21	3.1	754.16	17.95	77.9

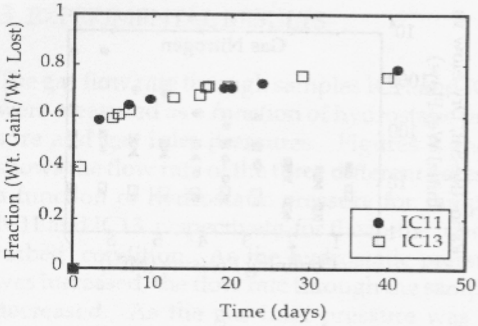

Figure 6. Fractional Weight Gain for Samples IC11 and IC13

to be stress-dependent (for both the dry and the re-saturated samples as compared to the initial 'un-disturbed' samples), it is postulated that the effect of such treatments altered the micro-structure of the rock, i.e. the production of new cracks, and/or inter-linking of existing cracks. Increased crack density or increased connectivity results in more flow paths that caused an increase in the gas flow rate. Or, shrinkage of the coal matrix produced by the loss of moisture may have produced larger aperture fractures (Harpalani, 1984).

ACKNOWLEDGMENT

The work presented in this paper was supported by GRI Contract No. 5092-260-2507.

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