energies

Supplementary Materials: Determining Coalbed Methane Production and Composition from Individual Stacked Coal Seams in a Multi-Zone Completed Gas Well

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Supplemental Materials: This draft contains detailed information about the Echometer liquid level measurement and natural gas sampling and analysis method.

1. Echometer Tests

The Echometer test is straightforward where the most important step in the Echometer liquid level process is the location of the Echometer in relation to the well head. The schematic and real test of Echometer liquid level survey is shown in Figure S1. Using the speed of sound of the gas in the casing, the Echometer computes the distance down-hole to the surface of the liquid based on the principle of creating a sound wave that travels from the surface, down the casing, reflects off the surface of the fluid and bounces back to the top of the well where the sound wave is picked up by a sensitive pressure transducer [1-2]. In practice, the optimal location would be in line with the direction of travel of the acoustic wave. This is not always possible and the results from field testing indicate the level of noise cancelation required negates the accuracy needed and makes the event horizontal nearly impossible to distinguish. The pressure of the Echometer gun requires that it be greater than that of the well to propagate a wave through the well, where the minimum pressure of the gun should be 150- 200 psi over the pressure of the well [3]. If this operating pressure is increased an order of magnitude to 300-400 psi above the well pressure, the level of precision does not increase. In this work, two methods are applied to calculate the water level: acoustic velocity method and collar counting method.

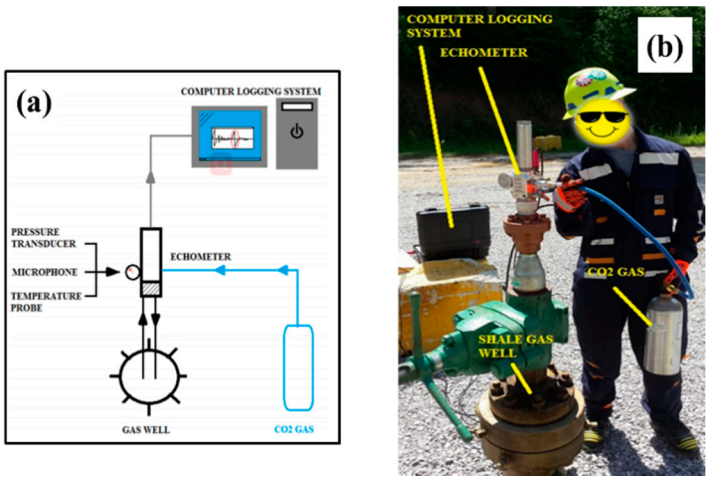

Figure S1. Schematic (**a**) and real test (**b**) of Echometer liquid level survey.

The Echometer records the microphone noise from the shot and converts it to data in real time. Figure S2 demonstrates a high pass unfiltered rendering of the acoustic data. The liquid level, circled in red, is the first and only marker in the well. This represents the round trip travel time for the wave to travel down the well and return to the microphone. In this test, the time was 6.846 seconds. This coupled with the acoustic velocity yields the total distance traveled.

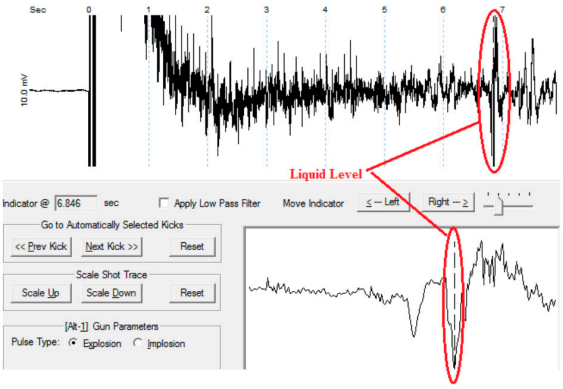

Figure S2. Acoustic test with reflection surface for depth.

Acoustic velocity is measured by two techniques in this study: collar counting and gas composition. Gas composition is used by in conjunction with gas chromatography. The results can then be calculated into an acoustic velocity using the equation below [4]:

$$v_{sound} = \sqrt{\gamma RT / X}$$

where v_{sound} is the velocity of sound, γ is abiabatic constant, R is gas constant, T is absolute temperature, and X is the molar mass of the gas composition.

Another method is to utilize tubing collars that are set at predefined intervals. Figure S3 show represent a reflection surface of the collars that connect the tubing where the tubing collars are set at 32 ft.

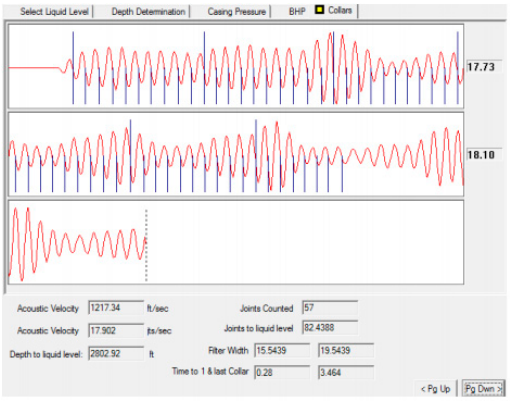

Figure S3. Collar counting for depth.

The illustration above demonstrates the technique of even spacing per collar. The distance is then extrapolated to the reflection surface seen as the dotted line. In this example, the reflection surface was the end of the tubing which was set at 2804 feet. The accuracy of this method is suggested by an error of 0.0385% from 3 tests in this test from the measure distance of 2802.94 feet to the installed distance of 2804 feet which was provided by the installer. More difficulties and uncertainty enter the equation when the distance extrapolated is greater. This method allows the user to tune the shot signal to a known horizon and utilize it to achieve greater accuracy for liquid level testing.

2. Gas Sampling and Analysis

The samples for natural gas analysis using the portable natural gas chromatograph were collected using stainless steel gas cylinders often referred to as "bombs". Figure S4a–c shows one of

the authors taking a gas cylinder sample at a natural gas well, a gas cylinder used for sampling the gas stream and the NGC system in the back of a truck ready for field deployment, respectively.

The gas cylinders are double-ended cylinders made of 316L stainless steel and have a maximum pressure rating of 1,800 psig. On each end is a nonrotating-stem needle valve. Each bomb is equipped with one rupture disk unit to remain compliant with the U.S. DOT regulation on pressure relief devices. The gas cylinders are filled using the ¼ inch, female NPT port located at the wellhead. Sampling procedure follows an adaptation of the GPA Standard 2166 for spot sample purging—fill and empty method [5]: (1) The well sample port is opened to clear any material (water, grease, etc.) that may be located at the sample port and then closed. (2) The gas cylinder is connected to the sample port and both needle valves are opened. (3) The sample port on the well is fully opened allowing for gas to flow through the gas cylinder. (4) The needle valve farthest from the sample port valve is closed allowing the gas cylinder to fill with gas. (5) The needle valve farthest from the sample port valve is reopened allowing gas to, again, flow through the gas cylinder. This concludes one purge of the gas cylinder. Steps 4 and 5 are repeated for the minimum number of cycles needed to purge the cylinder.

Figure S4. Gas composition sampling and analysis facilities.

The method for natural gas analysis for the GC/MS was developed using the ASTM Method D1945-96 [6]. Figure S5 displays the ASTM method as well as a typical chromatogram with separated analyses. In this work, the portable natural gas chromatograph (NGC) is used and the carrier gas is helium (Figure S4c). A calibration gas is used to verify peak retention times and to normalize the stream components. The inlet pressure range for the NGC is between 5 and 15 psig, so the carrier gas and calibration gas are regulated out of the tank to 10 ± 2 psig. In order to run a sample, the gas cylinder is connected to an inlet hose adapter. A two stage regulator and a water filter were retrofitted before the inlet of the chromatograph. This allows for the pressure of the sample to be reduced to the operating range, and any water in the sample to be filter, which can cause damage to the equipment. The sample analysis time is just over 5 minutes. Figure S6 shows a sample run report, including the calculated % gas stream, the calorific value, and relative density for each individual component. It also calculates the compressibility, density, and wet, dry, and ideal CV values for the entire gas stream based on the individual chromatographic results.

As a result, high sensitivity gas chromatographic equipment was identified and developed in order to analyze natural gas samples in the field. Sampling methods for natural gas samples and analysis methods were developed for both natural gas samples and tracer samples with excellent precision, separation, and analysis time.

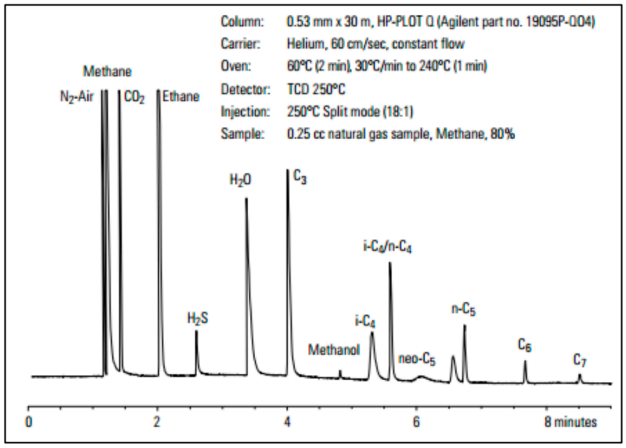

Figure S5. ASTM Method D1945-96 Natural Gas Analysis [6].

Comp	UnNorm %	Normal %	Liquids (USgal/MCF)	Ideal (Btu/SCF)	Rel. Density
Propane	3.20718	3.15353	0.87117	79.34592	0.04801
Hydrogen Sulfide	0.00000	0.00000	0.00000	0.00000	0.00000
IsoButane	0.15290	0.15034	0.04933	4.88903	0.00302
Butane	0.49659	0.48829	0.15436	15.92939	0.00980
NeoPentane	0.00086	0.00084	0.00031	0.03368	0.00002
IsoPentane	0.04490	0.04414	0.01619	1.76619	0.00110
Pentane	0.07186	0.07065	0.02568	2.83232	0.00176
Hexane+	0.11180	0.10993	0.00000	0.00000	0.00000
Nitrogen	2.21188	2.17488	0.23993	0.00000	0.02104
Methane	81.46175	80.09897	13.61639	808.99957	0.44367
CarbonDioxide	0.00055	0.00054	0.00009	0.00000	0.00001
Ethane	13.94111	13.70788	3.67604	242.58842	0.14232
Hexane	0.00000	0.10993	0.04533	5.22816	0.00327
Heptane+	0.00000	0.00000	0.00000	0.00000	0.00000
Heptane	0.00000	0.00000	0.00000	0.00000	0.00000
Octane	0.00000	0.00000	0.00000	0.00000	0.00000
Nonane+	0.00000	0.00000	0.00000	0.00000	0.00000
Nonane	0.00000	0.00000	0.00000	0.00000	0.00000
Decane	0.00000	0.00000	0.00000	0.00000	0.00000
Undecane	0.00000	0.00000	0.00000	0.00000	0.00000
Dodecane	0.00000	0.00000	0.00000	0.00000	0.00000
Ethane-	0.00000	0.00000	0.00000	0.00000	0.00000
Propane +	0.00000	0.00000	0.00000	0.00000	0.00000
Oxygen	0.00000	0.00000	0.00000	0.00000	0.00000
Water	0.00000	1.74067	0.00000	0.00000	0.00000
Total	101.70138	100.00000	18.69483	1161.61267	0.67578

Inferior Wobbe	1408.1687 (Btu/SCF)	Superior Wobbe	1420.5601 (Btu/SCF)
Compressibility	0.9970	Density	0.0517 (lbm/ft3)
Real Rel. Density	0.6758	Ideal CV	1161.6127 (Btu/SCF)
Wet CV	1147.5020 (Btu/SCF)	Dry CV	1167.7859 (Btu/SCF)

Figure S6. Sample NGC Chromatographic Report.

References

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6. Standard, ASTM D1945-96 (2001). Standard Test Method for Analysis of Natural Gas by Gas Chromatography.