Comparison of Lost Gas Projections in Coalbed Methane

(Rocky Mountain Section AAPG Poster Session, Denver, Colorado, August 2004-Received the Steve Champlain Memorial Award for Best Poster at the conference)

Noel B. Waechter[1], George L. Hampton III[1], James C. Shipps[1], and John P. Seidle[2]

(1) Hampton, Waechter & Associates, LLC, 11 Inverness Way South, Englewood, CO 80112, phone: 303 825 7140, www.hwa-cbm.com
(2) Sproule Associates Inc., 1675 Broadway, Ste 1130, Denver, CO 80202, phone: 303 592 8770, john.seidle@sproule.com

Direct measurement of the “sorbed” gas content of a coal sample enclosed in an airtight canister is a relatively simple procedure, but the total gas content of the coal includes two other important components—lost gas and residual gas. Lost gas is the volume of gas that escapes between the time a coal sample is retrieved from a wellbore and the time at which it is placed inside the canister. Residual gas is the amount of gas remaining in the coal when it is in sorption equilibrium with the desorbed gas inside the canister at a pressure of one atmosphere. Residual gas is measured after crushing the coal sample. Often gas measured by crushing before desorption is complete is referred to as “residual gas” or “remaining gas”.

Figure 1. Typical desorption setup: air-tight canister with valves, burette, and barometer.

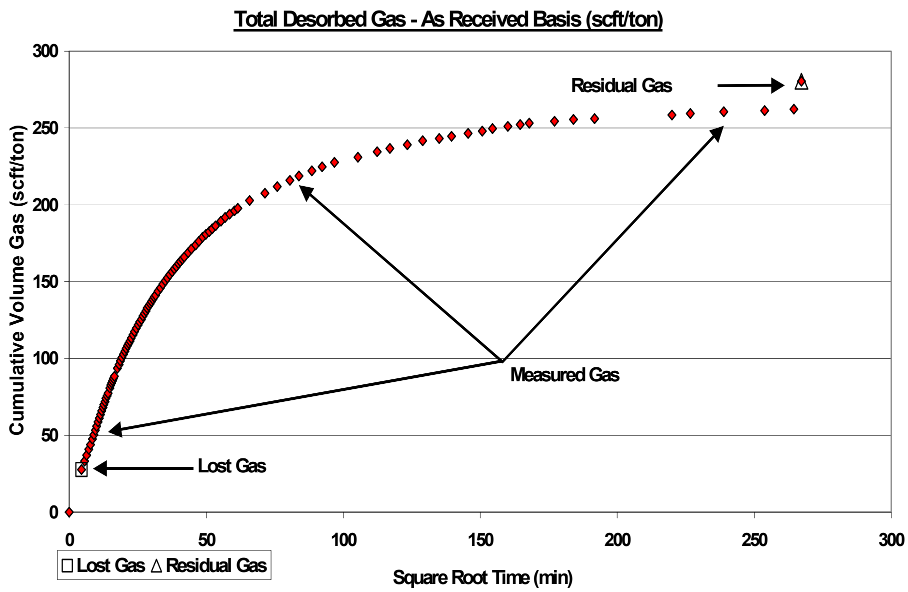
Lost gas is determined by projecting the first few hours of desorption measurements back to time zero (the time core retrieval is at the half-way point coming out of the drill hole with mud-filled or water-filled holes). This is the “Direct Method” introduced by the U.S. Bureau of Mines in the early 1970s for estimation of lost gas. Industry standard has been to project lost gas using a linear fit to cumulative-gas vs. square-root-of-time data. A polynomial projection for lost gas generally gives a better fit to the data and, by nature of the mathematics of the projection, yields a larger estimate of lost gas. The cumulative-gas vs. square-root-of-time curve is just that – a curve, not a straight line.

A curve fitting the data is a good start in any projection, but a good fit to the data does not necessarily mean that the results will be more consistent and more accurate with varying lost gas times. Here we will consider three examples to illustrate some of the problems associated with linear projections for lost gas. We will show how both projection methods compare with increasing lost gas times and how both projections compare using simulated lost gas curves for a sample with a known gas content.

The observed linearity to early parts of some desorption curves may be related to temperature disequilibrium (and concomitant increases in diffusion rates) as coals warm back up to reservoir temperature inside the canisters.

Example 1: Gas Content Data from a Typical Upper Cretaceous Coal

Figure 2. This example looks at plots of gas content data from a wireline core sample of a typical upper Cretaceous coal that contained 234 scft/ton of sorbed gas, paying particular attention to the differences between linear and polynomial projections for lost gas. The number of data points (i.e., time interval) used in the projections is increased, while keeping the lost gas time constant.



Estimated Lost Gas: 27.7 scft/ton   Measured Gas: 234.4 scft/ton
Measured Residual Gas: 18.3 scft/ton   Total Gas (LG+MG+DG): 280.4 scft/ton
Lost Gas Time: 20.8 minutes
10.0% Lost Gas
83.5% Measured Gas
6.5% Residual Gas
85% of Gas Desorbed in 10 Days

Figure 3. Linear lost gas projection using 2.8 hours of data (i.e., desorption measurements). Results: Good fit to the data, showing 1646 cc of estimated lost gas.

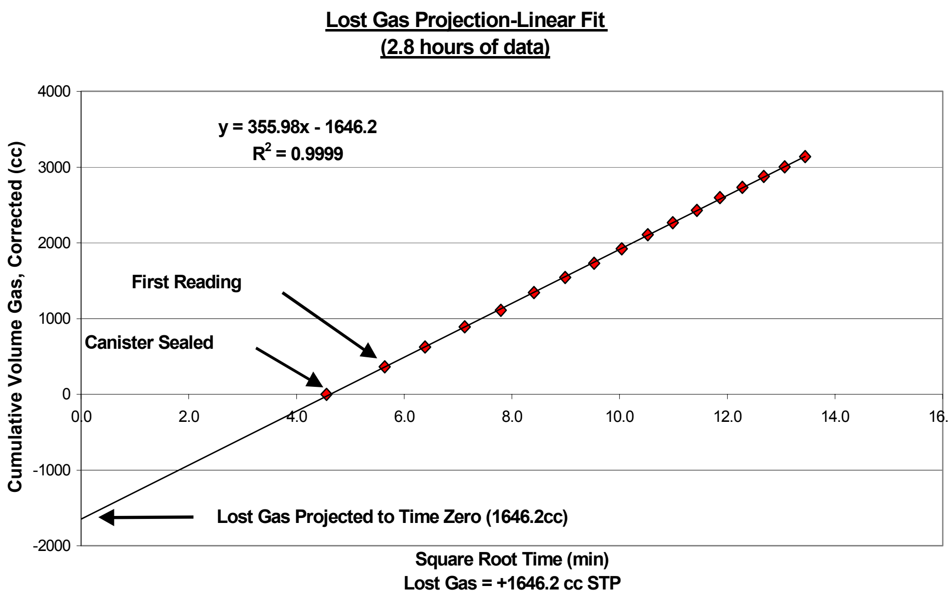


Figure 4. Linear lost gas projection using 6.8 hours of data (i.e., desorption measurements). Results: Not as good a fit to the data and a lower estimated lost gas (1469 cc of estimated lost gas).

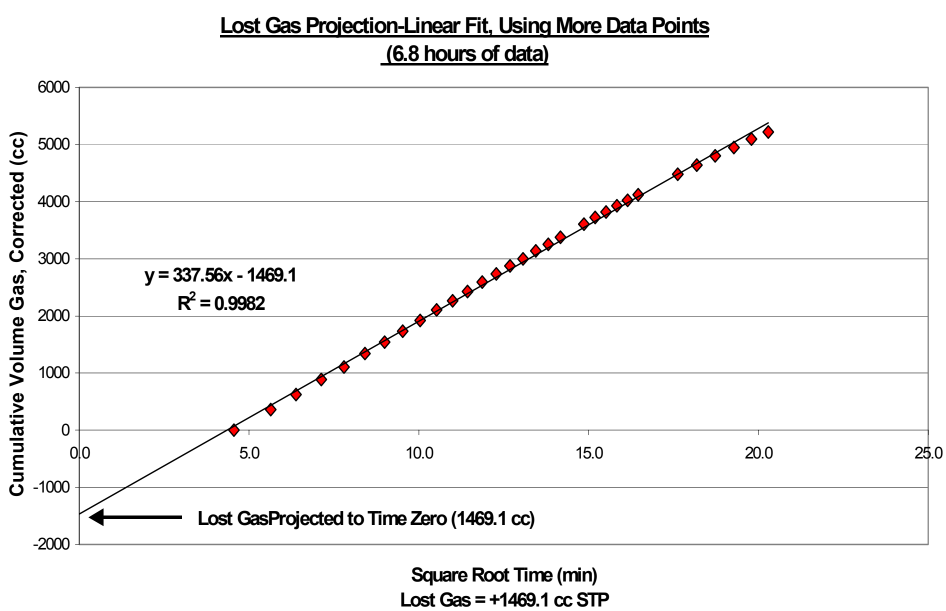
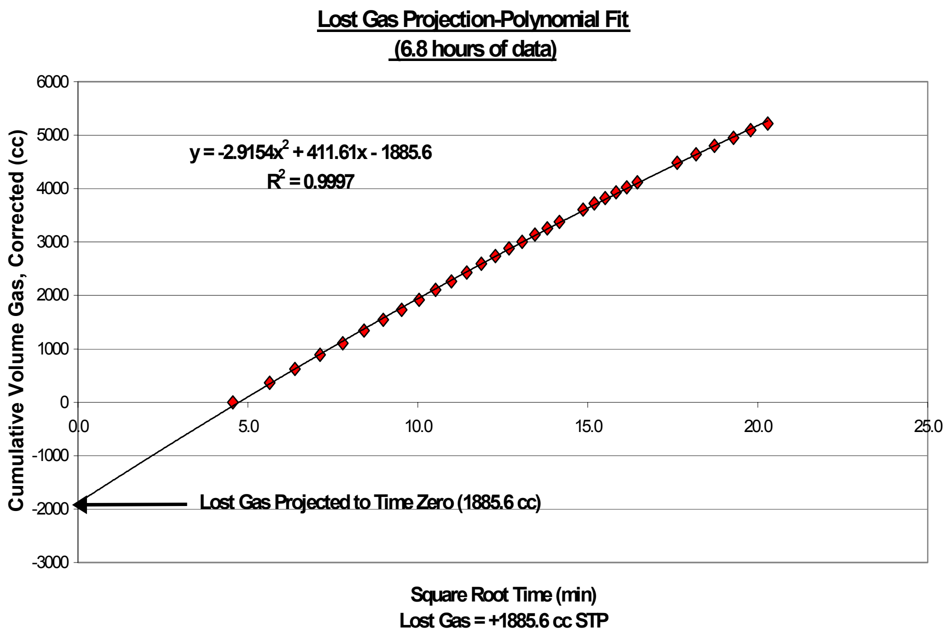


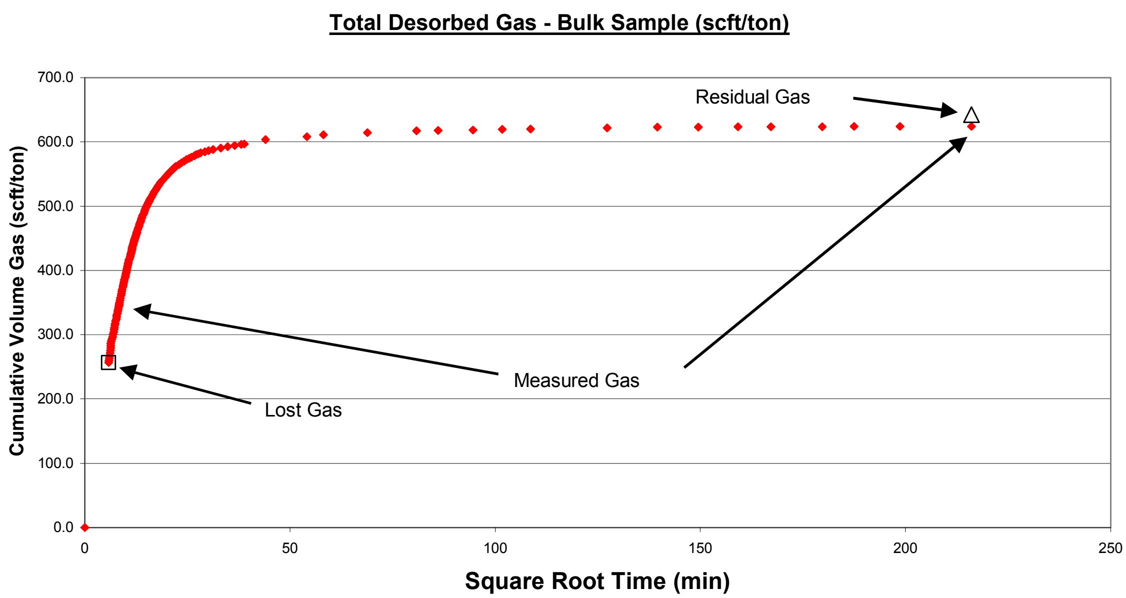
Figure 5. Polynomial lost gas projection using 6.8 hours of data (i.e., desorption measurements). Results: Good fit to the data for entire time period, and the highest estimated lost gas (1886 cc of estimated lost gas).



Conclusions for Example 1: Polynomial projection gives the best fit for the data. However, which method gives the most consistent results with increasing lost gas times and which method is more accurate?

Example 2: Gas Content Data from an Upper Cretaceous Coal with a High Diffusion Rate and a High Gas Content.

Figure 6. This example looks at plots of gas content data from a wireline core of an upper Cretaceous coal that had both a high diffusion rate and a high gas content (642 scft/ton). The differences between linear and polynomial projections for lost gas become apparent when the amount of lost gas time is increased while keeping the number of data points used in the projections relatively constant.



Estimated Lost Gas: 256.7 scft/ton
Measured Gas: 367.4 scft/ton
Measured Residual Gas: 18.2 scft/ton
Total Gas (LG+MG+DG): 642.2 scft/ton
Lost Gas Time: 33.8 minutes
40.0% Lost Gas
57.2% Measured Gas
2.8% Residual Gas
85% of Gas Desorbed in 4 hours

Figure 7. Comparison of polynomial and linear lost gas projection using 4.4 hours of data and a lost gas time of 34 minutes.
Results: The polynomial projection for lost gas gives a much better fit to the data than a linear projection, and over twice the amount of estimated lost gas.

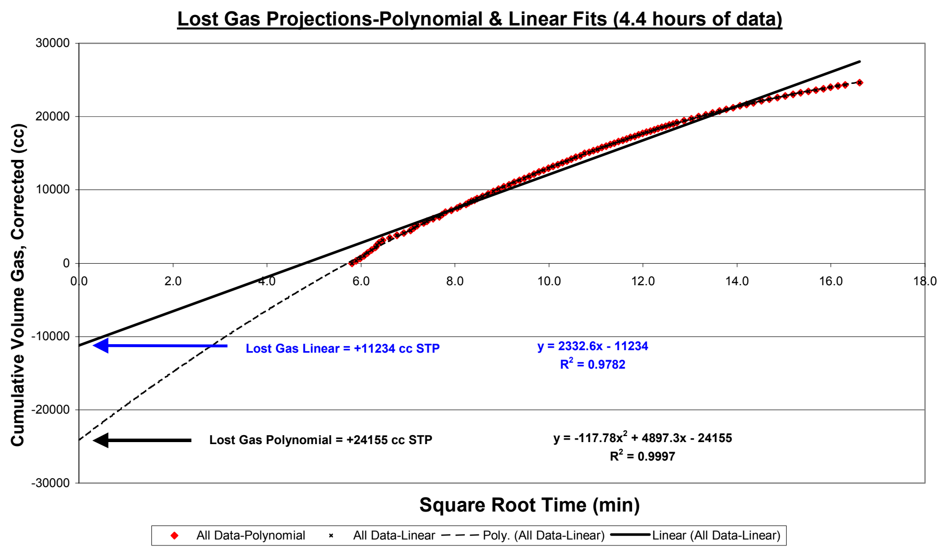
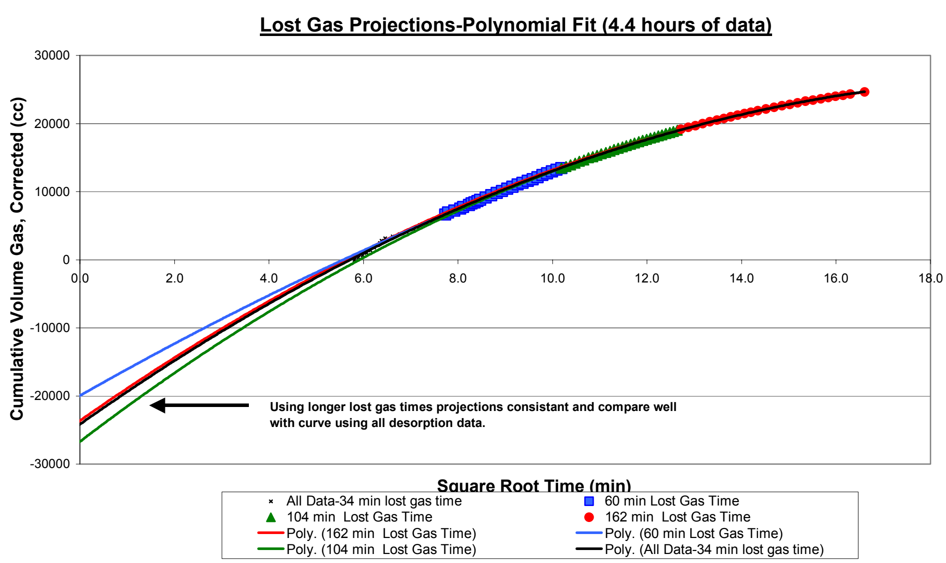
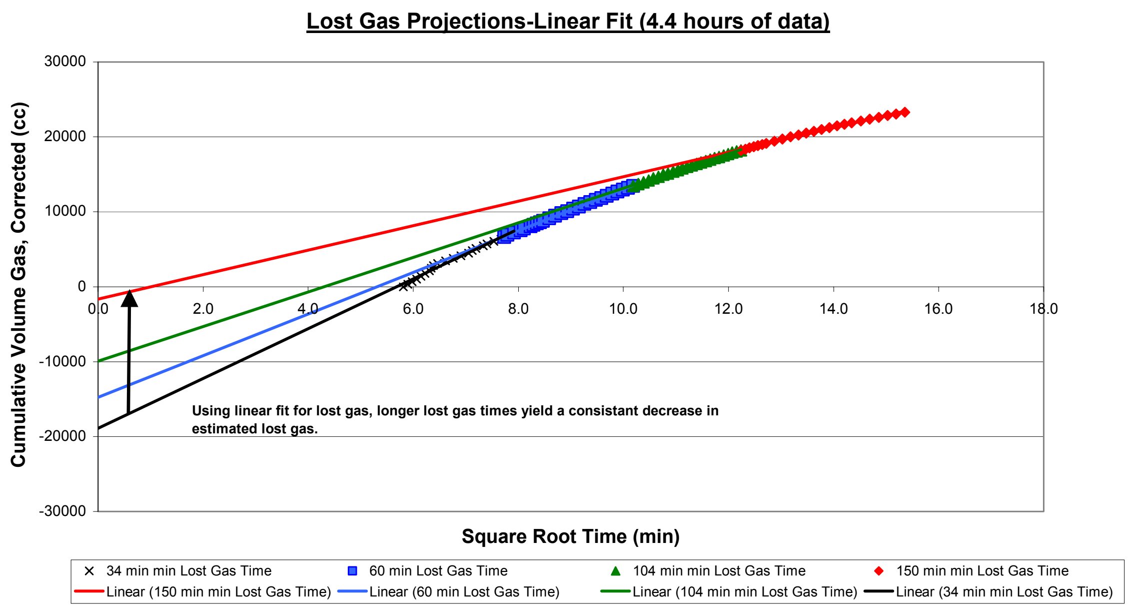


Figure 8. Using the same 4.4 hours of data, four lost gas projections are shown using a polynomial fit to the data: One, using all the data with 34 minutes of lost gas time (as in the previous example) and three others using data to give progressively longer lost gas times (60 minutes, 104 minutes, and 162 minutes). For each projection, a package of data was chosen to represent approximately the same amount of time for the measured gas data.



Results: The three longer lost gas projections bracket the projection that uses all the data (4.4 hours) and has the shortest lost gas time (34 minutes), plus the curves show no progressive changes with increasing lost gas time.

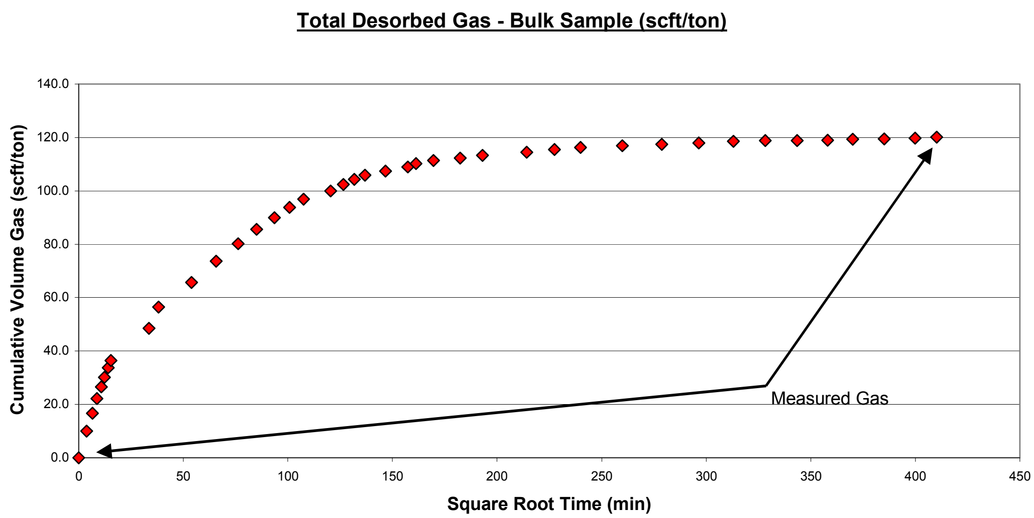
Figure 9. Again, using the same 4.4 hours of data, four lost gas projections are shown using a linear fit to the data: One with 34 minutes lost gas time, then 60 minutes, 104 minutes, and 162 minutes lost gas time. For each projection, a package of data was chosen to represent approximately the same amount of time for the measured gas data, but using progressively longer lost gas times, as we did with the polynomial fits. The linear curve using all the data was shown in the first lost gas curve for this example, and clearly did not fit the data well.
Results: In contrast to the polynomial fits for lost gas, each linear fit yields progressively less lost gas, and all lower estimates of lost gas than with any of the polynomial fits.



Conclusions for Example 2:
Polynomial projection gives the best fit for the data, more consistent results, and no progressive changes with increasing lost gas time. However, we still have to determine which method is more accurate.

Example 3: Gas Content Data from an Upper Cretaceous Coal with Known Gas Content.

Figure 10. This example examines plots of gas content data from an upper Cretaceous coal that has a known gas content (120 scft/ton). The sample was collected and placed in a canister at a mine and then allowed to equilibrate for a week, so that the gas concentration in the coal was in equilibrium with the concentration of gas in the canister headspace. This, in effect, gave us a coal that was analogous to a pressure core. The canister was then bled to allow pressure equilibrium with the atmosphere, and the coal was then desorbed over time, giving us a known total sorbed gas content for the core at the time the sample was collected in the mine. Instead of estimating lost gas, since there is no lost gas in this example, projections are made back to the time the canister was bled. The "simulated lost gas curves" shown in the plots are projections from varying "lost gas times" back to the time the canister was bled. Those projections which pass closest to the origin (zero time, zero gas) best predict the known gas content of the coal. The number of data points used for the projection in each curve was kept relatively constant.



Total Desorbed Gas Curve:
Estimated Lost Gas: None
Measured Gas: 120.1 scft/ton
Measured Residual Gas: NA
Total Gas: 120.1 scft/ton
Lost Gas Time: None
No Lost Gas
100% Measured Gas
85% of Gas Desorbed in 11 days

Figure 11. Using a polynomial fit for the data, 14 minute, 42 minute, and 116 minutes of simulated lost gas time were projected back to origin.
Results: The polynomial projections at 14 and 42 minutes "lost gas time" both plot very close to the known gas content. The 116-minute projection over-estimates the simulated lost gas in this data set.

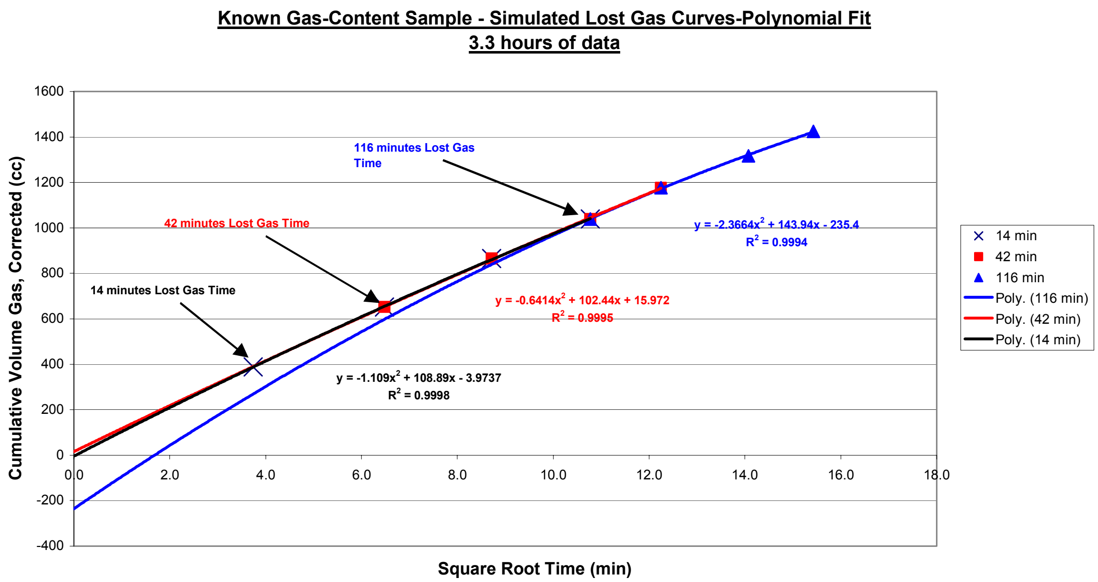
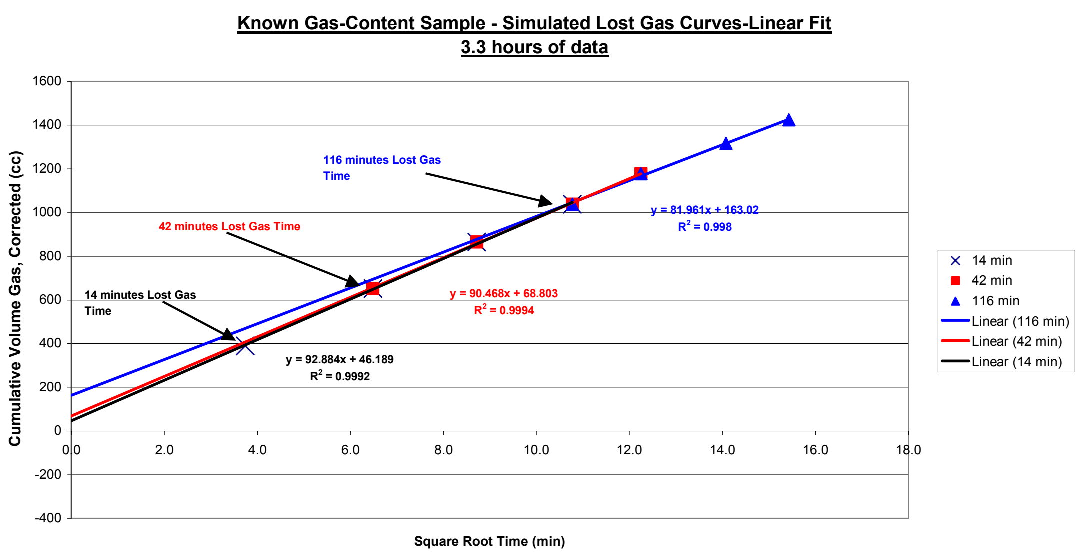


Figure 12. Now using a linear fit for the data, 14 minute, 42 minute, and 116 minutes of simulated lost gas time were projected back to origin.
Results: The linear projections all tend to underestimate the simulated lost gas, and show progressively smaller estimates of lost gas as seen in the previous examples of linear projections.



Conclusions for Example 3:

The differences between linear and polynomial projections for lost gas become apparent when the amount of "simulated lost gas time" is increased. The linear projections all tend to underestimate the simulated lost gas, and show the progressively larger under-estimations of lost gas that were seen in the previous examples.

OVERALL SUMMARY AND CONCLUSIONS

In determining the total in situ gas content of a coal or carbonaceous shale, lost gas is the only component of total gas that is estimated. With short core recovery times such as those of wireline coring, variations in the estimates of lost gas due to different curve projection methods have little impact on the total gas picture, as we saw in Example 1. With increasing lost gas times and higher diffusivity coals, the lost gas projection technique has a larger impact upon the estimation of gas in place, as we saw in Example 2.

In a "typical" upper Cretaceous coal (Example 1), increasing the number of data points (time) used in making a linear lost gas made a poorer linear fit to the data and a decreased estimation of lost gas. Using a polynomial fit for the increased number of data points gave a good fit to the data and gave the highest estimate of lost gas.

In Example 2, an upper Cretaceous coal with a high diffusivity and high gas content showed the effects of increasing lost gas time on linear and polynomial lost gas projections. Polynomial projections showed little variation and only random variation with increasing lost gas time, whereas linear projections gave progressively lower estimates of lost gas with increasing lost gas time.

In Example 3, an upper Cretaceous coal with known gas content showed the effects of increasing lost gas time on estimating the known gas content using simulated linear and polynomial lost gas projections. Polynomial projections of 14 and 42 minutes matched the known gas content of the coal very closely, whereas linear projections all underestimated the gas content and gave progressively lower estimates of lost gas with increasing lost gas time, as we saw in the preceding example. (The polynomial projection made from 116 minutes did show a marked divergence from the known gas content, but we think that is related to temperature variation of the canister during measurement of the late desorption data. The data on this coal were not collected with the intention of using it for an example of a known gas content coal.)

These three examples show that with increasing lost gas times, polynomial fits for lost gas provide more consistent and more accurate estimates of lost gas.

Linear projections for estimating lost gas were first applied to coal cores by the U.S. Bureau of Mines in the early 1970's, and have been used widely by the coalbed methane industry since that time. The observed linearity to early parts of some desorption curves may be related to temperature disequilibrium and concomitant increases in diffusion rates as coals warm back up to reservoir temperature inside the canisters. Sorption by coals of air components in headspace gas inside desorption canisters can also move the curve toward linearity early in the desorption cycle.