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Efficient Production of Methane from Deeper Coal Seam

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SUMMARY

The primary problem with deep coal seams is decrease in permeability with depth. It is evident that hydraulic fracturing enhances the production significantly only when permeability is in the range of 1-10 md and minimal enhancement in production in 0.1-1 md permeability range but for permeabilities less than 0.1 md there is negligible enhancement in production.

This paper focuses on a revised permeability vs. depth curve which shows that the overly pessimistic exponential relation discussed earlier is incorrect due to the counterpoints like lower horizontal stress gradients in certain areas, unduly low permeability measured by slug tests because of skin effects from formation damage near the wellbore and the Kozeny-Carmen equation. This paper discusses the variation of permeability in a coal reservoir during production via three mechanisms: Klinkenberg effect and effective stress. The effect of variation of permeability on flow rates of methane is also discussed. At high stresses, the initial permeability reduction is significantly reduced and the increase in permeability due to decrease in gas pressure results in high flow rates during the latter part of the life of producing wells in deep coal beds.

Introduction

The primary problem with deep coal seams is decrease in permeability with depth. It is evident that hydraulic fracturing enhances the production significantly only when permeability is in the range of 1-10 md and minimal enhancement in production in 0.1-1 md permeability range but for permeability less than 0.1 md there is negligible enhancement in production. The permeability vs. depth curve plotted using the data from coal seams in the Piceance, San Juan and Warrior Basins showed that permeability falls exponentially with depth and drops to extremely low levels at 4,000 ft. making methane production uneconomic.

This paper focuses on a revised permeability vs. depth curve which shows that the overly pessimistic exponential relation discussed earlier is incorrect due to the counterpoints like lower horizontal stress gradients in certain areas, unduly low permeability measured by slug tests because of skin effects from formation damage near the wellbore and the Kozeny-Carmen equation, originally developed for flow through conventional pores, which is still unproven for fractured coal formations. The effect of variation of permeability on flow rates of methane is also discussed. At high stresses (deep coal seams), the initial permeability reduction is significantly reduced and the increase in permeability due to decrease in gas pressure results in high flow rates during the latter part of the life of producing wells in deep coal beds.

Theory

A review of the theory and assumptions used in the initial depth versus permeability publications lead to

1. The initial theory assumed that the dominant stress influencing fracture closure is the vertical or litho static stress. However, with vertical fractures the stress direction of interest is the horizontal stress which is usually considerably lower than the vertical stress. The effect of using horizontal as opposed to litho static (vertical) stress is shown below:

- Starting with litho static (vertical) stress of 1.00 psi/ft. (more or less) and subtracting the hydrostatic pressure of 0.43 psi/ft. leaves an effective vertical stress gradient of 0.57 psi/ft. use of this high and singular value for stress would relegate all coal formations to a high stress setting.

- However, in certain areas the horizontal stress gradient may be much lower. The measured horizontal stress gradient at the Brookwood Degas field is 0.7 psi/ft. subtracting the hydrostatic pressure leaves an effective stress of 0.27 psi/ft., a value less than half of the litho static based stress value an even lower minimum horizontal stress gradient of about 0.51 psi/ft for one sequence of coals. Because stress (not depth) is the controlling variable, with a lower net stress gradient, a coal could be buried much deeper yet retain the same permeability as a shallower coal with a high stress gradient.

2. The early permeability and stress data were limited and gathered using short-term slug and other testing methods on unstimulated wells. The limited radius of investigation from using slug tests, particularly on wells with high skin damage, often led to low initial estimates for permeability.

For example, the initial well tests at Rock Creek indicated a permeability of about 3 md for the Mary Lee coals. Subsequent gas production, testing and modeling show that the coals in this area have much higher permeability of 15 to 20 md.

3. Finally, the depth versus permeability theory rests on a key assumption that does not hold for coal bed methane. Assumed that the stress on the reservoir reduces the porosity or void space of the formation. They calculated permeability by substituting the equation for pore (porosity) compressibility into the Kozeny-Carmen equation, as set forth below: The Kozeny-Carmen was developed for flow through conventional pores and does not hold for fractured reservoirs.

Findings

The most important finding from this work is that alternative stress regions, rather than a single high stress region, exist. The resulting data indicate three broad stress regions -low, moderate and high -- and the relationship of permeability with these three stress regions. These stress regions were used to

construct alternative stress (depth) versus permeability curves for these two basins, as shown on **Figure 1**

Reservoir Modeling of Deep Coals under Alternative Geologic Conditions would be to develop (or adapt by analogy) the depth (stress) versus permeability curves similar to those presented on **Figures 1**. The second step would be to identify whether the basin held any low-stress (or enhanced permeability) areas. The third step would be to assemble the other key coal reservoir properties (such as gas content, desorption pressures, sorption isotherms, porosity, and net pay) that would influence its production.

Figure 1

	Deep Coal	Shallow Coal
Depth (ft)	6000	1500
Net Pay (ft)	30	30
Porosity (%)	0.4	2
Reservoir Pressure (psia)	2600	650
Desorption Pressure	2600	650
Water Saturation (%)	100	100
Langmuir Pressure (psia)	300	300
Langmuir Volume (cm ³ /ton)	28	28

Table 2

As an example of this process, we will examine the producibility and expected recovery from a hypothetical deep coal basin having the characteristics set forth in **Table 2**.

Finally, we will compare the performance of this deep coal, under alternative geologic conditions, with the performance of a shallow 1,500 foot coal.

The results of this comparative analysis are shown in **Table 1**.

	Deep Coal		Shallow Coal	
Stress Condition	Permeability	Rate	Permeability	Rate
Low Stress	3 md	2730	30 md	2130
Moderate Stress	.03 md	100	7 md	900
High Stress	-	-	2 md	430

Depth V/s Gas Peak Rate (Mcf/d)

Table 1

Conclusion

A deep coal seam has a vast volume of natural gas, in India, China and the rest of the world. Favorable geologic conditions, such as low stress and dry coals, would enable these deep coals to be productive. While some initial tests are underway to explore these deep coals, unless the economic feasibility of deep coals can be established, they may remain more of a scientific curiosity than a commercial target for gas reserves.

References

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