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METHANE CONTROL PROGRAM

BEHAVIOR OF COAL-GAS RESERVOIRS

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ILLUSTRATIONS

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Joseph Cervik[1]

ABSTRACT

Gas occurs in coalbeds in an adsorbed and a free gas state. Adsorbed gas is stored in the micropore structure and its transport is governed by Fick's law. The free gas occurs in the fracture system and flows according to Darcy's law. These two modes of mass transport are interdependent. Production decline curves of coal-gas wells are of the constant percentage decline type and, thus, show no indications of flow characteristics peculiar to coal-gas reservoirs. The effectiveness of surface boreholes as a degasification scheme depends upon both good fracture permeability and a high fracture density. Conventional methods of reservoir engineering analysis are not applicable to coalbeds.

INTRODUCTION

Mining of deep coalbeds (1,500 to 2,000 feet) and production of the associated gas is analogous to a gas well with an expanding well bore radius. Gas production of 10 to 15 million standard cubic feet per day is not uncommon from deep mines. State and Federal codes require that each unit volume of gas be diluted with approximately 100 volumes of air in order to maintain methane-air mixtures below the explosibility range of 5 to 15 percent methane.

Mining deeper coalbeds requires smaller mine openings and these mines tend to be more gassy. Thus, the use of ventilation (dilution) as a means of controlling methane concentrations at active face areas and in the returns is limited severely. Degasification of coalbeds prior to mining and methods of controlling the flow during mining are necessary. Before effective methods of control and degasification can be developed, the laws governing mass transport through coalbeds must be understood.

The purpose of this paper is to present the fundamental concepts governing the transport of gases through a coalbed, and to define one of the environmental problems related to rapid, economical, and safe mining of coal deposits.

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MICROPORE STRUCTURE OF COAL

Coal is formed from plant substances which were preserved in various states of degradation in a favorable environment, and later altered by chemical and physical processes. However, there is no universal agreement on what chemical and physical changes take place in the transformation of plant substances to coal. The origin, petrography, and classification of coal are adequately discussed in the first and supplementary volumes of Chemistry of Coal Utilization (3, 4)[2] and need not be repeated here.

Methane is a byproduct of the coalification process. Under proper burial conditions, methane cannot escape from the coal forming substance and is dispersed through the bed as a free gas during various stages of coalification. One of the outstanding features of coal is its microporous texture, which plays an important part in many physicochemical properties of coal such as its gas-retaining capacity, its reactivity towards various chemical reagents, and the possibility of transforming coal into highly adsorbing materials such as activated carbons.

In the study of sorption of gases and vapors on solids having fine pores, mass transport by diffusion plays an important role. In earlier studies, adequate attention was not paid to the contribution of diffusional resistance to the rate of establishment of an equilibrium concentration. Consequently, discrepancies existed between values of internal surface area of coal obtained by low temperature gas adsorption, and those obtained from heat of wetting in methanol at about room temperature. Marsh (5) reviews the various methods of determining surface areas of coal and concludes that surface area of coals are mostly in the range 200 to 300 square meters per gram (2,150 to 3,230 square feet per gram), Van der Sommen and others (7) measured the volume of methane adsorbed on the internal surface area of coal to about 7,500 psig. They determined a saturation value of 21.34 cubic centimeters per gram (684 cubic feet per ton) for pressures above 1,500 psig. It is interesting to note that the amount of gas adsorbed is approximately 28 times the volume of coal at standard conditions. Consequently, an acre-foot of such coal contains approximately 1.2 million standard cubic feet of methane. Anderson and others (1) show that the micropore diameter is of the order of 5 Angstrom units.

MASS TRANSPORT LAWS

Coalbeds in the United States are naturally fractured. The degree of fracturing varies from one coalbed to another. For example, the Pittsburgh coalbed is a blocky-type coal with prominent cleavage planes at 90 degrees

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[2] Underlined numbers in parentheses refer to items in the list of references at the end of this report.

and a fracture spacing of the order of 6 inches. The Pocahontas No. 3 coalbed is a friable-type deposit with cleavage planes at approximately 90 degrees that are not as prominent as the planes in the Pittsburgh coalbed. The fracture spacing in the Pocahontas No. 3 coalbed is of the order of 1/4-inch. Coalbeds, therefore, have a fracture porosity and permeability. Mass transport through the fracture system is governed by Darcy's law, namely:

$$q = -\frac{kA}{\mu}\frac{dP}{dL}. \qquad (1)$$

The driving force for this mode of transport is a pressure gradient.

Presumably, a coalbed in a late diagenetic stage is one solid mass and all gas was contained in the micropore structure. Later, jointing developed in the coalbeds and allowed gas to bleed from the solid coal into the fracture system. Mass transport through solid coal (micropore structure) is governed by Fick's law of diffusion, namely:

$$q' = -DA\frac{dC}{dL}. \qquad (2)$$

The driving force for this mode of transport is a concentration gradient. Sevenster (6) found that the diffusion coefficient of powdered coal for a number of gases is of the order of 10^{-13} square centimeters per second at atmospheric pressure.

Although these two modes of transport are separate and distinct phenomena, they are interdependent. This interdependency can be expressed over a limited range of pressures by the following empirical equation (1):

$$C_o = bP^n. \qquad (3)$$

In virgin coal, the pressure in the fracture system and the concentration of gas in the micropore structure are in equilibrium. If the pressure is reduced, the equilibrium is broken and gas begins to bleed from the matrix until a new equilibrium is reached that is characteristic of the gas pressure in the fracture system.

Coal-gas reservoirs, thus, consist of two distinct elements; namely, fractures and matrix. Each has its characteristic mode of mass transport that are interdependent. Such reservoirs are more complex than "conventional" gas reservoirs having the distinct elements, fractures, and matrix, each with its characteristic permeability and porosity. Therefore, the extension of conventional methods of reservoir engineering analysis to coalbeds thus is not justified.

The desorption of gas from coal is not an instantaneous process. Its release can be described qualitatively as "slow bleeding." For example, 1 pound of 1/4-inch coal and 1 pound of fine coal (275- to 325-mesh) will adsorb the same quantity of methane at 15 psig. However, when pressure is reduced to atmospheric, the fine coal (275- to 325-mesh) desorbs all its gas in about

1 hour; the 1/4-inch coal requires about 30 days. For solid coal particles of the order of 1/2-inch, the desorption process may take 6 months to 1 year. Consequently, the rate of desorption of gas from coal depends upon equilibrated pressure, coal particles size and geometry, and the diffusivity coefficient.

Most coalbeds have an associated gas or reservoir pressure. Reservoir pressure in the Pittsburgh coalbed is of the order of 260 psig and in excess of 550 psig in the Pocahontas No. 3 coalbed. These pressures are far in excess of those used in sorption studies in the United States. Most of the studies of the physical properties of coal relating to diffusion transport were made on European coals, and no comparable studies have been made on United States coals. Consequently, very little is known about the sorption process at these pressures.

CLASSIFICATION OF COALBEDS

Mass transport in European coalbeds is controlled predominantly by Fick's law. Methane control measures in European coalbeds are concerned primarily with the diffusion coefficient, D. This is supported by the fact that all effective methods of degasifying European coalbeds require fracturing of the coal. The rate of desorption of gas is dependent upon effective coal particle size, with smaller particles releasing gas much faster than larger particles.

In contrast, coalbeds in the Appalachian area of the United States appear to fall into the category of mass transport predominantly by Darcy's law. Figure 1 shows the variation of methane content in a return entry of a section of a mine where a continuous miner was operating. Air velocity was constant during these measurements. During the 78-minute mining period, methane content in the outby air rose from 0.52 to 0.97 percent. The small dips represent intervals of time the miner ceased mining. This part of the curve represents a steepening of the pressure gradient by advancing into the reservoir, and according to Darcy's law, gas flows will increase. The second part of the curve is a 140-minute idle period and reflects the readjustment of the pressure gradient to lower values. The significant feature of this figure is that the continuous-mining machine is able to advance the face at a much faster rate than the drainage radius is able to recede into the coalbed.

Coalbeds can be classified according to modes of mass transport into mine openings. This classification is shown in figure 2. No coalbed exhibits mass transport by Darcy's law alone. Methane and other gases have an affinity for coal and, therefore, diffusion transport exists always. Undoubtedly, there are coalbeds where transport by both Fick's and Darcy's laws is important and of equal magnitude. Experience in mining United States coalbeds is generally limited to shaft depths of less than 1,500 feet. Most of the coal mines of Great Britain and Western Europe are much deeper. As deeper coalbeds are exploited in the United States, the mode of mass transport may shift gradually with depth from the Darcy mode to diffusion transport. Methane control measures and degasification techniques developed for Darcy's mode of transport are not applicable to beds where diffusion transport predominates. The converse also is true.

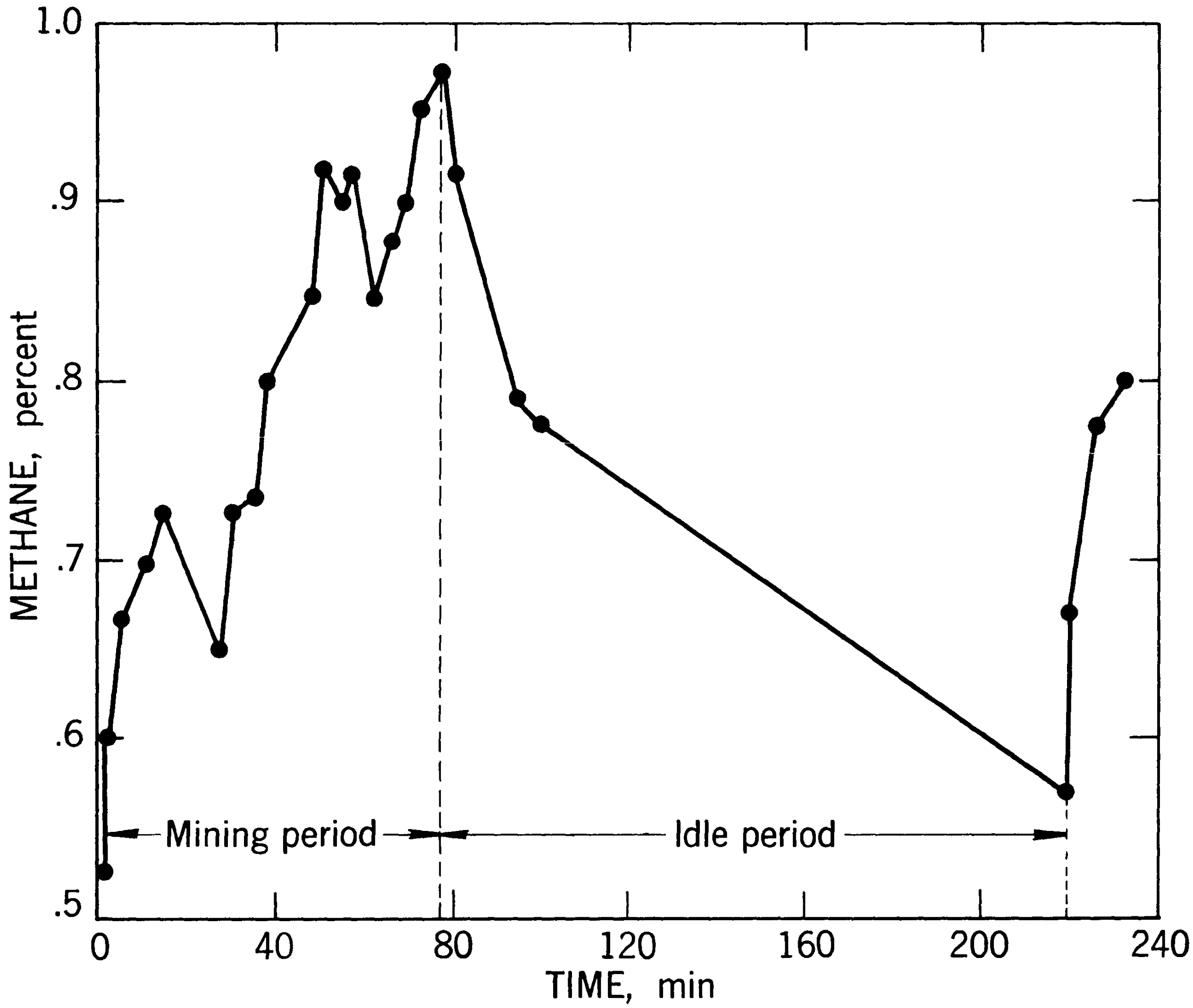

FIGURE 1. - Comparison of Methane Liberation During a Mining and Idle Period.

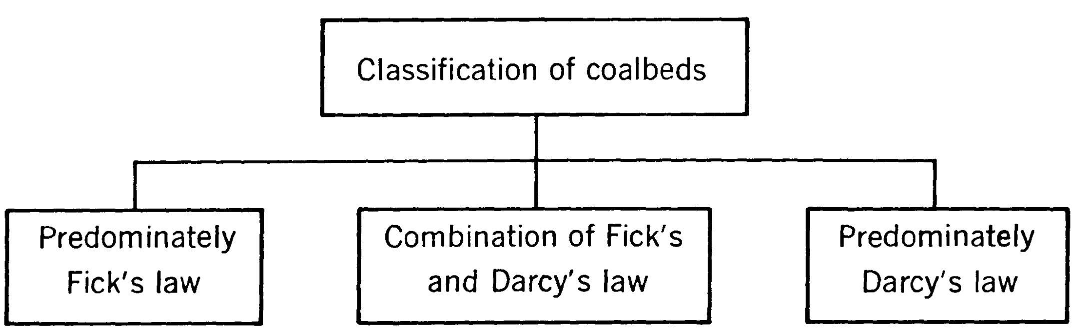

FIGURE 2. - Classification of Coalbeds According to Mode of Mass Transport.

DEGASIFICATION BY SURFACE BOREHOLES

For Darcy type flow, degasification and methane control measures will be directed towards methods of reducing pressure, reducing fracture permeability, or filling of the fracture pore volume with a more viscous fluid. There are several methods of controlling gas flows underground during mining; these methods include water infusion, use of foam, and underground blocking method. These methods have been presented by Cervik (2). The only degasification scheme that will be discussed in this paper is surface boreholes.

Surface boreholes provide a method of degasifying a coalbed before it is opened to production or degasifying a section of a coalbed far in advance of mining. Coalbeds contain large quantities of gas; however, the production rates are generally small because reservoir pressures may be relatively low in comparison to other producing horizons, and diffusion transport through the matrix is a slow process. The design of an economical degasification scheme is dependent strongly upon proper well spacing. The cost of such a program must be balanced against cost reduction in ventilation, higher productivity, and, possibly, revenue from the sale of produced gas.

Figure 3 shows measurements of pressure gradients that exist around mine openings. Curve 1 was measured in an area where coal was being mined actively. Curve 2 was measured in an area that had been inactive 6 months. Note that the gradients are much steeper near the active face areas; these are the areas where heavy gas flows occur. Figure 3 shows that the drainage radius near an active face is about 80 feet, and about 1,300 feet (extrapolated) at an exposed rib. These curves were obtained by drilling horizontal holes incrementally and measuring pressure.

Curve 2 of figure 3 was monitored for a period of approximately 4 months. During this interval no pressure changes occurred, indicating that the drainage radius was stationary. These measurements substantiate the observation that gassy mines left idle for a number of years do not degasify. When the mine is reopened and entries are driven for approximately 1,000 feet, the mine is as gassy as before closure. Based on the data presented in figure 3, a reasonable spacing program for the Pocahontas No. 3 coalbed is of the order of 0.5 mile or one well per 160 acres.

Figure 4 shows a production decline curve for a group of 20 wells drilled into the Pittsburgh coalbed. These wells are on a 1,500-foot spacing. The curve is a typical constant percentage decline, and there are no indications of flow characteristics peculiar to coal-gas reservoirs. Initial production rates were of the order of 15 to 20 million standard cubic feet per day and the economic life is of the order of 35 to 40 years. Adequate technical data are not available such as shut-in pressures, drawdown tests, and in situ permeability tests.

The successful use of surface boreholes as a degasification scheme in coalbeds will depend upon two necessary conditions; namely, good fracture permeability and high fracture density. Both conditions must be met. A bed with good fracture premeability and low fracture density is in the same

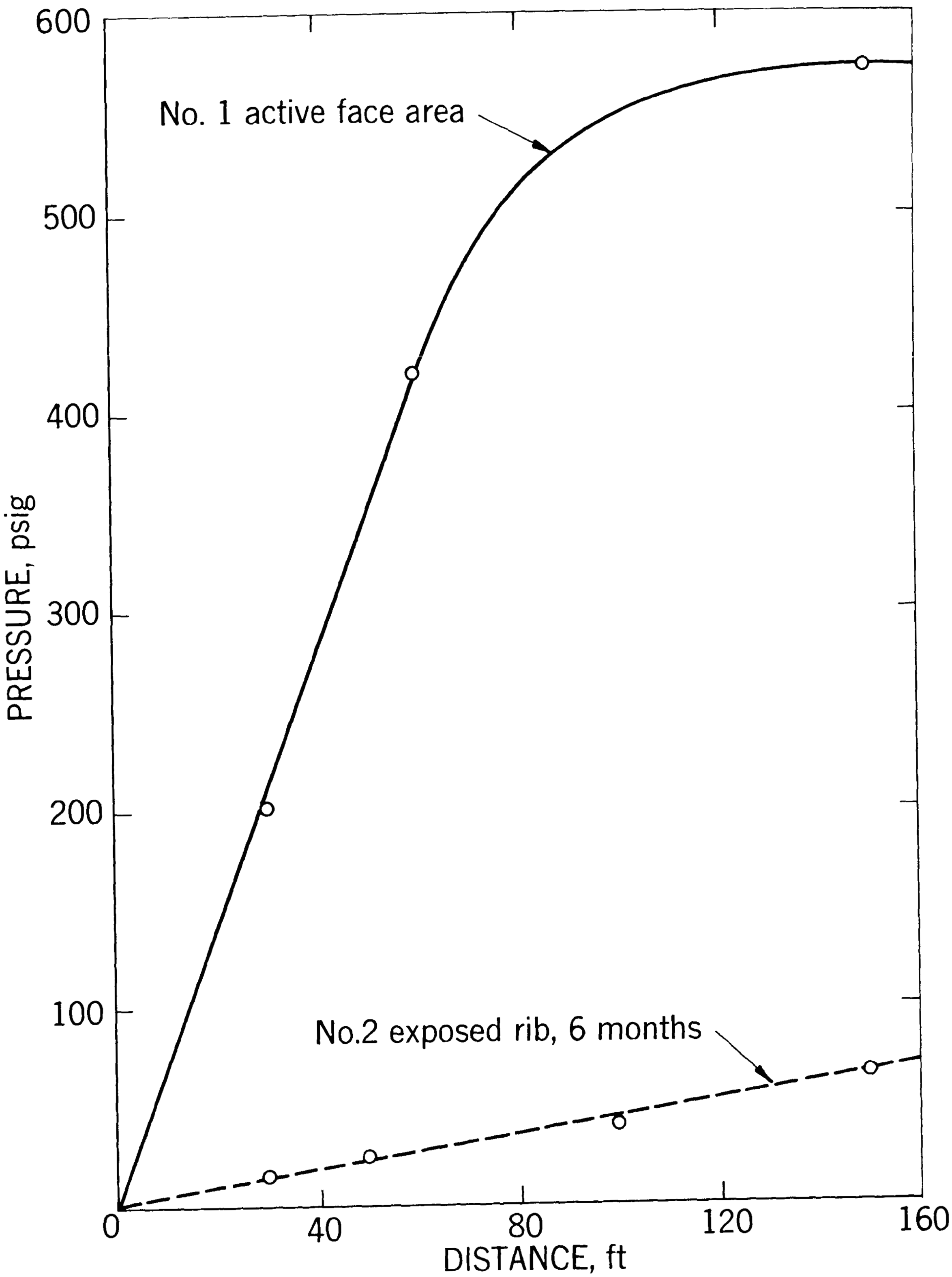

FIGURE 3. - Comparison of Pressure Gradients Near Active and Inactive Areas of a Mine.

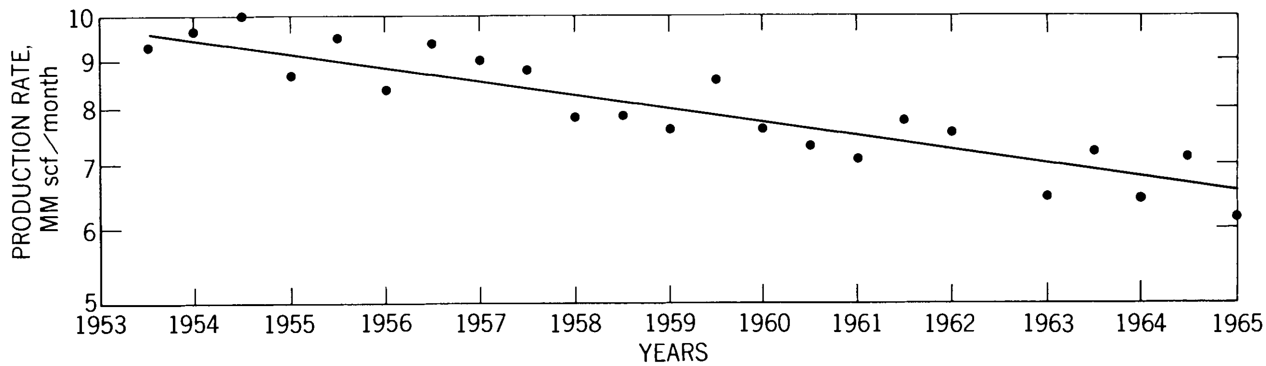

FIGURE 4. - Production Decline Curve for Coal-Gas Wells.

category as a bed with poor fracture permeability and high fracture density. Neither is susceptible to surface borehole degasification. Both can be classified as beds where diffusion transport predominates. As mass transport shifts from the Darcy mode toward diffusion transport, the effectiveness of surface boreholes as a means of degasification decreases.

SUMMARY AND CONCLUSIONS

Mass transport through coalbeds is governed by Darcy's law and Fick's law of diffusion. Thus, the extension of conventional methods of reservoir engineering analysis to coalbeds is not justified.

Internal surface area of coal can be as high as 1.5 million square feet per pound of coal and 0.34 standard cubic feet of gas per pound of coal can be adsorbed on the internal surface area at the saturation pressure of 1,500 psig.

The effectiveness of surface boreholes as a degasification scheme will depend upon two necessary conditions--good fracture permeability and high fracture density. Both conditions must be met.

Production decline curves show no indications of flow characteristics peculiar to coalbeds. Economic life of coal-gas wells is of the order of 35 to 40 years.

NOMENCLATURE

q = volume flow rate (cm^3/sec)

k = fracture permeability (Darcy)

A = cross-sectional area (cm^2)

μ = gas viscosity (centipoise)

P = gas pressure (atm)

L = length (cm)

q' = volume flow rate (cm^3/sec)

D = diffusivity coefficient (cm^2/sec)

C = concentration of CH_4 in solid coal (cm^3 of CH_4/cm^3 of coal)

Co = equilibrated concentration of CH_4 in solid coal (cm^3 of CH_4/cm^3 of coal)

b and n = constants

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