GAS TRANSPORT THROUGH SECTIONS OF SOLID COAL

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ABSTRACT

Measurements were made for helium and methane flowing through thin disks of coal. Flow increased with pressure differential and temperature. At room temperature and a pressure differential of one atmosphere the flows along the bedding plane were: helium, 873 x 10^{-10} cm^2sec^{-1}, and methane 1.2 x 10^{-10} cm^2sec^{-1}. Flow rates were 50 percent lower across the bedding plane of the coal than along the coal seam. Activation energies were 3.9 kcal $mole^{-1}$ for helium and 13.6 kcal $mole^{-1}$ for methane for flow measured either along or across the bedding plane.

Knowing the rate at which gases will diffuse through coal will help not only in understanding reactions that can alter the properties of coal, such as oxidation, but also in studying the drainage of methane and other combustible gases from coal mines. Of all the methods of measuring diffusion, varying from the determination of massive emission from a coal-mine face to the measuring of desorption from micron-size particles, gas transport through solid coal sections appears the most promising. For the present experiments, thin disks were prepared from sections of coal cut parallel and perpendicular to the bedding planes of the coal seam. Tests with a series of disks from various locations in the same mine have shown reproducible results. Previous investigators have encountered difficulty in measuring low flow rates through solid coal. With a high sensitivity (500,000 divisions per torr) mass spectrometer we have measured the flow of methane and of helium, a reference gas, through solid sections of coal. Methane, the chief component of fire damp in a coal mine, has a very low rate of diffusion at the temperatures usually found in mines. Cervik[1/] has discussed the flow of gas in coal mines; flow mechanisms include diffusion through the micropore structure and permeation through the fracture system.

Laboratory-diffusion experiments reported by other investigators have been of two types. One type of experiment is the measurement of sorption or desorption on ground coal where gas penetration into the ultrafine pore structure is diffusion controlled. A second technique is the direct measurement of gas flow across a thin section--the method used in this investigation. Zwietering[2/] and Schilling[3/] based diffusion coefficients on methane sorption on powdered coal. Graham[4/] and Sevenster[5/] reported diffusion coefficients for methane flow through a thin section of coal.

Investigator	Coal form	Pressure differential, torr	Gas flow rate, cm^2sec^{-1}
Swietering[2/]	Powder	27	2 x 10^{-12}
Schilling[3/]	Powder	736	3 x 10^{-10}
Graham[4/]	Disk	760	15 x 10^{-8}
Sevenster[5/]	Disk	400	3 x 10^{-11}

Sorption methods require an estimate of surface area, path length, and frequently a temperature extrapolation. Hofer[6] using adsorption and Walker using desorption[7] reported data in terms of $cm^3g^{-1}sec^{-1}$. These data are useful for comparing gas flow at various temperatures and pressures. The data presented in this paper may be more properly defined as flow rates than diffusion coefficients. The rates are expressed as cm^2sec^{-1} based on the volume of gas transported, the geometric area of the face, and the thickness of the coal disk.

EXPERIMENTAL

Our experimental procedure is a modification of the method reported by Sevenster.[5] Coal disks were prepared from sound coal samples selected from the Bruceton Mine in the Pittsburgh seam (hvab coal). A sample was considered sound if it had no visible cracks and if the helium flow met standards established by testing a large number of coal disks. The disks were cut and ground to 13 to 19 mm diameter and 1 to 6 mm thickness. Disks about 1 mm thick were good for pressure differentials of 20 to 120 torr, but 6 mm thickness was necessary for pressure differentials of about 1 atmosphere. The disks were prepared so that gas flow could be measured either along or across the bedding plane of the coal. Each coal disk was sealed with epoxy cement to the flared end of a glass tube which had been fused inside another glass tube (Figure 1). This established two bulbs separated by the coal disk. The bulbs were evacuated to less than 1 micron pressure over a period of 18 hours at 100° C. After evacuation bulb A was filled with helium or methane at 20 to 760 torr. Bulb B was opened at appropriate intervals and the gas analyzed by mass spectrometry. Gas flows were measured at approximately 10° C intervals between room temperature and 100° C with the temperature controlled with an electric heating jacket and thermostat. Gas flow rates were expressed as cubic centimeters (at standard conditions) of helium or methane which would pass per second through a disk 1 square centimeter in cross section and 1 centimeter in thickness (cm^2sec^{-1}). The pressures in the two bulbs remained essentially constant during each experiment.

The pretreatment of the coal disk strongly influenced the initial rate of gas flow. The standard pretreatment (evacuation at 100° C for 18 hours) was designed to evacuate gases from the coal-pore system without altering the coal. Gas flow through a freshly evacuated disk was rapid at first but decreased with time, and reproducible data could only be obtained after an induction period of several days. After 3 days a constant flow rate was observed. Initial flow rates varied with the extent of evacuation, but in all cases the data were reproducible after a steady flow rate was established.

RESULTS

Data were obtained for 10 disks of varying thickness and cut either along or across the bedding plane of the coal seam. Helium flows were measured both along and across the bedding planes at several temperatures between 24° and 100° C. Arrhenius plots gave activation energies of 3.9 kcal $mole^{-1}$ for flow in either direction. The flow rate along the bedding plane was approximately three times the rate across the bedding plane. Helium flows were measured also at a series of pressures between 4 torr and 760 torr and at room temperature. These data were extrapolated to zero flow at zero pressure drop.

Since the flow varied directly with pressure, helium flow rates could be calculated at room temperature and a pressure differential of 1 atmosphere.

Gas flows at room temperature and a pressure differential of 1 atmosphere, observed directly, have been verified by extrapolation of a series of observations at several pressures and temperatures.

	Helium flow, $cm^2 sec^{-1} atm^{-1} \times 10^{10}$		
	from temperature data	from pressure data	direct
Flow along	1114	786	780
Flow across	361	325	300

In like manner methane flows were measured both along and across the bedding plane at several temperatures. Arrhenius plots (Figure 2) gave activation energies of 13.6 kcal $mole^{-1}$ for flow in either direction. Methane flow also varied with pressure (Figure 3).

Methane flow rates were obtained from three sources.

	Methane flow, $cm^2 sec^{-1} atm^{-1} \times 10^{10}$		
	from temperature data	from pressure data	direct
Flow along	1.2	1.2	1.2
Flow across	0.3	1.2	0.5

DISCUSSION

The mechanism for gas flow through coal could be molecular diffusion through the small pores, bulk diffusion through the larger pores, or permeation through the fracture system of the coal bed. Zwietering and van Krevelen,[8] using mercury penetration, measured the pore-size distribution for a low-volatile bituminous coal and found pores varying from a few angstroms to 50,000 A. Cervik[1] described the various flow mechanisms encountered in mine workings. The reproducibility between coal disks makes it unlikely that fracture porosity was encountered in the laboratory tests described in this paper. Diffusion of gases through porous solids has been described[9] as proportional to the concentration gradient (Fick's law) and inversely proportional to the square root of the molecular weights of the gases. This paper has confirmed the applicability of Fick's law but not the molecular weight dependence. For molecular flow helium should diffuse at twice the rate of methane; the ratios observed were 800:1 at room temperature and 40:1 at 100° C. This might be explained as diffusion modified by gas adsorption on the pore walls or by activated diffusion as suggested in references 5 and 8.

Flow along the bedding plane was faster than flow across the bedding plane. The assumption that the rate of gas transport would vary inversely with the disk thickness was supported where a disk 2.2 mm thick was compared with a disk 6.0 mm thick.

Methane flow data obtained in this study ($1.2 \times 10^{-10} cm^2 sec^{-1} atm^{-1}$ along the bedding plane, 0.7×10^{-10} across) can be compared with the value 0.28×10^{-10} $cm^2 sec^{-1} atm^{-1}$ reported by Senenster.[5] The two experiments were carried out on different coals and possibly different orientations of the bedding plane. The activation energies reported here for methane (13.6 kcal $mole^{-1}$) and helium (3.9 kcal $mole^{-1}$) are consistent with data in the recent literature. Kayser[10] measured gas sorption on a 30-percent volatile-matter coal and reported 10.9 and 2.4 kcal $mole^{-1}$ respectively.

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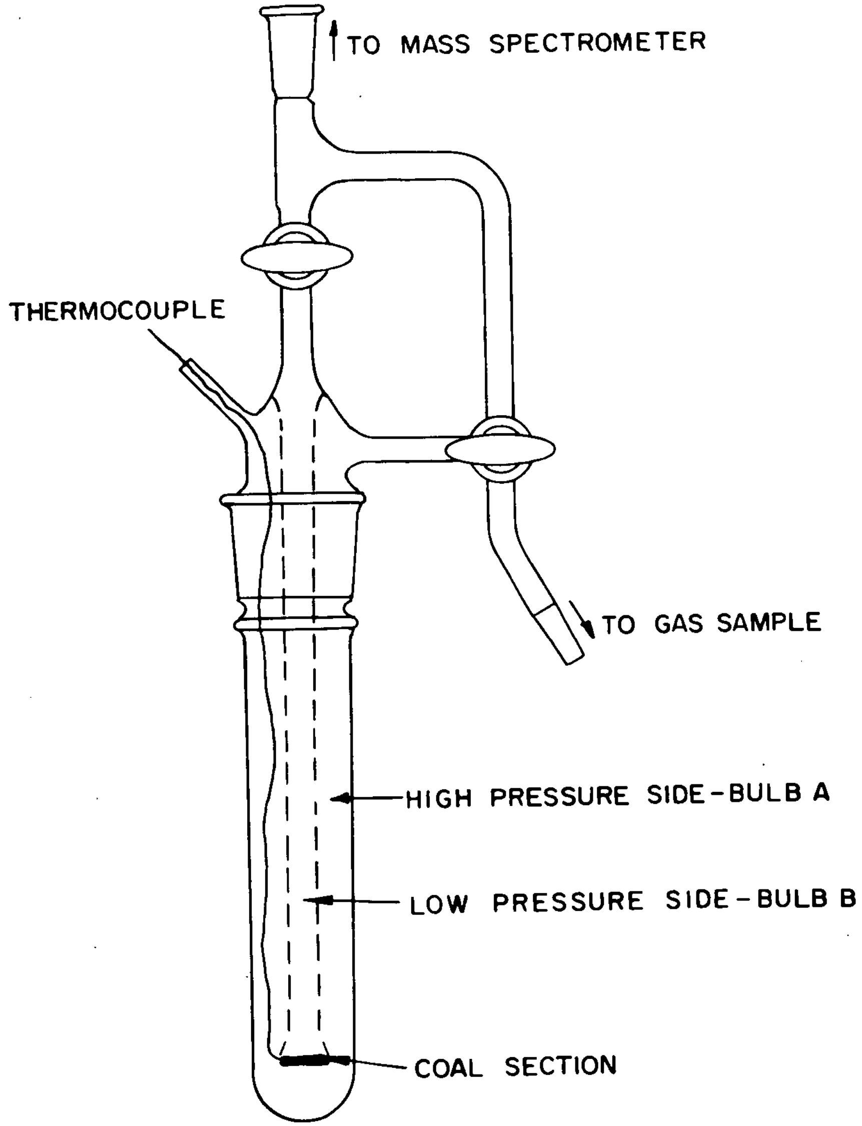

Figure 1.- Diffusion apparatus.

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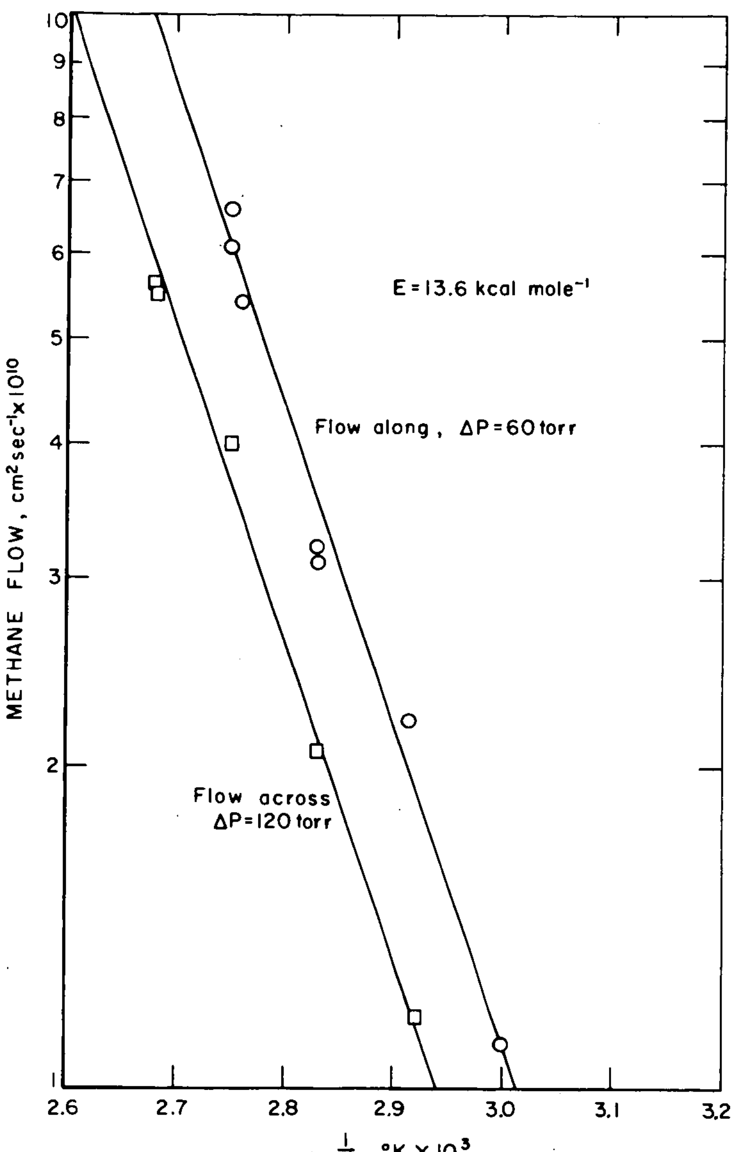

Figure 2.- Gas flow as a function of temperature. Methane flow along and across the bedding plane of Pittsburgh seam coal.

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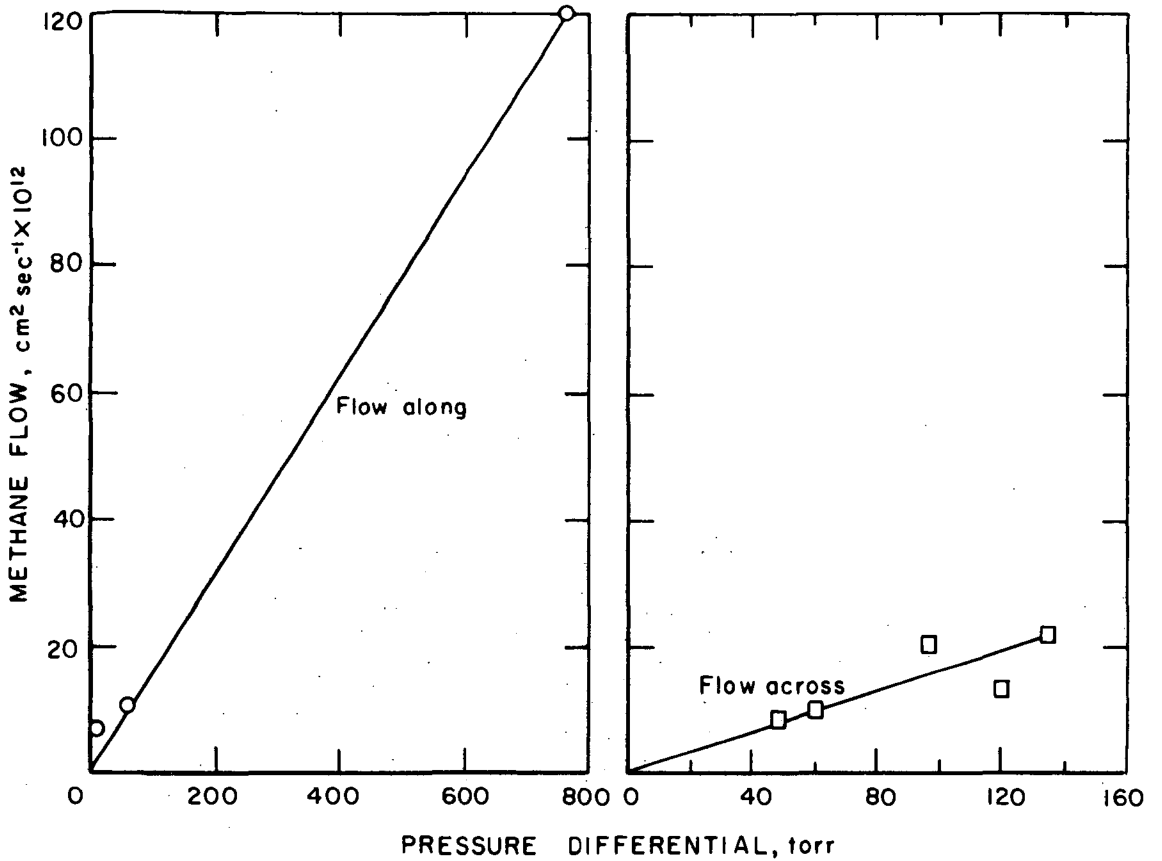

Figure 3.- Gas flow as a function of pressure differential. Methane flow along and across the bedding plane of Pittsburgh seam coal. Temperature 24° C.

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