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One-Dimensional Model of the Physico-Chemical Processes Occurring Inside a Burning Coal Surface

A one-dimensional model has been developed to account for the physicochemical processes occurring inside a burning wet coal surface. The model considers the vaporization of coal moisture and the existence of a moving evaporation front, pyrolysis and char/gas reactions in the hot zone, molecular diffusion and Darcy flow through the dry porous coal, transpiration cooling effect of the water vapor and pyrolysis gases, temperature-dependent reaction kinetics and coal thermal conductivity, and variable porosity of the coal due to pyrolysis and char/gas reactions.

The model and associated assumptions have been verified with experimental data from the combustion and drying of coal. The results also show that the model prediction of the heat transferred from the coal surface into the coal is much higher than that calculated by the simple heat conduction equation.

The fraction of the water in the coal that reacts with char is shown as a function of the linear burn velocity and the surface temperature. In addition, the effect of variations in coal moisture and the thermal conductivity on the thickness of the dry zone are also shown.

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SCOPE

One of the main problems that arises in modeling of underground coal gasification (UCG) is accounting for the processes occurring between the coal surface and the evaporation front. Most importantly, it is necessary to know how much heat is transferred into the coal, the fraction of coal moisture that reacts with the char and the thickness of this reaction zone. Existing models for simulating UCG have treated the heat transfer in the surrounding seam as a simple pseudosteady-state heat conduction problem (Wong, 1975; Riggs et al., 1979), or, in some cases, arbitrary assumptions about temperature distributions within the coal have been made (Dinsmoor et al., 1978). The possibility of pyrolysis and carbon/steam reactions occurring within the seam is usually ignored and all char/gas reactions are assumed to occur at the cavity wall. A rigorous model of a burning coal surface could be used to assess the relative importance of the various processes occurring in addition to evaluating simplifying assumptions that are used in various coal conversion models.

Figure 1 is a one-dimensional representation of a burning coal surface found during UCG operation. This model is markedly different from coal combustion models used to describe other coal gasification processes. Due to the countercurrent contacting nature of these other coal gasification processes, their combustion zone involves only char gasification. But the combustion zone for a UCG process involves pyrolysis, drying and char gasification, simultaneously. Figure 2 shows the one-dimensional system that is analyzed in this paper. Note that Figure 2 is a subset of Figure 1.

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In this paper, the coal surface temperature and the burn velocity are used as independent variables for the model. In fact, they are interrelated and are the result of the overall combustion process. But, to examine the physico-chemical processes occurring inside a burning, wet coal slab, they have been set independent of one another but maintained between limits that are reasonable for underground coal gasification.

Analysis of the temperature distributions within the seam shows that the temperature gradient is largest in the direction perpendicular to the cavity wall. Neglecting changes in the other direction, one can reduce the problem to that of drying of semi-infinite porous slab with the additional feature of chemical reactions between the vapor and the coal matrix. Furthermore, we can transform the partial differential equations describing the system to a set of ordinary differential equations by defining a moving coordinate system. The solution of the resulting equations is compared with data reported in the literature.

CONCLUSIONS AND SIGNIFICANCE

The description of a burning wet coal surface is a prerequisite for the understanding and quantification of resources recovery during underground coal gasification (UCG). This is because the ultimate cavity shape found during UCG is significantly affected by the combustion process and the flame extinction process of the coal. The model presented in this work describes the physico-chemical processes that occur inside a burning wet coal slab. For a given coal surface temperature, burn velocity and set of coal physico-chemical properties, the model calculates the temperature profile, gas composition and local coal porosity in the dried coal. It also calculates the thickness of the dry zone and the semicoking zone.

Model predictions of the thickness of the dry zone and the *semicoking zone* were compared with limited experimental data with reasonable agreement. It was found that the thickness of the dry coal zone and the semicoking zone beneath a coal surface decrease with an increase in the burn velocity and increase with an increase in the coal surface temperature. In addition, an increase in the water content of the virgin coal and an increase in the thermal conductivity of the dried coal were both found to result in a significant decrease in the thickness of the dried coal zone.

The fractional conversion of the coal moisture with the char was described as a function of burn velocity and coal surface temperature. Under typical UCG conditions, the fractional conversion of the coal moisture was found to be significant. Finally, the heat flux at the coal surface as calculated by the model is much larger than estimated by a previous model, because this work includes the effect of transpiration cooling and the effect of the endothermic char/steam reaction.

INTRODUCTION

There are presently many coal reserves in the world which are not recoverable using conventional mining techniques because the seams are either too thin or too deep. Also, a large fraction of those that can be mined exhibit a high sulfur or mineral matter content which severely limits the end use of these coals. Underground (or *in-situ*) coal gasification offers a potentially economic means of extracting the energy content from such coals while at the same time diminishing many of the health, safety and environmental problems associated with deep mining.

For the purpose of commercialization of UCG (underground coal gasification), a number of specific models are needed to describe its behavior quantitatively. Such models can be subsequently used for design and control. There is a need to be able to predict the resource recovery obtained with a particular well pattern. This involves the determination of the expected maximum burn width and sweep efficiency which have a dominant effect on the economics of the process. The sweep efficiency will determine the number and spacing of process wells.

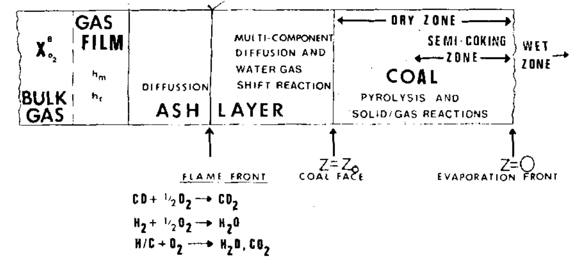

Figure 1. Physical model for combustion of wet coal.

The success of any global model for predicting cavity growth rate during UCG depends on how well it describes the individual processes that occur in the field, including the coupled heat and mass transfer that occurs in the seam surrounding the burned-out cavity. During the conversion process, some of the heat generated is lost into the surrounding seam. The moisture in the coal vaporizes and pyrolysis occurs. Also, if the temperature is sufficiently high, char/steam and char/CO_2 reactions can occur inside the seam. The problem is similar to the drying of porous half-space with the additional feature of chemical reactions in the matrix.

Note that during UCG (Figure 1), drying pyrolysis, and char gasification occur simultaneously. This feature is unique only to UCG. In other gasification processes, drying, pyrolysis, and combustion occur separately with each stage being completed before the other begins due to the countercurrent nature of these processes. Therefore, the studies of char or carbon particle combustion do not adequately describe the combustion process during UCG.

Tsang (1980) developed a mathemtatical model describing the heat and mass transfer occurring inside a cylindrical coal block during drying. He modeled a wet cylindrical block that was heated at a constant rate from an initially uniform temperature. The predicted results were compared with experimental results reported by Westmoreland et al. (1977, 1979). Similar work on the drying of a porous coal bed during forward combustion has been reported by Gunn and Whitman (1978).

This paper presents a model that considers not only the effects of drying and pyrolysis, but also includes the effects of char/gas kinetics and the effect of a receding char surface. The model is used to predict the thickness of the dry coal zone during UCG operation and these predictions are compared with reported laboratory measurements.

THE MODEL

The model (Figure 2) assumes that significant changes in temperature, pressure and concentration within the coal occur in a

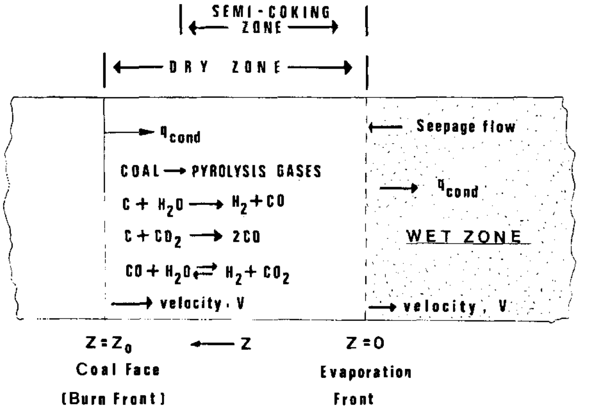

Figure 2. Physical model for heat and mass transfer in a burning coal.

direction perpendicular to the cavity wall extending into the seam. Changes in physical properties occurring in other directions are not considered. It is further assumed that the linear burn rate (burn velocity, m/s) at the wall is V and that the cavity wall temperature is T_o. Both V and T_o are parameters in this model. The actual values of V and T_o, as in a complete system, are interdependent and will largely depend on the flux of oxygen to the coal surface and the heat loss from the surface.

The burning coal is assumed to have two zones (Figure 2): the wet zone and the dry zone. The two zones are separated by the evaporation front, and the transition from the wet zone to the dry zone is assumed to be sharp (Westmoreland and Forrester, 1977). In the wet zone it is assumed that the only processes occurring are the Darcy flow of aquifer water to the evaporation front and heat conduction into the virgin coal. The total mass of vapor released at the evaporation front is the sum of the aquifer seepage water and the bed moisture vaporized as a result of the backward movement of the dry zone. It is assumed also that at steady state both the burn front and evaporation front move at the same velocity. In the dry zone, the temperature rises from the water front temperature, T_w, to the coal surface temperature, T_o. Above 500°C, pyrolysis gases are released; above 700°C, the steam and pyrolytic CO_2 react with the hot char. Within the dry zone is the semicoking zone which is between the evaporation front and the point at which pyrolysis is assumed to begin.

To develop a mathematical formulation for the dry zone, it is necessary to first decide on a suitable flow model for the flux of the gases and suitable kinetic models for the pyrolysis and other reactions in this zone.

Diffusion and Viscous Flow in Dry Coal

The flow of multicomponent gases through a porous medium is very complex because of the wide variety of flow types that can occur: Knudsen, molecular diffusion and viscous. Most mathematical models for gas-solid reactions assume that the mass flux in the solid follows Fick's law (Aris, 1975). This assumption is valid in the Knudsen diffusion flow regime and in the special case of equimolar counterdiffusion. However, the mass flux in the dry coal is not in the Knudsen diffusion regime, because as the coal dries and pyrolysis occurs the local porosity of coal will increase and the mean free path of the pyrolysis products and evaporated water is then much less than the pore radius of coal. This has been confirmed by studies conducted on American coals (Gan et al., 1972). Also, comparison of the time constants of molecular diffusion and viscous flow shows that the latter predominates if the permeability of the dry coal is greater than 10^{-12} m^2 (or 0.1 Darcy) (Russell et al., 1978). Thompson et al. (1978) have shown that the permeability of dry coal is unlikely to fall below 10^{-12} m^2 even under the compression of the overburden. Thus, in this work the simple Darcy law is used.

Kinetic Models

The following reactions are assumed to occur in the dry zone of the coal:

Coal	Pyrolysis →	(Pyrolysis Gases)
$C + H_2O$	→	$H_2 + CO$
$C + CO_2$	→	$2CO$
$CO + H_2O$	⇄	$H_2 + CO_2$

In this work, the simultaneous, independent reaction model of Juntgen and Van Heek (1968) and the data of Campbell (1978) are used to describe the pyrolysis reactions. For the char/gas and water/gas shift reactions, the correlations used are presented in Table 1.

GOVERNING EQUATIONS

The following assumptions are implicit in this formulation:

1. A one-dimensional system is employed.
2. The temperature of the solid and of the interstitial fluid phase is the same at any point, Z.
3. The thermal conductivity of the coal matrix is assumed to be a function of temperature (Badzioch et al., 1964).

TABLE 1. RATE CORRELATIONS USED IN MODELS

Reaction	Correlation	Reference
C/CO_2	Rate $= 2.0 \times 10^9\, \alpha_v \exp(-248{,}000/RT) P \rho_c X_{CO_2}/12RT$ (kmol/m^3·s) where α_v is a reactivity factor.	Dutta and Wen (1977)
C/H_2O	Rate $= k_v \rho_c P \left(X_{H_2O} - \dfrac{X_{H_2O} X_{CO}}{K_{C-H_2O}}\right)/12RT$ (kmol/m^3·s)	Wen (1972)
	where K_C—$H_2O = \exp(17.64 - 16{,}810/T)$	
	$k_v = \exp(24.3 - 25{,}720/T)$	
Water Gas Shift	Rate $= F_w\, (2.77 \times 10^5)(X_{CO} - X_{CO}^*) \exp(-27{,}760/1.98T) x$	Singh and Saraf (1977)
	$P^{(0.5-P/250)} \exp(08.91 + 5553/T)$	
	where $X_{CO}^* = \dfrac{1}{P}\left[\dfrac{P_{CO_2} P_{H_2}}{K_{eq} P_{H_2O}}\right]$ kmol/[S. kg of ash]	
	and $K_{eg} = \exp(-3.6893 + 7{,}234/1.8T)$	

F_w represents the relative catalytic activity of ash to that of iron-base catalyst and is equal to 0.02 in this work.

TABLE 2. COMPOSITION OF COAL—WYODAK SUB-BITUMINOUS COAL

Proximate Analysis	
Volatile Matter	29.6
Fixed Carbon	29.3
Moisture	34.7
Ash	6.7
Other Properties	
Specific Gravity	1.35

4. The ideal gas law is applicable.
5. The porosity of the coal is a function of the fractional conversion of carbon in the char/gas reactions. The permeability of the coal is given by:

$$B/B_d = (\epsilon/\epsilon_d)^{2.8}$$

The index is higher than that normally suggested for flow in a porous medium because of the possibility of cracks occurring in the wall (Tsang, 1980; Thompson et al., 1977). Note that swelling is neglected in this study.

6. The specific heat capacity of the coal is a function of temperature.
7. Variations in the molar heat capacities of the gas phase with temperature are neglected because they are not strong functions of temperature.

Using the pseudosteady state assumption, the partial differential equations can be transformed to ordinary differential equations. To apply this transformation, it is further assumed that the burn velocity is constant and that a definite temperature profile is established. In other words, the temperature and concentration profiles are unchanged with respect to an observer moving at the same velocity as the burn front.

The fixed coordinates are transformed to moving coordinates using the following equation:

$$Z = Z' + Vt \quad \text{where } V \text{ and } Z' \text{ are constant}$$

Wet Zone

Energy

$$k_o \frac{d^2T}{dZ^2} = \rho_o C_{p_o} V \frac{dT}{dZ} \tag{1}$$

Mass

$$\frac{d^2P}{dZ^2} = \left(\frac{\mu_w \epsilon_o V C_w}{B_o}\right) \frac{dP}{dZ} \tag{2}$$

Boundary conditions

$$P = P_H \qquad Z \rightarrow -\infty$$

$$P = P_w \qquad Z = 0$$

$$T = T_\infty \qquad Z \rightarrow -\infty$$

$$T = T_w \qquad Z = 0$$

Dry Zone

The following reactions occur in the dry zone:

$$(\text{Coal}) \xrightarrow{R_j} (\text{Pyrolysis Product})_j \qquad j = 1\ldots8$$

$$C + CO_2 \xrightarrow{R_9} 2CO$$

$$C + H_2O \xrightarrow{R_{10}} H_2 + CO$$

$$CO + H_2O \overset{R_{11}}{\rightleftharpoons} H_2 + CO_2$$

Species balance

$$\frac{dN_i^*}{dZ} = \sum_1^{11} \nu_{ij} R_j \qquad (i = 1.\ldots8) \tag{3}$$

Solid balance

$$V\frac{d\rho_c}{dZ} = -\sum_{j=1}^{8} M_j R_j - M_c(R_9 + R_{10}) \tag{4}$$

Volatile matter remaining in the coal

$$V\frac{dW_i}{dZ} = -k_i W_i \qquad (i = 1,2.\,.8) \tag{5}$$

Energy equation

$$(-\Delta H_p)\sum M_j R_j + \sum_1^{11} (-\Delta H_j) R_j = VC_{pc}\frac{d}{dZ}(\rho_c T) + \frac{d}{dZ}\left(-k\frac{dT}{dZ} + \sum N_i^* C_{pi} T\right) \tag{6}$$

Pressure drop

$$\frac{dP}{dZ} = \frac{\mu RT}{BP}\sum N_j^* \tag{7}$$

Boundary conditions

BC (i)	at $Z = 0$	$T = T_w$
BC (ii)	at $Z = 0$	$N_i^* = 0$ (except H_2O)
BC (iii)	at $Z = 0$	$W_i = m_i^*$
BC (iv)	at $Z = 0$	$\rho_c = \rho_c$
BC (v)	$-k\frac{dT}{dZ}\Big\vert_{0+} = -k\frac{dT}{dZ}\Big\vert_{0-}$	$-h_{fg} x_w \rho_o V$
BC (vi)	at $Z = Z_o$	$P = P_o$
BC (vii)	at $Z = Z_o$	$T = T_o$

In BC (ii) the seepage flux of aquifer water has been neglected because it has been shown to be very small (Schwartz, 1979). BC (vii) will be used to find the thickness of the dry zone. The net flux at the burn front is given as:

$$Q_s = -k\frac{dT}{dZ}\bigg\vert_{Z_o} + \sum N_i^* C_{pi}(T_o - T_w) \tag{8}$$

Conduction heat loss into seam $q_s = -k\dfrac{dT}{dZ}\bigg\vert_{Z_o}$

Solution Procedure

A set of nonlinear coupled differential equations is solved simultaneously in a computer scheme. The solution is as follows:

(i) First assume a value for pressure at $Z = 0$ (i.e., a value for P_w).

(ii) Calculate T_w using the Antoine equation for water

$$P_w = A^* \exp(-B^*/T_w + C^*).$$

(iii) After the first two steps, Eqs. 1 and 2 are solved and that solution used to define BC (v). Equations 3–7 then become an initial value problem. However, these equations become very stiff at high temperatures. Accordingly, a special technique developed by Gear (1971) for the solution of stiff initial value problems is used.

(iv) Starting from $Z = 0$, proceed in small steps to the point where $T = T_o$. If an inappropriate step size were used (either too large or too small), the method by Gear (1971) would recognize the fact and call for a change in the step size. Typically, a step size the order of 1.5×10^{-3} m was found to yield satisfactory results. The point at which $T = T_o$ is the burn front; therefore, the assumption made in step (ii) is checked to verify that P at $T = T_o$ is in fact P_o. If not, a new guess for P_w is made and the procedure returns to step (ii).

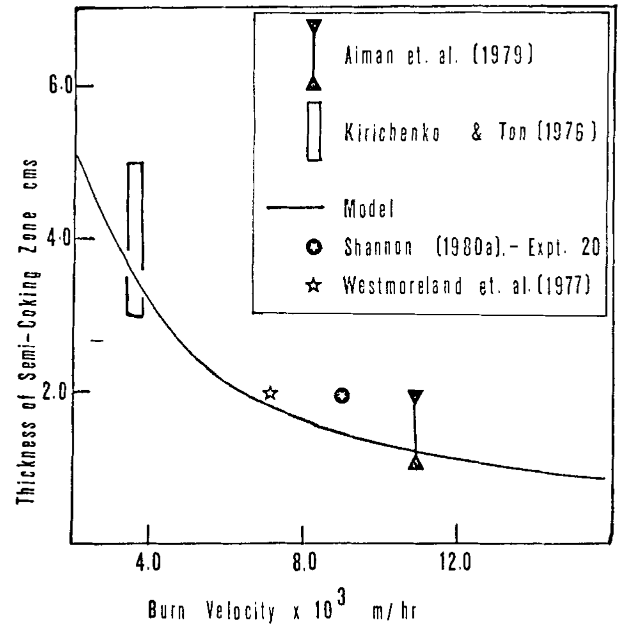

Figure 3. Comparison of predicted and measured values of semicoking zones.

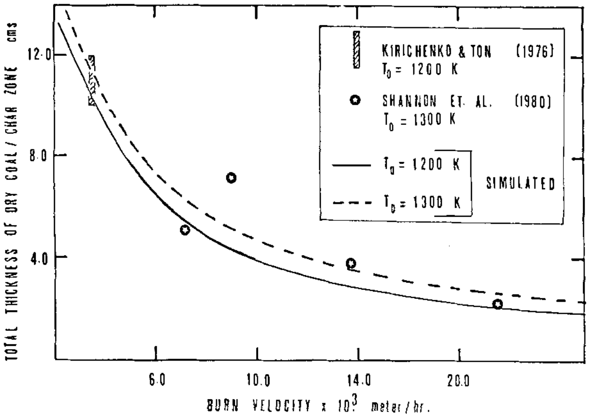

Figure 4. Comparison of predicted and measured distance separating the evaporation front and the burn front.

NUMERICAL RESULTS AND DISCUSSION

Numerical results predicted by the model are presented in Figures 3–8. Figures 3 and 4 are model comparisons with laboratory experimental data from the literature. Model predictions for the relative effect of coal water content and thermal conductivity of the dried coal are shown in Figures 5 and 6. In addition, Figure 7 indicates the dependence of the fractional reaction of the vaporized water with the char.

It should be reemphasized that although in this work both the coal surface temperature, T_o, and the burn velocity, V, are set independently. In actual situations these variables are linked through the combustion process. But in an effort to study the physico-chemical processes occurring within the coal during the combustion of a wet coal slab, T_o and V are supplied as input data to the model.

Comparison with Experimental Results

Figure 3 shows the comparison between the model and laboratory data taken for the thickness of the semicoking zone (Figure 2). The semicoking zone is defined as the region between the evaporation front and the point at which pyrolysis begins ($T = 773$ K). The laboratory data that was used as reported by Kirichenko and Ton (1976), Shannon et al., (1980a), Aiman et al., (1979), and Westmoreland. All the laboratory data except the Kirichenko and Ton (1976) data were obtained using Wyodak sub-bituminous coal with approximately the same proximate analysis. The data by Kirichenko and Ton (1976) and Shannon et al., (1980a) were obtained from bore hole experiments conducted in the forward combustion mode (i.e., ignition started at the oxidant injection

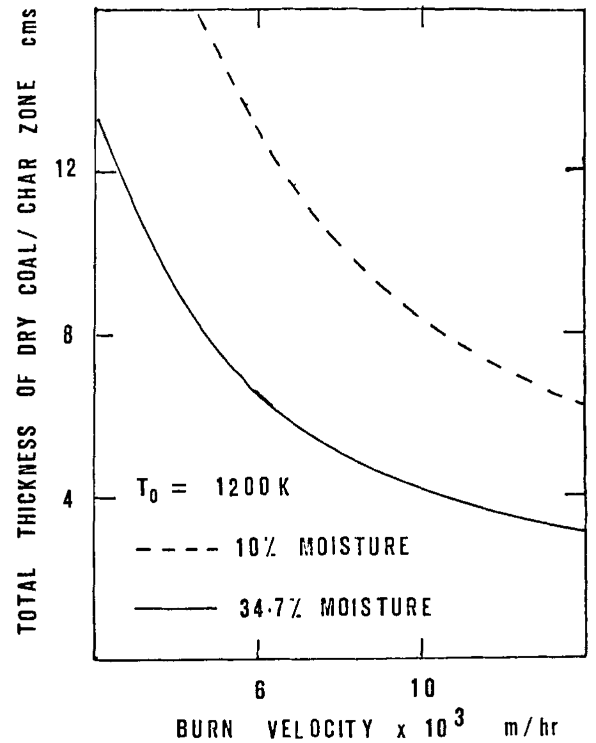

Figure 5. Effect of coal moisture content on the separation distance between evaporation front and the burn front.

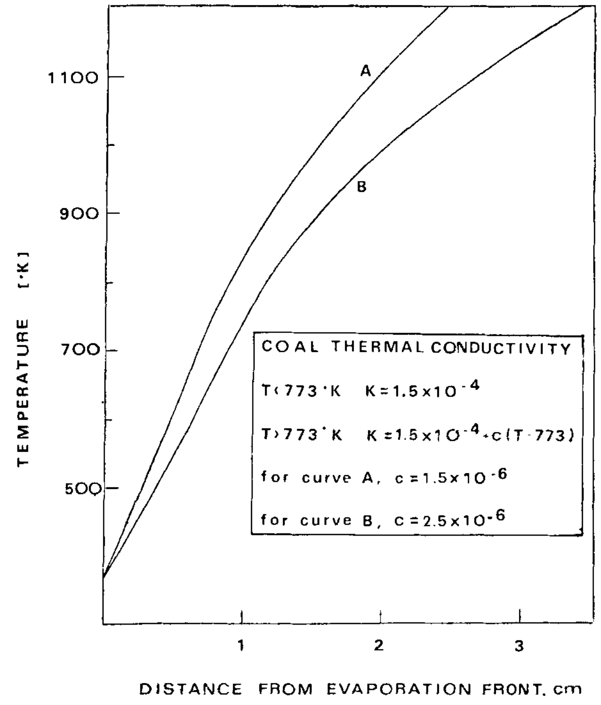

Figure 6. Effect of thermal conductivity on the temperature profile in the coal.

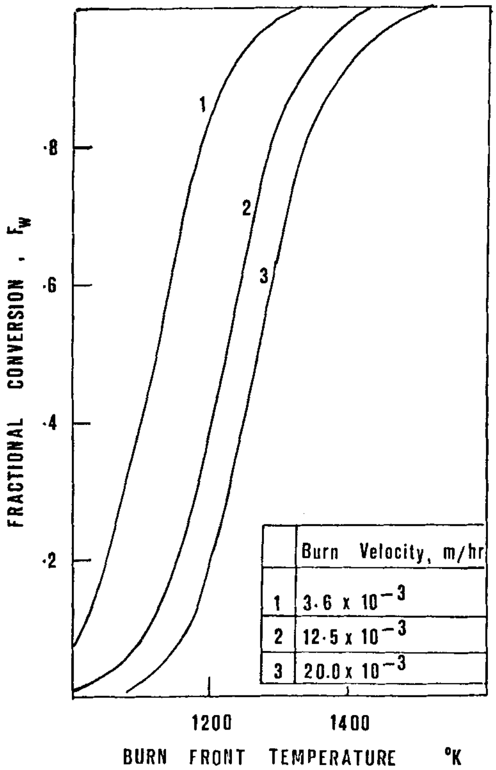

Figure 7. Fraction conversion of coal moisture in internal reactions.

point). The data of Aiman et al. (1979, 1980) were obtained by reverse combustion (i.e., ignition started at the production end) in a bore hold experiment. Also, the thickness of the semicoking zone was measured in the pyrolysis/drying experiment of wet Wyodak sub-bituminous coal (Westmoreland et al., 1977, 1979). Although the overall operation during the Westmoreland et al. (1977, 1979) tests were an unsteady-state phenomenon, the semicoking zone was found to move in a pseudosteady-state manner with a velocity of 2.0×10^{-6} m/s.

Figure 4 shows a comparison between model predictions and laboratory experiments for the overall separation between the coal face and the evaporation front. The data of Kirichenko and Ton (1976) and Shannon et al., (1980) were used for this comparison. The comparison is very good, except for one of the points in Figure 4. One possible explanation for this discrepancy is that the particular sample of coal used in this experiment could have lost some moisture before the start of the experiment. As can be observed in Figure 5, such a loss of moisture could increase the thickness of the dry coal zone.

Sensitivity Analysis

Model simulations are used to show the effect of water content in the coal and the thermal conductivity of the coal and these results are shown respectively in Figures 5 and 6. In Figure 5, it was found that the distance between the evaporation and burn front decreased as the moisture content of the coal was increased. This is because a higher moisture content generates a larger transpiration cooling effect resulting in a sharper temperature gradient and therefore a smaller zone thickness.

In Figure 6, it is observed that if the thermal conductivity of a particular coal is higher, the distance between the evaporation front and burn front increases. Because the heat flux is a product of the thermal conductivity and the temperature gradient, as the thermal conductivity increases, the temperature profile becomes flatter.

Fractional Reaction of Evaporated Water

As water is evaporated at the evaporation front, it flows through the porous dried coal toward the coal surface. As it approaches the coal surface, its temperature rises and part of this water reacts with the char to form CO and H_2. The fractional conversion of the evaporated water is shown in Figure 7 as a function of the coal surface temperature, T_o, and the burn velocity, V. One can see that as the burn velocity decreases and as the surface temperature increases, the fractional conversion of the water will increase.

Heat Transfer into Coal

The heat flux at the char surface as predicted by the model can be compared with the heat flux predicted by an analytical model (Wong, 1975). Wong's equation is given as

$$q_s = V\rho_o C_{P_o}\left(T_o - T_\infty + \frac{h_{fg}x_w}{C_{P_o}}\right)$$

The heat conducted into the coal calculated by the numerical routine is much higher than that determined by the Wong equation because the numerical routine includes the effect of the endothermic char/gas reactions and the effect of transpiration cooling from the evaporated water while the Wong model does not include these effects.

NOTATION

A^* = Antoine equation constant
B^* = Antoine equation constant
B_o = permeability of wet coal (m^2)
B = permeability of dry coal (m^2)
B_d = permeability of dry coal at $Z = 0$ (m^2)
C = total concentration of gas mixtures ($gmol/m^3$)
C^* = Antoine equation constant
C_{p_c} = specific heat of dry coal (kJ/kg·K)
C_{p_i} = molar heat capacity of species (kJ/kmol·K)
C_{p_o} = specific heat of wet coal (kJ/kg·K)
$C^v_{p_w}$ = specific heat of water vapor (kJ/kg·K)
C_w = compressibility of water
E_j = activation energy for jth reaction (kJ/Kmol)
F_w = fractional conversion of the water that is evaporated in the coal that reacts with the char
h_{f_g} = enthalpy of vaporization of water (kJ/kg)
$(-\Delta H_p)$ = heat absorbed in pyrolysis (kJ/Kmol)
$(-\Delta H_{10})$ = heat absorbed in the C/CO_2 reaction (kJ/Kmol)
$(-\Delta H_9)$ = heat absorbed in the C/steam reaction (kJ/Kmol)
h_c = film heat transfer coefficient ($kW/m^2 \cdot K$)
h_m = film mass transfer coefficient ($kmol/m^2 \cdot s$)
k = thermal conductivity of dry coal (kW/m·K)
k_i = rate constant for the ith reaction
k_o = thermal conductivity of wet coal (kW/m·K)
k_{oj} = frequency factor of jth reaction
m_c^* = mass fraction of fixed carbon in coal
m_i^* = initial mass fraction of species in the dry coal
m_i = mass fraction of species released
M_j = molecular weight of species j released
N_i^* = molar flux of species in the seam ($kmol/m^2 \cdot s$)
P = pressure (N/m^2)
P_H = hydrostatic pressure (N/m^2)
P_i = partial pressure (N/m^2)
P_o = pressure at the burn front (N/m^2)
P_w = pressure at the evaporation front (N/m^2)
q_{cond} = conduction heat flux (kW/m^2)
q_s = conduction heat flux at wall face (kW/m^2)
Q_s = net heat flux into coal block
R = gas law constant (kJ/kmol·K)
R_j = reaction rate of the jth reaction ($kmol/m^2 \cdot s$)
T = temperature (K)
t = time (s)
T_∞ = virgin coal temperature (K)
T_o = temperature at coal face (K) (T at $Z = Z_o$)
T_w = temperature at evaporation (K) (T at $Z = 0$)

V = burn velocity (m/s)
W_i = mass fraction of pyrolysis gas remaining in coal
$X_{O_2}^B$ = bulk oxygen mole fraction
Z' = fixed distance coordinate
Z = moving coordinate
Z_o = thickness of dry zone
α_ν = reactivity factor
ϵ_o = porosity of wet coal
ϵ = porosity of dry coal
ϵ_d = initial porosity of dry coal at $Z = 0$
ρ_c^o = initial density of dry coal at $Z = 0$
ρ_o = density of wet coal
ρ_c = density of dry coal (variable)
μ_w = viscosity of water
μ = viscosity of gas
ν_{ij} = stoichiometric coefficient of ith species in jth reaction

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Hydrodynamic Model for Gas-Liquid Slug Flow in Vertical Tubes

A series of equations are developed based on the physical processes thought to take place during slug flow which are used to predict the hydrodynamic character of this complex flow pattern. New experimental results are reported which appear to validate the model.

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SCOPE

Gas-liquid slug flow in vertical tubes is a flow pattern commonly found in many industrial applications. It occurs in process equipment (vapor-liquid contactors or absorbers, vapor generators, thermosyphon reboilers and gas-liquid chemical reactors), in two-phase oil and gas pipelines, particularly in risers from subsea wells to platforms, as well as in oil, gas and geothermal wells.

The objective of this work was to develop a physically-based hydrodynamic model for this flow pattern and to obtain experimental data by which the model could be evaluated. The results should permit the calculation of holdup, pressure drop, characteristic velocities, frequency and backmixing characteristics for slug flow.