ASSESSING THE RISK OF SPONTANEOUS IGNITION OF COAL AND BIOMASS

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INTRODUCTION

Coal, biomass and other combustible materials are often stored in stockpiles over long periods of time. These materials have exothermic reactions with oxygen even at ambient temperatures. Spontaneous ignition of a coal or biomass stockpile results when the rate of heat generation within the stockpile is greater than the rate at which heat can be transported to and dissipated in the external environment.

Problems of self-heating have led to many investigators proposing models for the full description of the physical and chemical processes leading to spontaneous ignition [1]. However, coal producers and users require immediate methods for assessing the self-heating potential of different coals, and a simple criterion is developed here. Existing methods for assessing self-heating properties include the basket methods and the determination of minimum self-heating temperature and the rate of rise in temperature of a coal under adiabatic conditions [1-3].

In a previous publication [4], it was shown that the effects of particle size on critical ambient temperatures, activation energies (E_a) and the products of exothermicity and pre-exponential factor (QA) were almost negligible for low rank coals, but significant for high rank coals. Furthermore, it has been observed that a typical critical ambient temperature is about 400K for these coals (regardless of rank) when crushed to 0.06 mm particle diameter and tested using a 50 mm cubical basket. A correlation has also been found between heat release and activation energy in these investigations [5]. This paper and a fuller version [6] predicts the liability of coals to spontaneous combustion using a new risk index which was developed from a substantial set of kinetic data concerning the low temperature oxidation of low rank to high rank coals. The method can also be used for woody biomass. The risk index is based on the rate of rise in temperature of a coal or biomass sample and the critical heat release rate at an oven temperature of 400K.

THEORY AND METHOD

The kinetic parameters of oxidation were determined from basket heating experiments and using the crossing-point method described in our previous papers. This method relies on finding the center temperature at the point in time when a flat temperature profile is observed thus at this instant there is no heat conduction. The main equation, presented previously, obeyed at this crossing point temperature, T_{cp}, is given by

$$\ln\left[\frac{dT}{dt}\right]_{T=T_{cp}} = \ln\left(\frac{QA}{C_{ps}}\right) - \left(\frac{E_a}{RT_{cp}}\right) \quad . \qquad (1)$$

Thus, one can estimate the kinetic parameters for coal or biomass oxidation (E_a and QA) from the slope and the intercept of a plot of $\ln(dT/dt)_{T_{cp}}$ against $(1/T_{cp})$.

While one can deduce the kinetic parameters of a sample experimentally using the crossing point method, the correlation between E_a and QA at criticality can be approximated by re-arranging equation (1) into the following form:

$$\ln\left[(QA)\big|_{crit}\right] = \ln\left(\frac{2.57kRT_a^2}{\rho\lambda^2 E_a e^{1.886}}\right) + \frac{E_a}{RT_a} \quad . \qquad (2)$$

Therefore by plotting $\ln(QA)$ against E_a , it is possible to establish an approximate relationship between QA and E_a for a given sample size (half-width l) at a different ambient temperature T_a. In previous work on both high temperature oxidation [7] and low temperature oxidation [8] a strong correlation has been shown between apparent activation energy and pre-exponential factor. This correlation lies very close to the Frank-Kamenetskii critical line from equation (2) for $T_a \approx 400$K and $l = 0.025$m. The significance of $T_a \approx 400$K for the criticality analysis using a half-width of 0.025m is suggested by experimental results [4]. Thus, we use this temperature as the basis for estimating the critical heat release rate. Given a value of QA and E_a, the heat generation rate can be determined from

$$q = \rho QA \exp\left(-\frac{E_a}{RT_a}\right) \quad , \qquad (3)$$

and becomes critical near $T_{a\ crit} \approx 400$K.

Thus substituting QA from equation (2) into equation (3), the heat release rate along a critical line is given by,

$$q_c \approx \frac{2.57k}{\lambda^2}\frac{RT_{a\ crit}^2}{E_a}e^{-1.886} \quad . \qquad (4)$$

Equations (3) and (4) show that for a given size of basket and an ambient temperature, one can get a reasonable assessment as to whether the condition is super-critical or sub-critical by analysing the ratio of q and q_c. Thus if

$$\frac{q}{q_c} < 1 \quad ,$$

then this represents a safe region of heat release rate to avoid self-ignition. On the basis of the earlier work [2] this then suggests a useful method for testing coals using small baskets.

EXPERIMENTAL SET-UP AND TYPICAL RESULTS

Figure 1 illustrates the experimental oven and ancillaries used for the controlled heating of the sample baskets of the coal or biomass.

Kinetic parameters. Figure 2 shows typical Arrhenius plots performed to obtain E_a and QA values at different particle sizes for Arutmin coal and South Bangko coals using the crossing-point procedure. At least five sets of crossing-point temperature data were obtained for each kinetic plot of $\ln(dT/dt)_{T_{cp}}$ against $(1/T_{cp})$. The ambient (oven) temperature used for the Arutmin coal ranged from 115°C to 135°C for the finely crushed samples (d_p = 0.24 mm) and from 125°C to 190°C for the coarser samples (d_p = 2.67 mm). It was found that the plots for the Arutmin coal have different slopes depending on particle size. The activation energy E_a and the product of the exothermicity and the pre-exponential factor QA of this coal increase with decreasing particle size..

Similar findings were also found for the woody biomass but kinetic parameters indicated, as expected, higher reactivity compared to coal.

Small-scale heat release tests. Figures 3A and 3B show typical temperature - time histories for South Bangko and Arutmin coals when tested at a constant ambient temperature of 400K using a 50 mm cubical basket. In general, coals with smaller particle size release more heat than those of bigger sizes. This is clearly shown by the rate of change in the central temperatures (dT/dt) at the crossing point temperature T_{cp} when the ambient temperature T_a was 400K. The Arutmin coal has a (dT/dt) value of 0.72 $Kmin^{-1}$ at d_p = 0.24mm and reduces to only 0.04 $Kmin^{-1}$ at d_p = 2.67mm. Meanwhile, the values of (dT/dt) for the South Bangko coal decrease slightly from 0.62 $Kmin^{-1}$ at d_p = 0.24mm to 0.40$Kmin^{-1}$ at d_p = 2.67mm. Data for the biomass will also be presented in the full paper.

Risk classification. On the basis of the safety criteria $q/q_c < 1$, and the approximation for heat release rate from the rate of rise in temperature of a coal sample at an oven temperature of 400K, we propose a new risk index. Using this risk index coals with the rate of temperature change (dT/dt) at T_{cp} values between 0 $Kmin^{-1}$ and 0.2 $Kmin^{-1}$ are classified as poorly susceptible to self ignition; those above 0.6 $Kmin^{-1}$ as very highly susceptible; and those in the range 0.2 to 0.6 $Kmin^{-1}$ as moderate to high susceptibility. The (dT/dt) at T_{cp} values for poorly susceptible coals correspond to the ratio of q/q_c less than 1, and those of very highly susceptible coals has q/q_c values greater than 3. For moderate to high susceptibility coals, the q/q_c value ranged between 1 and 3. In addition to the (dT/dt) at T_{cp} and the q/q_c criteria, a coal which is considered to be very highly susceptible to self-ignition undergoes super-critical conditions when tested using a 50mm cubical basket at T_a = 400K. The risk classification for the coals used in the present work is shown in Figure 4. In addition to our own data, we can also apply the risk index for classifying the self-ignition tendency of other coals for which kinetic data are available in the literature. A fuller report of this method is available [6]. In the case of biomass the tendency for self-ignition is considerably greater than for coal of a similar size.

Application for large piles. In attempts to consider the application of the proposed risk classification for large piles, we carried out calculations for a 3m cube (l = 1.5m) at a maximum temperature of 38°C (= 311K) [9]. The results show that coals with smaller particle sizes have lower values of q_c indicating the increase of risk of the finely crushed coals to spontaneous combustion. A large pile of woody biomass also poses a much larger propensity to spontaneously combust than an equivalent coal pile.

CONCLUSION

The spontaneous combustion risk of coal or biomass can be ranked according to the rate of temperature rise and critical heat release rate values of small-scale experiment using a 50mm cubical basket at an oven temperature of 400K. The low rank coal has greater propensity to self-ignition than the high rank coal. However, a finely crushed bituminous coal can exhibit a strong tendency to spontaneous combustion similar to those of lower rank coal. Biomass however presents the greatest risk of spontaneous combustion. A practical risk index has been devised for predicting the thermal behaviour of large piles of coal or biomass.

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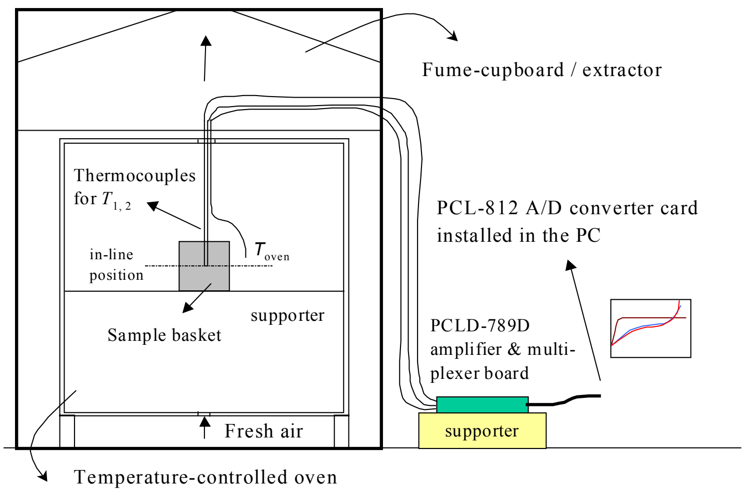

Figure 1 The experimental set-up for the oven heating test.

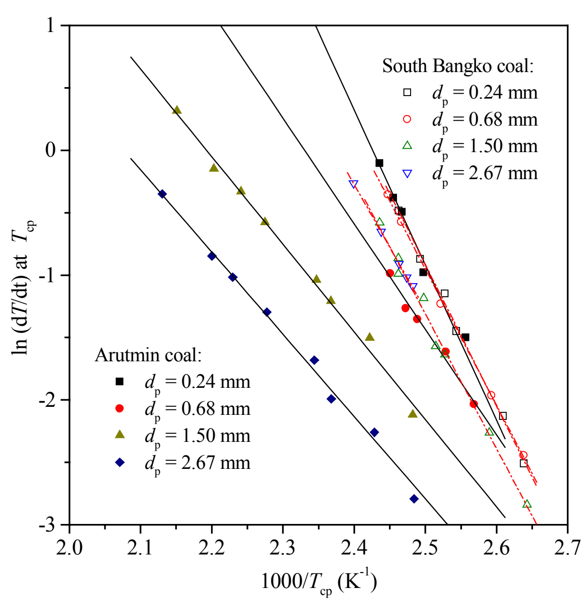

Figure 2. Plot of ln $(dT/dt)T_{cp}$ against $(1/T_{cp})$ for the Arutmin and the South Bangko coals at different particle sizes

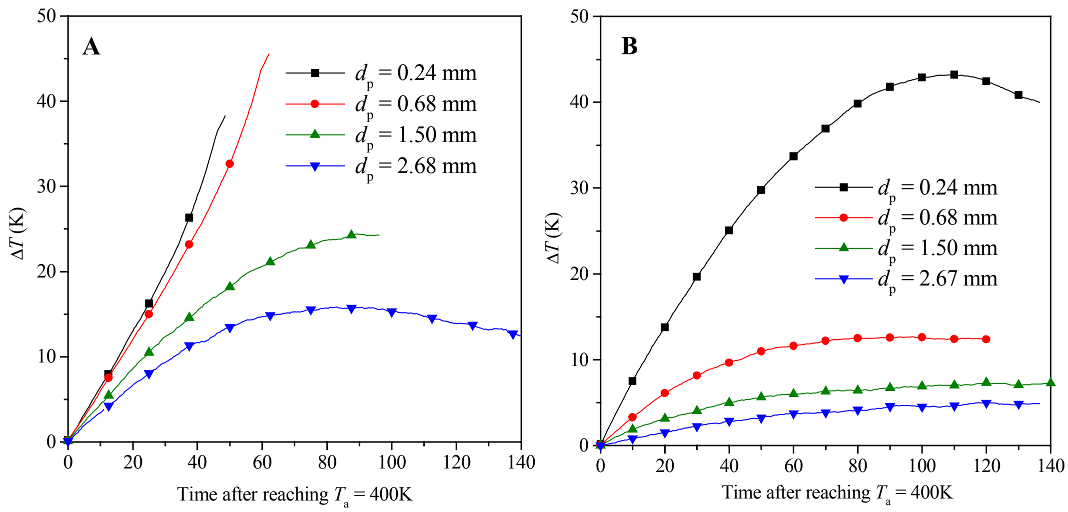

Figure 3 The effect of particle size on the central temperature-time trajectories for the South Bangko coal (A) and for the Arutmin coal (B), measured using a 50 mm cubical basket.

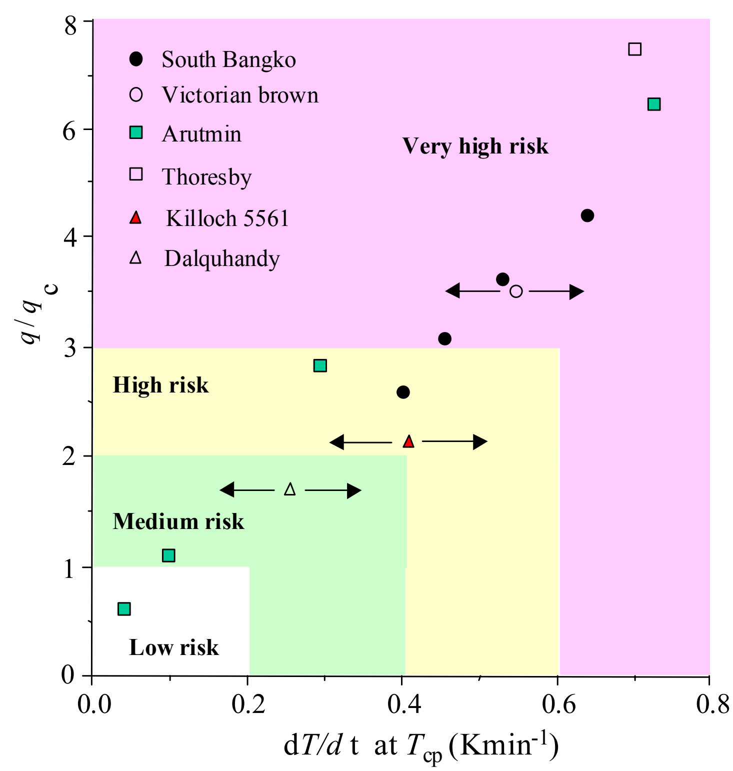

Figure 4 Spontaneous combustion risk assessment for the coals based on their q/q_c and/or dT/dt values.