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TECHNICAL NOTE

Relations between Coal Properties and Spontaneous Combustion Parameters

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Abstract

The results of linear and multiple regression analyses to determine the relationship between spontaneous combustion parameters (derived from time-temperature curves obtained from laboratory tests) and coal parameters (obtained from proximate, ultimate and petrographic analyses) have been explained. The linear regression analyses have shown that ash (A), volatile matter (VM), carbon (C), hydrogen (H), exinite (E), inertinite (I) and mineral matter (MM) are the major factors affecting spontaneous combustion. According to the multiple regression analyses, these major factors are volatile matter, carbon, hydrogen, nitrogen (N), oxygen (O), sulphur (S) and inertinite. As a result of this study, some empirical equations have been derived using statistical models.

Key Words: Spontaneous combustion, Coal.

Introduction

Almost all types of coal may ignite spontaneously in suitable environmental conditions. This leads to serious safety problems as well as economic losses for coal mines and storage areas. The determination of the liability of a coal type to spontaneous combustion is quite important in dealing with the problem before, during and after mining. In this study, following a brief literature survey, a statistical model developed for this purpose regarding the hard coals of the Zonguldak region is introduced.

The crossing point technique is used to obtain time-temperature curves of the coal samples in an originally designed laboratory set-up (Didari and Kaymakçı, 1995). Crossing point temperature (CPT), average heating rate (AHR), Feng, Chakravorty, Cochrane Liability Index (FCC) and slope of the time-temperature curve on the crossing point (CPS) (Figure) are taken as the spontaneous combustion parameters.

To obtain various coal properties proximate analyses to determine the fixed carbon, volatile matter, ash and moisture contents, ultimate analyses to determine carbon, oxygen, hydrogen, nitrogen and sulphur contents and petrographic analyses to determine the exinite, inertinite, vitrinite and mineral matter contents of the coal samples are carried out by standard procedures (Didari and Kaymakçı, 1995).

Linear and multiple linear regression analyses are applied to determine the relations between spontaneous combustion parameters and coal properties.

The mechanism of spontaneous combustion of coal

Although many factors affect heat producing reactions, the oxidation of carbonaceous matter in coal at ambient temperatures is the major cause for the initiation of spontaneous combustion (Güney, 1968; Banerjee, 1985; Goodarzi and Gentzis, 1991).

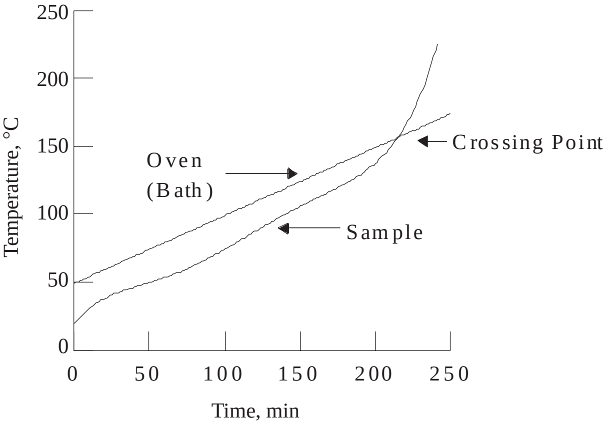

Figure Time - temperature curve

The oxidation of coal, like all oxidation reactions, is exothermic in character. The exact mechanism of the reaction is still not well understood. However, scientists agree that the nature of the interaction between coal and oxygen at very low temperatures is fully physical (adsorption) and changes into a chemisorption form starting from an ambient temperature (Münzner and Peters, 1965; Banerjee, 1985; Postrzednik *et al.*, 1988). The rate of oxygen consumption is extremely high during the first few days (particularly the first few hours) following the exposure of a fresh coal surface to the atmosphere. It then decreases very slowly without causing problems unless generated heat is allowed to accumulate in the environment. Under certain conditions, the accumulation of heat cannot be prevented, and with sufficient oxygen (air) supply, the process may reach higher stages.

The loose coal-oxygen-water complex formed during the initial stage (peroxy-complexes) decomposes above 70-85°C, yielding CO, CO_2 and H_2O molecules. The rate of chemical reactions and exothermicity change with the rise in temperature, and radical changes take place, starting at about 100°C, mainly due to loss of moisture (Oresko, 1959; Banerjee, 1985; Handa *et al.*, 1985). This process continues with the rise in temperature, yielding more stable coal-oxygen complexes until the critical temperature is reached. From then on, it is fairly safe to assume that an actual fire incident will result.

Factors affecting the spontaneous combustion of coal

The main reason for the difficulties in understanding the mechanism of spontaneous combustion is the presence of many internal and external factors affecting the initiation and development of the phenomenon (Table 1). These factors have been reviewed by various researchers (Kröger and Beier, 1962; Güney, 1968; Chamberlain and Hall, 1973a; Feng *et al.*, 1973; Beier, 1973; Kim, 1977; Banerjee, 1982; Didari, 1988; Goodarzi and Gentzis, 1991; Didari and Ökten, 1994). The main factors which have significant effects on the process are summarized below:

Table 1. Factors affecting spontaneous combustion of coal (Güney, 1968).

Intrinsic Factors (Nature of Coal)	Extrinsic Factors (Atmospheric, Geological and Mining Conditions)
√ Pyrites √ Moisture √ Particle size and surface area √ Rank and petrographic constituents √ Chemical constituents √ Mineral matter	√ Temperature √ Moisture √ Barometric pressure √ Oxygen concentration √ Bacteria √ Coal seam and surrounding strata √ Method of working √ Ventilation system and air flow rate √ Timbering √ Roadways

Table 2. Dependent and independent variables used in statistical analyses (Kaymakçı, 1998).

Dependent Variables	Symbol	Independent Variables	Symbol
		Ash (%)	A
		Carbon (%)	C
Average Heating Rate	AHR	Calorie (%)	Cal
		Exinite (%)	E
		Fixed Carbon	FC
		Hydrogen (%)	H
Crossing Point Temperature	CPT	Inertinite (%)	I
		Moisture (%)	M
		Mineral Matter (%)	MM
Liability Index	FCC	Nitrogen (%)	N
		Oxygen (%)	O
		Sulphur (%)	S
Crossing Point Slope	CPS	Vitrinite (%)	V
		Volatile Matter (%)	VM

- Pyrite content may accelerate spontaneous combustion,

- Changes in moisture content; i.e., the drying or wetting of coal, have apparent effects,

- As the particle size decreases and the exposed surface area increases, the tendency of coal towards spontaneous combustion increases,

- It is widely recognized that lower rank coals are more susceptible to spontaneous combustion than higher rank coals. The abnormalities in this relationship may be attributed to the petrographic constituents of coal. However, this phenomenon has not yet been fully understood and requires further study,

- Ash content generally decreases the liability of coal to spontaneous heating. Certain parts of the ash, such as lime, soda and iron compounds, may have an accelerating effect, while others, such as alumina and silica, produce a retarding effect. It is clear that some chemicals promote combustion while others inhibit its development. Also, it is known that oil shale bands adjoining coal seams play an important role in mine fires,

- The temperature of the underground atmosphere is a direct factor,

- The presence of faults and zones of weakness around faults may contribute to the danger by allowing air leakage into coal mass,

- Mining methods with partial extraction, in which part of the coal seam is left in the goaf and pillars (designed for several purposes), can contribute to the potential for spontaneous combustion,

- Air flow rate is a complex factor because an air supply provides oxygen while it carries away the heat produced. There is a critical air quantity which allows the coal to oxidize and also allows the generated heat to accumulate. Therefore, it favours the process,

- High ventilation differentials and changes in the mine ventilation system also affect the development of the spontaneous combustion process.

In this research, the intrinsic factors are evaluated.

Sampling and laboratory work

Samples are taken from the mines in the Zonguldak coal region applying an originally modified sampling procedure (channel sampling). About 119 samples are used for tests and analyses (petrographic analyses are made only on 40 samples). Details of the sampling and laboratory work are given elsewhere (Kaymakçı and Didari, 1992; Didari *et al.*, 1993; Didari and Kaymakçı, 1995).

Table 3. The results of linear regression analyses between coal properties and spontaneous combustion parameters (Kaymakcı, 1998).

	CPT	FCC	AHR	CPS	A	MM	M	VM	FC	C	H	N	O	S	E	I	V	Cal
CPT	1.00 (119)																	
FCC	-0.90 (119)	1.00 (119)																
AHR	-0.85 (119)	0.99 (119)	1.00 (119)															
CPS	-0.83 (109)	0.90 (109)	0.89 (109)	1.00 (109)														
A	0.67 (119)	-0.58 (119)	-0.55 (119)	-0.55 (109)	1.00 (119)													
MM	0.70 (41)	-0.62 (41)	-0.60 (41)	-0.69 34	1.00 (41)	1.00 (41)												
M	0.16 (119)	-0.10 (119)	-0.09 (119)	-0.15 (109)	0.18 (119)	-0.07 (41)	1.00 (119)											
VM	-0.81 (119)	0.70 (119)	0.65 (119)	0.69 (109)	-0.66 (119)	-0.53 (41)	-0.30 (119)	1.00 (119)										
FC	-0.50 (119)	0.42 (119)	0.41 (119)	0.39 (109)	-0.96 (119)	-0.87 (41)	-0.13 (119)	0.42 (119)	1.00 (119)									
C	-0.63 (119)	0.53 (119)	0.50 (119)	0.51 (109)	-0.99 (119)	-0.97 (41)	-0.19 (119)	0.61 (119)	0.96 (119)	1.00 (119)								
H	-0.75 (119)	0.64 (119)	0.62 (119)	0.62 (109)	-0.84 (119)	-0.62 (41)	-0.28 (119)	0.83 (119)	0.70 (119)	0.82 (119)	1.00 (119)							
N	-0.34 (119)	0.21 (119)	0.21 (119)	0.15 (109)	-0.68 (119)	-0.32 (41)	-0.19 (119)	0.29 (119)	0.72 (119)	0.68 (119)	0.51 (119)	1.00 (119)						
O	-0.17 (119)	0.22 (119)	0.22 (119)	0.18 (109)	0.01 (119)	-0.13 (41)	-0.04 (119)	0.17 (119)	-0.08 (119)	-0.17 (119)	-0.04 (119)	-0.08 (119)	1.00 (119)					
S	-0.34 (118)	0.26 (118)	0.23 (118)	0.33 (109)	-0.21 (118)	-0.42 (41)	-0.05 (118)	0.40 (118)	0.09 (118)	0.18 (118)	0.30 (118)	0.00 (118)	0.06 (118)	1.00 (118)				
E	-0.82 (41)	0.85 (41)	0.81 (41)	0.82 34	-0.68 (41)	-0.69 (41)	-0.03 (41)	0.74 (41)	0.37 (41)	0.61 (41)	0.54 (41)	-0.03 (41)	0.30 (41)	0.31 (41)	1.00 (41)			
I	-0.82 (41)	0.87 (41)	0.83 (41)	0.83 34	-0.69 (41)	-0.71 (41)	0.02 (41)	0.70 (41)	0.41 (41)	0.61 (41)	0.55 (41)	-0.03 (41)	0.38 (41)	0.29 (41)	0.95 (41)	1.00 (41)		
V	0.03 (41)	-0.20 (41)	-0.18 (41)	-0.07 34	-0.53 (41)	-0.52 (41)	0.09 (41)	-0.14 (41)	0.71 (41)	0.59 (41)	0.19 (41)	0.48 (41)	-0.25 (41)	0.22 (41)	-0.23 (41)	-0.22 (41)	1.00 (41)	
Cal	-0.62 (70)	0.55 (70)	0.53 (70)	0.58 61	-0.98 (70)	-0.96 (41)	-0.07 (70)	0.59 (70)	0.89 (70)	0.96 (70)	0.77 (70)	0.48 (70)	0.19 (70)	0.27 (70)	0.64 (41)	0.65 (41)	0.54 (41)	1.00 (70)

Note: The values in brackets are the number of samples evaluted.
(Symbols are explained in Table 2)

Statistical work

Data coming from the analyses and tests of 119 samples are evaluated statistically. Spontaneous combustion parameters are taken as dependent and coal properties are taken as independent parameters (Table 2).

Results

The results of this unique and comprehensive research are given below. Since the study is related to a specific coal region, and any reported information on similar studies is not available, a comparison is not possible.

Linear Regression The results of the linear regression analyses are given in Table 3. Correlation coefficients between CPT, AHR and CPS are naturally high due to the dependence of AHR, FCC and CPS to the CPT, technically. Based on this reality, CPT can be taken as the major parameter to evaluate the relations. As seen in Table 3, there are high correlations (0.63-0.82) between CPT and the volatile matter, ash, carbon, hydrogen, exinite, inertinite and mineral matter of coal.

Multiple Linear Regression The results of multiple linear regression analyses are given in Table 4. Independent parameters naturally showing high correlations with carbon, hydrogen, nitrogen, oxygen, sulphur, volatile matter and inertinite (Table 3) are eliminated in the analyses. Correlation coefficients in the developed models are quite high (0.87-0.91).

Symbols

A : ash
AHR : average heating rate
C : carbon
Cal : calorie
CPS : slope on the crossing point
CPT : crossing point temperature
E : exinite
FC : fixed carbon
FCC : liability index
H : hydrogen
I : inertinite
M : moisture
MM : mineral matter
N : nitrogen
O : oxygen
r : correlation coefficient
r^2 : coefficient of determination
S : sulphur
V : vitrinite
VM : volatile matter

Table 4. The results of multiple regression analyses (Kaymakçı, 1998).

Dependent Variable	Models	Correlation coefficients (r)	Coefficient of determination (r^2)	Standard error	F Value
FCC	FCC = 1.87 + 0.46 N + 0.21 H + 0.06 VM + 0.13 I – 0.43 S – 0.04 O – 0.01 C	0.91	0.82	0.74	21.53
CPT	CPT = 227.09 – 7.61 N – 1.29 H – 0.87 VM– 0.9 I – 1.23 S + 0.33 O – 0.04 C	0.90	0.82	7.48	21.30
AHR	AHR = 0.47 + 0.06 N + 0.04 H + 0.006 VM+ 0.02 I – 0.08 S – 0.004 O – 0.002 C	0.87	0.76	0.11	15.30
CPS	CPS = 0.43 + 0.001 N – 0.01 H + 0.007 VM+ 0.003 I + 0.02 S + 0.004 O + 0.002 C	0.89	0.81	0.05	15.66

(Symbols are explained in Table 2)

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