The Study of the Liability of Coals to Spontaneous Combustion

Kömürün Kendiliğinden Yanmaya Yatkınlığının Araştırıması

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ABSTRACT

The paper traces the study of the liability of coals to self-heating at the university of Nottingham. The adiabatic oxidation technique has been used a measure means to investigate the mechanism of spontaneous combustion. The test procedure and condition have been standardized to enable all coal samples to be tested under identical condition. An example is given on the application of the laboratory results for the prevention of spontaneous combustion coals at a UK based Colliery.

Current research into the development of computerized intelligent system interfacing laboratory hardware is introduced. The system could be used to develop an Intelligent Mine Monitoring System by combining artificial neural networks to assist the early detection of spontaneous heatings and mine fires.

ÖZET

Bu bildiri, Nottingham Üniversitesi'nde kömürün kendiliğinden yanmaya yatkınlığı çalışmalarının bir devamıdır. Kendiliğinden yanma mekanizmasını incelemek için adyabatik oksidasyon yöntemi kullanılmıştır. Tüm kömür numunelerinin benzer şartlar altında denenmesini mümkün kılmak için deney yöntemi ve şartları standart hale getirilmiştir. İngitere'deki bir kömür madeninde kömürün kendiliğinden yanmasını önlemek için laboratuvar sonuçlarının uygulaması ile ilgili bir örnek verilmiştir.

Laboratuvar donanımıyla koordineli zeka sistemindeki gelişmelerle ilgili mevcut araştırma tanıtılmıştır. Kendiliğinden yanma ve ocak yangınlarının erken algılanmasına yardımcı olmak için yapay sinir ağlarının birleştirilmesiyle bir Ocak Ortamını Uzaktan Algılama Sistemi'nin geliştirilmesi için bu sistem kullanılabilir.

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1. INTRODUCTION

Spontaneous combustion of coal is generally defined as the slow heating and oxidation initiated by the adsorption of oxygen at low temperatures. Fires due to self-heating of coal can occur in underground mines, quarry benches of open cast mines, stockpiles and sea-borne cargoes. It has been a major problem in the mining industry, particularly with coal and sulphide ores. Spontaneous combustion of coal and other carbonaceous materials is an environmental issue of great importance associated with waste management that needs to be taken into account during the planning of a new mine and land reclamation. The importance of an adequate prediction of the potential liability of coals to spontaneous combustion is justified when selecting mining methods, storage procedures, transportation means, and the prevention measures to be employed.

Since earlier 60's, the Department of Mineral Resources Engineering at the University of Nottingham has been active in conducting research work into the problem of spontaneous combustion of coal. Adiabatic Oxidation technique was used in the laboratory to study the propensity of coals to self-heating. The research work has generated a large amount of data and some interesting points. Recently a computerised system using a Knowledge Based approach has been introduced to evaluate the potential heating risk in à proposed mining situation.

2. PREVIOUS RESEARCH

The study of spontaneous combustion of coal in the Department of Mineral Resources Engineering at the University of Nottingham was started by Hodges and Hinsley in 1960 (1,2,3). Their research work concentrated on the influence of moisture on the spontaneous combustion of coal. They found that moisture has an important bearing on the occurrence of spontaneous heatings, and that both the atmospheric humidity and the moisture associated with the coal take part in the process. Their work was latterly joined by Acherjee (4), Bhattacharrya (5) and Guney (6). Most of their work focused on the influence of humidity on the initial stages of the spontaneous heating. Guney also examined the gaseous products from the heating process and individual factors affecting the oxidation of coal (7). Although their work were widely referenced by other researchers in the world, substantial work in the department was rare in the following fifteen years.

The work was resumed by Singh and Demirbilek in early 80's. Their work standardised the experimental condition and developed a risk classification system (8,9,10). They also conducted a statistical study of the intrinsic factors affecting spontaneous combustion of coal (11). The research work was joined by Atkinson, Morris, Richards and Watt in other areas associated with spontaneous combustion. Atkinson examined 'coal fires' in ships holds (12), and with Morris, the geological, mining and seam factors affecting the spontaneous heating of coal (13,14). Morris studied the interpretation of the state of a mine fire behind the fire stoppings(15) while Richards and Watt approached the problem by examining the movement of air through the waste(16).

The massive information generated from this research was summarised and refined by Ren and encoded into an Expert System for the assessment of Spontaneous Heating, known as ESSH (17,18). The system consists of four application modules covering underground mining (19), surface stockpiling (20), coal shipment and waste disposal (21). The system utilises laboratory experimental results, extrinsic parameters, and incorporates uncertainty analysis wherever appropriate to assess the degree of spontaneous heating risk. It is able to identify the major factors contributing to the risk and to recommend measures to counter the hazards.

Present research work in the department is directed towards the computerisation of the adiabatic oxidation apparatus in the laboratory. The expert system is linked with the apparatus through interfacing a real-time data acquisition and control system (22). A more detailed description will be given in this paper.

3. ADIABATIC OXIDATION

A number of laboratory methods have been used to study the liability of coal to ignite spontaneously, however, none is in universal use. In order to more precisely determine the liability of coals to spontaneous combustion, the experimental condition should be controlled in a way that is close to the actual situation.

It is generally agreed that the adiabatic oxidation test is the most direct approach and the conditions during the test can be simulated closer to the actual conditions found underground. As a result of past experience gained in the department, the adiabatic oxidation method was chosen to evaluate the liability of coals to self-heating. The test procedure and condition have been standardised to enable all coal samples to be tested under identical condition. The initial rate of heating (IRH) and total temperature rise (TTR) under vacuum dry coal/saturated air condition has been chosen as the criterion of the spontaneous heating liability. This provides an opportunity to compare the oxidation potential of different coals.

The study of the experimental results together with their historically known spontaneous combustion record enabled the development of a risk classification system, as shown in Table 1 (8). The results are classified into four groups as very high, high, medium and low risk to indicate their inherent liability to heating.

3.1. Experimental Set-up

The adiabatic apparatus was constructed in a silvered dewar flask of approximately 9 litres capacity, filled with low-temperature oil. Figure 1 shows a schematic diagram of the

Risk Classes	Adiabatic Oxidation Test Results		Risk Rating in Adiabatic Test	Total Risk Rating	Incubation Period (months)
	Initial Ritt of Heating "C/hr	Total Temperature Rbe°C			
low risk	<0.6	<25	1	1-10	>18
medium risk	06-1.2	2.5 -4.5	2	11-20	9-18
high risk	1.2-20	4.5-7.0	4	21-40	3-9
very high risk	>2.0	>7.0	8	>40	0-3

Table 1. Spontaneous Combustion Risk Classification of Coals (8)

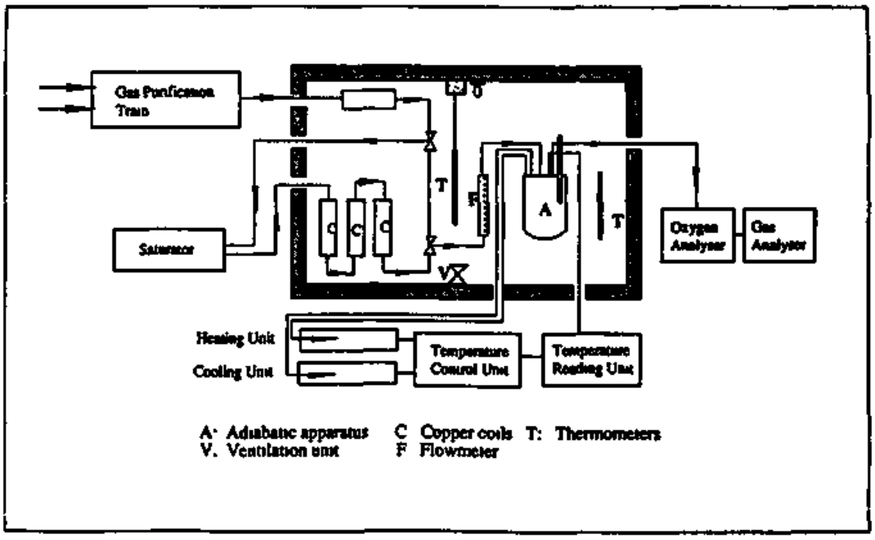

Figure 1 Schematic Diagram of the Adiabatic Oxidation Experimental Set-up

experimental set-up. The design principles of the apparatus are described in detail by Hodges (1). The main design and construction features of the adiabatic apparatus is that, it allows the low temperature oxidation reaction to take place without any significant heat transfer to and from the surroundings. Temperature measurements in the adiabatic apparatus are made by an array of thermocouples.

3.2. Standardised Experimental Conditions

The conditions during the test are designed to be similar to those found in an actual underground mine or coal storage environment. The operating variables such as initial temperature, air flow rate, humidity of air, moisture content of coal and duration of test are standardised in order to produce comparable results for the liability determination.

Since it is accepted that no or little heat exchange occurs between the coal and its immediate surroundings due to poor conductivity, adiabaticity of the apparatus will resemble the actual mine environment Variables are selected either based on previous experience or determined in the laboratory by preliminary tests.

3.2.1 Coal Samples

Coal samples were collected from working faces and sealed as quickly and adequately as possible by using polythene bags. This preserved moisture and excluded air so as to reduce any partial oxidation taking place to a minimum during transportation which may not only cause deterioration of the sample, but also adversely effects the adiabatic oxidation test results. Coal samples obtained were temporarily stored in their original sealings filled with nitrogen in the laboratory. It is considered that possible interaction of oxygen with coal on the surface of the sample can be ignored and will not serious affect the experiment results.

3.2.2 Sample Size

Previous work has indicated that the increase in external surface accompanying reduction of particle size is of minor significance compared with the increase in accessible internal surface. Oxidation experiments carried out on separate samples of the same coal with particle sizes of 420-250 microns and -210 microns showed no significant difference in oxidation rate (23). Consequently, the upper limit of-the particle size of the samples in this study was standardised to be -210 microns and lower limit was not defined due to the actual particles produced by degradation of coal underground also being small.

Samples were prepared one by one as required for the test while the rest were kept in their polythene bags. All the samples were ground to -210 microns and put into small polythene bags with zips and filled with nitrogen. The ground samples were divided into two parts: Some were stored under vacuum for at least 48 hours at room temperatures to dry the specimen and to avoid premature oxidation; the rest were left in the bags for subsequent experiments.

32.3. Initial Test Temperature

It is well known that the initiation of the self-heating of coal is "greatly affected by temperature to which it is exposed. Underground mine temperature mostly depends upon the thickness of the overburden and the characteristics of the atmospheric air entering into the mine. Nevertheless, other factors existing in the mine environment have a significant role over the ambient temperature.

The actual temperature at the face in British coal mines varies, but is usually around 30°C and this was measured between 38-43°C in goaf areas (7). Therefore, an initial test temperature of 40°C was chosen in the test in order to simulate the underground mining environment in an worked-out areas (goaf).

3.2.4. Moisture Content of Sample and Humidity of Air Flow

There are two sources of moisture that need to be considered, namely, the inherent moisture in the coal substance and the moisture associated with the oxygen of the air which is in contact with the coal. It is found that the combination of dry coal and saturated air provide the most reactive test and gave remarkable demonstrations of the propensity of coal to self-ignite and therefore vacuum dry coal/saturated air was chosen as the standard test condition.

3.2.5. Air Flow Rate and Temperature

The rate of spontaneous heating of coal is dependent on the accumulation of heat generated from its oxidation reaction. It is therefore essential that an ideal condition can be created for the accumulation of heat reflecting the heating potential of coals. There are three major problems which should be resolved for the establishment of the ideal accumulation state during the tests, which are:

a. Prevention of heat exchange between coal sample and its surroundings;
b. Provision of sufficient oxygen in order to maintain maximum heat generation;
c. Prevention of heat loss due to convection by excess air.

Prevention of heat exchange between the coal sample and its surroundings is achieved by the use of the adiabatic apparatus. In addition, the air flow (or nitrogen) was firstly allowed to pass through the water bath which was maintained at 40°C, and the oil bath, before entering the sample container. This eliminates the cooling effect which could occur while the stream is passing through the calorimeter. Air supply of 100 ml/min., 200 ml/min. and 300 ml/min. were tried under the conditions of dry coal/saturated air. These tests indicated an air rate at 200 ml/min was ideal to provoke the maximum oxidation of the coal sample.

3.2.6. Experimental Time

The spontaneous combustion process takes weeks and even months due to the slow rate of oxidation of coal. For the present experiment, a test period between 6 to 10 hours is considered sufficient to determine the spontaneous combustion characteristics. The sampling of temperature was taken at 5 minutes interval.

3.2.7. Test Procedure

After the specimen was dried under vacuum for at least 48 hours, a 150 gram of coal sample was placed in the reaction vessel without any compaction. This ensured that there was an uniform distribution of air flow within the sample. A 100 ml/min. dry oxygen-free nitrogen gas flow was allowed to pass through the sample for at least 24 hours to further dry the specimen while preventing any partial oxidation. The test was not ready to proceed until the temperature of whole system was stabilised at 40°C and the sample is sufficiently dried.

Once the system had attained the desired test condition, the nitrogen flow was cut off and a 200 ml/min. saturated air flow was allowed to pass through the coal sample.

Throughout the test, the system was carefully controlled and temperature readings were recorded with time.

4. AN EXAMPLE

D Colliery is a UK based underground coal mine works exclusively in the Thick Coal taking upper leaf and, where faulting permits, a lower leaf. As shown in Figure 2, the Thick Coal is formed from a series of seams. In descending order, they are the Two Yard, Bare Coal, Ryder, Top Nine Feet and Bottom Nine Feet.

The Thick Coal is particularly liable to spontaneous combustion owing to its rank, ambient conditions, oxygen and moisture content, particle size and the presence of trace elements. It has been the usual practice to advance faces in the top section, and then to retreat faces in the bottom section of the seam, as shown in Figure 2. This mining system has been developed from experiences at Collieries working the Thick Coal over a number of years. The new roadways for retreat working are driven in the destressed area below the goaf of the upper working. The system of longwall mining in either the upper section or in the lower one has resulted in major spontaneous combustion fires with consequent loss of districts.

4.1. Experiment Result and Its Application

Samples representing Two Yard, Ryder and Bare Coal were collected from a working face at D Colliery and subsequently subjected to adiabatic oxidation test. The results are given in Table 2, 3 and 4. A plot of temperature vs. time for the three samples is illustrated in Figure 3. These results indicate the following points:

a. All three samples are highly liable to ignite spontaneously and Bare Coal is the most reactive one with IRH = 7.88 °C/hr and TTR = 8.15°C

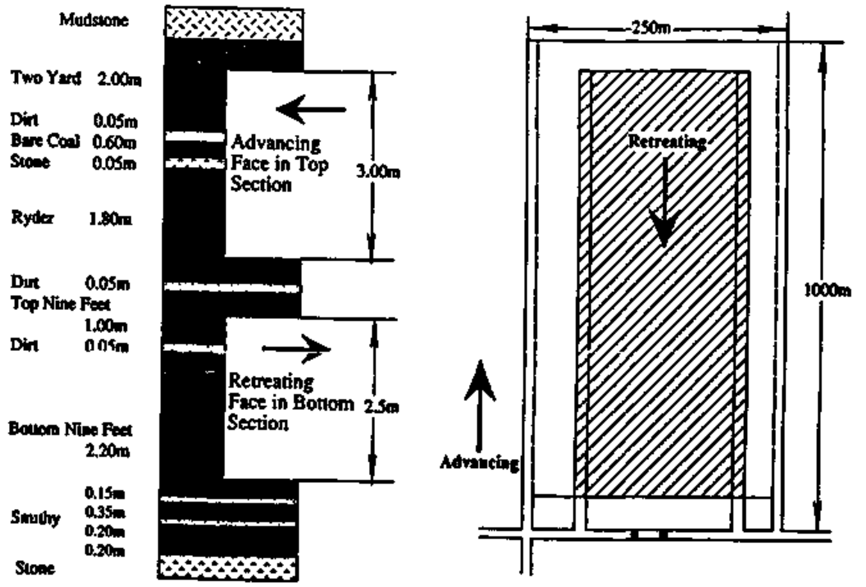

Figure 2. Seam Section and Two-leaf Extraction of the Thick Coal at D Colliery

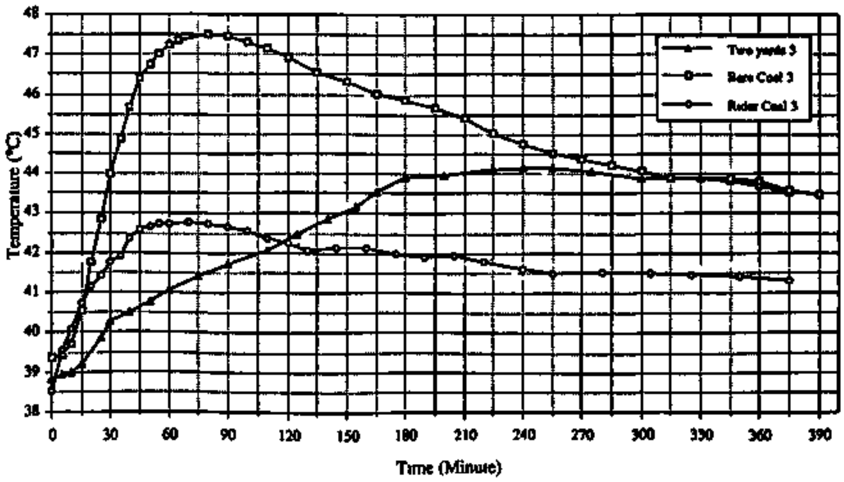

Figure 3. A Plot of Temperature vs Time - Results of Adiabatic Oxidauon Test

Time: 10:15 D»le: Thundıjr, 16 April 1992 Simple: two yanb

	Nal	TCQ	•		Na2	•		No.3	*		No.4	•		NaS	*		No.6	•
•Time (Mi.) *	MV	TCQ	TRCCM)*	MV	TfO	TRfC/H)*	MV	TCO	TRCQH)*	MV	TCQ	TKCC/H)*	MV	TTC)	TSOOH)»	MV	TCQ	TRfOIO*
0.00	1768	38.94	0	1767	39.05	0	1765	38.85	0	1766	38.89	0	1768	40.76	0	1770	39.08	0
5.00	1777	39.14	0.2	1770	39.11	0.06	1769	38.94	0.09	1770	38.98	0.09	1770	40.81	0.05	1770	39.08	0
10.0	1815	39.97	1.03	1788	39.51	0.46	1772	39	0.15	1773	39.05	0.16	1772	40.85	0.09	1772	39.13	0.05
15.0	1860	40.96	2.02	1821	40.24	1.19	1782	39.22	0.37	1777	39.14	0.25	1774	40.9	0.14	1775	39.19	0.11
25.0	1930	4151	3.57	1888	41.72	167	1812	39.88	1.03	1786	39.33	0.44	1780	41.04	0.28	1780	39.3	0.22
30.0	1964	43.25	4.31	1925	4X54	3.49	1831	40.3	1.45	1799	39.62	0.73	1782	41.09	0.33	1791	39.55	0.47
40.0	1976	43.52	4.58	1939	42.85	3.8	1841	40.52	1.67	1808	39.82	0.93	1801	41.52	0.76	1800	39.75	0.67
50.0	1984	43.7	4.76	1953	43.16	4.11	1853	40.78	1.93	1817	40.02	1.13	1810	41.73	0.97	1808	39.92	0.84
60.0	1987	43.76	4.82	1963	43.38	4.33	1867	41.09	124	1827	40.24	1.35	1818	41.92	1.16	1816	40.1	1.02
75.0	1985	43.72	4.78	1971	43.55	4.5	1883	41.44	159	1835	40.41	1.52	1824	42.05	1.29	1821	40.21	1.13
90.0	1979	43.59	4.65	1974	43.62	4.57	1895	41.71	2.86	1844	40.61	1.72	1831	4X21	1.45	1828	40.36	1.28
110	1973	43.45	4.51	1974	43.62	4.57	1912	42.08	3.23	1853	40.81	1.92	1837	42.35	1.59	1832	40.45	1.37
125	1972	43.43	4.49	1978	43.71	4.66	1930	42.48	3.63	1865	41.07	2.18	1841	42.45	1.69	1836	40.54	1.46
140	1979	43.59	4.65	1987	43.91	4.86	1948	42.88	4.03	1877	41.34	2.45	1848	4161	1.85	1841	40.65	1.57
155	2000	44.05	5.11	2004	44.21	5.23	1962	43.18	4.33	1888	41.58	2.69	1855	42.77	101	1846	40.76	1.68
165	2008	44.22	5.28	2016	44.55	5.5	1979	43.56	4.71	1905	41.96	3.07	1860	42.88	2.12	1849	40.83	1.75
ISO	2007	44.2	5.26	2021	44.66	5.61	1996	43.93	5.08	1926	42.42	3.53	1873	43.1*	2.42	1857	41.00	1.92
200	2007	44.2	5.26	2019	44.62	5.57	1998	43.98	5.13	1927	42.44	3.55	1882	43.39	263	1867	41.22	2.14
225	2001	44.07	5.13	2017	44.57	5.52	2004	44.11	5.26	1943	42.79	3.90	1891	43 60	2.84	1875	41.40	232
240	1991	43.85	4.91	2009	44.39	5.34	2007	44.17	5.32	I960	43.17	4.28	1899	43.78	3.02	1882	41.56	248
255	1983	43.67	4.73	2002	44.24	5.19	2006	44.15	5.3	1968	43.34	4.45	1906	43 94	3.18	1884	41.60	2 52
275	1971	43.41	4.47	1990	43.97	4.92	2003	44.09	5.24	1984	43.70	4.81	1919	44.24	3.48	1886	41.64	256
300	1973	43.45	4.51	1988	43.93	4.88	1995	43.91	5.06	1973	43.45	4.56	1917	44.20	3.44	1882	41.56	2.48
3IS	1970	43.39	4.45	1986	43.89	4.84	1994	43.89	5.04	1972	43.43	4.54	1919	44.24	3.48	1895	41.84	176
330	1968	43.34	4.4	1984	43.84	4.79	1994	43.89	5.04	1979	43.59	4.70	1921	44.29	3.53	1895	41.84	176
345	1963	43.23	4.29	1978	43.71	4.66	1990	43.8	4.95	1976	43.52	4.63	1925	44.38	3.62	1896	41.87	179
360	1956	43.08	4.14	1971	43.53	4.5	1985	43.69	4.84	1977	43.54	4.65	1928	44.45	3.69	1895	41.84	2.76
375	1950	42.95	4.01	1965	43.42	4.37	1979	43.56	4.71	1972	43.43	4.54	1930	44.50	3.74	1895	41.84	176

KH = *2.24'Cftu* *TTR* = 5.32°C

Table 2 Results of Adiabanc Oxidation Studies - Two Yards

Time: 11:04 Date: Thursday, 16 April 1992 Sample: Bare Coal

Time (Min)	No.1			No.2			No.3			No.4			No.5			No.6		
	MV	T(°C)	TR(°C/H)	MV	T(°C)	TR(°C/H)	MV	T(°C)	TR(°C/H)	MV	T(°C)	TR(°C/H)	MV	T(°C)	TR(°C/H)	MV	T(°C)	TR(°C/H)
0	17*6	39.33	0	1787	39.49	0	1788	39.35	0	1788	39J8	0	1789	4135	0	1789	39.5	0
5	1807	39.8	0.47	1792	39.6	0.11	1792	39.44	0.09	1791	39.44	0.06	1792	41.32	0.07	1792	39*31*	0.07
10	1887	41.56	123	1823	40.28	0.79	1805	39.73	0.38	1796	39.55	0.17	1794	41.36	an	1793	39*39*	0.09
IS	1984	43.7	4.37	1888	41.72	123	1843	40.56	U l	1819	40.06	0.68	1805	41.62	0.37	1800	39.75	035
20	2073	45.66	6.33	1969	43.51	4.02	1898	41.77	142	1858	40.92	1.54	1829	4117	0.92	1814	40.05	0.55
25	2133	46.98	7.65	2036	44.99	*53*	1947	4185	*33*	1895	41.74	136	1854	4175	1J	1829	40.39	0.89
30	2181	48.03	8.7	2097	46.34	6.85	2000	44.02	4.67	1939	417	3.32	1884	43.44	119	1848	40.81	1.31
35	2205	48 *36*	9.23	2135	47.18	7.69	2040	44.9	5.55	1971	43.41	4.03	1912	44.08	183	1867	4132	1.72
40	2223	48.96	9.63	2169	47.93	8.44	2075	45.67	6.32	2008	44.22	4.84	1942	44.77	3.52	1889	41.71	121
45	2231	49.13	9.8	2194	48.48	8.99	2108	46.4	7.05	2043	44.99	5.61	1975	45.53	4.28	1914	4236	176
50	2231	49.13	9.8	2203	48.68	9.19	2124	46.75	7.4	2062	45.41	6.03	1993	45.95	4.7	1928	4157	3.07
55	2228	49.07	9.74	2209	48.81	9.32	2136	47.01	7.66	2077	45.74	6.36	2010	46.34	5.09	1943	419	3.4
60	2221	48.91	9.58	2212	48.88	9.39	2146	4733	7.88	2093	46.1	6.72	2028	46.76	5.51	1960	43.28	3.78
65	2214	48.76	9.43	2212	48.88	9.39	2152	47.37	8.02	2102	46.29	6.91	2040	47.03	5.78	1971	43.52	4.02
«0	2186	48.14	8.81	2199	48.59	9.1	2158	47.5	8.15	2121	46.71	7.33	2071	47.75	6.5	2004	44.25	4.75
90	2167	47.73	8.4	2183	48.24	8.75	2157	47.48	8.13	2125	46.8	7.42	2082	48	6.75	2019	44.58	5.08
100	2145	47.24	7.91	2169	47.93	8.44	2150	47.32	7.97	2125	46.8	7.42	2089	48.16	6.91	2030	44.82	5.32
110	2128	46.87	7.54	2155	47.62	8.13	2143	47.17	7.82	2121	46.71	7.33	2090	48.19	6.94	2036	44.96	5.46
120	2106	46.38	7.05	2136	47.2	7.71	2132	46.92	7.57	2114	46.56	7.18	2089	48.16	6.91	2040	45.04	5.54
135	2081	45.83	*63*	2114	46.71	7.22	2116	46.57	7.22	2104	46.34	6.96	2083	48.02	6.77	2042	45.09	5.59
150	2061	45.39	6.06	2094	4637	6.78	2105	46.33	6.98	2093	46.1	6.72	2076	47.86	6.61	2040	45.04	5.54
165	2045	45.04	5.71	2078	45.92	6.43	2091	46.02	6.67	2084	45.9	*632*	2071	47.75	6.5	2040	45.04	5.54
180	2036	44.84	5.51	2068	45.7	6.21	2084	45.87	6.52	2077	45.74	6.36	2065	47.61	6.36	2037	44.98	5.48
195	2024	44.58	5.25	2055	45.41	5.92	2075	45.67	6.32	2068	45.55	6.17	2059	47.47	6.22	2034	44.91	5.41
210	2011	44.29	4.96	2043	45.15	5.66	2063	45.41	6.06	2057	45.3	5.92	2048	47.22	5.97	2028	44.78	5.28
225	1996	43.96	4.63	2025	44.75	5.26	2047	45.05	5.7	2042	44.97	5.59	2034	46.89	5.64	2018	44.56	5.06
240	1982	43.65	4.32	2011	44.44	4.95	2034	44.77	5.42	2031	44.73	5.35	2024	46.66	5.41	2011	44.4	4.9
255	1971	43.41	4.08	1999	44.17	4.68	2023	44.53	5.18	2021	44.51	5.13	2016	46.48	5.23	2005	4437	4.77
270	1967	43.32	3.99	1993	44.04	4.55	2016	44.37	5.02	2015	44.38	5.0	2011	46.36	5.11	2002	44.21	4.71
285	1961	43.19	3.86	1986	43.89	4.4	2009	44.22	4.87	2009	44.25	4.87	2006	46.25	5	1998	44.12	4.62
300	1956	43.08	3.75	1979	43.73	4.24	2003	44.09	4.74	2003	44.11	4.73	2001	46.13	4.88	1994	44.03	4.53
315	1949	4192	3.59	1984	43.84	4.35	1995	43.91	4.56	1996	43.96	4.58	1995	46	4.75	1990	43.94	4.44
345	1947	4288	3.55	1969	43.51	4.02	1994	43.89	4.54	2003	44.11	4.73	2010	46.34	5.09	2008	44.34	4.84
360	1940	4173	3.4	1964	43.4	3.91	1991	43.82	4.47	2002	44.09	4.71	2010	46.34	5.09	2012	44.43	4.93
375	1926	4242	3.09	1952	43.13	3.64	1981	43.6	4.25	1994	43.92	4.54	2004	463	4.95	2009	44.36	4.86
390	1922	4233	3.0	1946	43	3.51	1976	43.49	4.14	1989	43.81	4.43	2000	46.11	4.86	2004	44.25	4.75

IRH = 7.88°C/hr   TTR = 8.15°C

Table 3 Results of Adiabatic Oxidation Studies - Bare Coal

Time: 12 23 Date: Thursday, 16 April 1992 Sample:Ryder Coal

	No.1			No.2			No.3			No.4			No.5			No.6		
Time (Min)	MV	T(°C)	TR(°C/H)	MV	T(°C)	TR(°C/H)	MV	T(°C)	TR(°C/H)	MV	T(°C)	TR(°C/H)	MV	T(°C)	TR(°C/H)	MV	T(°C)	TR(°C/H)
0	1756	38.67	0	1755	38.78	0	1751	38.54	0	1741	38.34	0	1740	40.12	0	1739	38.4	0
5	1820	40.08	1.41	1808	39.95	1.17	1791	39.42	0.88	1768	38.94	0.6	1758	40.53	0.41	1750	38.64	0.24
10	1883	41.47	2.8	1853	40.95	2.17	1822	40.1	1.56	1794	39.51	1.17	1780	41.04	0.92	1765	38.97	0.57
IS	1931	42.53	3.86	1891	41.79	3.01	1850	40.72	2.18	1818	40.04	1.7	1802	41.55	1.43	1785	39.41	1.01
20	1961	43 19	4.52	1916	42.34	3.56	1869	41.14	2.6	1835	40.41	2.07	1818	41.92	1.8	1799	39.72	1.32
25	1977	43 54	4.87	1933	42.71	3.93	1883	41.44	2.9	1847	40.68	2.34	1829	42.17	2.05	1811	39.99	1.59
30	1990	43.83	5.16	1947	43.02	4.24	1898	41.77	3.23	1860	40.96	2.62	1841	42.45	2.33	1823	40.25	1.85
35	1994	43.92	5.25	1954	43.18	4.4	1905	41.93	3.39	1866	41.1	2.76	1847	42.58	2.46	1830	40.41	2.01
40	2004	44 14	5.47	1970	43.53	4.75	1926	42.39	3.85	1889	41.6	3.26	1869	43.09	2.97	1846	40.76	2.36
45	2012	44 31	5.64	1979	43.73	4.95	1935	42.59	4.05	1898	41.8	3.46	1876	43.25	3.13	1856	40.98	2.58
50	2012	44.31	5.64	1982	43.8	5.02	1939	42.68	4.14	1902	41.89	3.55	1881	43.37	3.25	1862	41.11	2.71
55	2008	44 22	5.55	1983	43.82	5.04	1942	42.74	4.2	1905	41.96	3.62	1884	43.44	3.32	1867	41.22	2.82
60	2005	44.16	5.49	1983	43.82	5.04	1943	42.77	4.23	1908	42.02	3.68	1886	43.48	3.36	1873	41.36	2.96
70	1992	43.87	5.2	1977	43.69	4.91	1944	42.79	4.25	1910	42.07	3.73	1888	43.53	3.41	1876	41.42	3.02
80	1981	43.53	4.96	1972	43.58	4.8	1942	42.74	4.2	1910	42.07	3.73	1890	43.57	3.45	1880	41.51	3.11
90	1969	43.36	4.69	1963	43.38	4.6	1939	42.68	4.14	1908	42.02	3.68	1891	43.6	3.48	1881	41.53	3.13
100	1953	43.01	4.34	1952	43.13	4.35	1933	42.55	4.01	1905	41.96	3.62	1890	43.57	3.45	1882	41.56	3.16
110	1940	42.73	4.06	1942	42.91	4.13	1926	42.39	3.85	1901	41.87	3.53	1888	43.53	3.41	1881	41.53	3.13
120	1927	42.14	3.77	1932	42.69	3.91	1920	4X26	3.72	1897	41.78	3.44	1886	43.48	3.36	1879	41.49	3.09
130	1918	42.24	3.57	1924	42.52	3.74	1912	42.08	3.54	1893	41.69	3.35	1884	Ï3.44	3.32	1876	41.42	3.02
145	1915	42.18	3.51	1921	42.45	3.67	1914	42.13	3.59	1895	41.74	3.4	1886	43.48	3.36	1880	41.51	3.11
160	1914	42.15	3.48	1919	42.41	3.63	1914	4113	3.59	1897	41.78	3.44	1888	43.53	3.41	1882	41.56	3.16
175	1903	41.91	3.24	1910	42.21	3.43	1908	41.99	3.45	1894	41.71	3.37	1886	43.48	3.36	1881	41.53	3.13
190	1896	41.76	3.09	1904	42.07	3.29	1905	41.93	3.39	1891	41.65	3.31	1885	43.46	3.34	1880	41.51	3.11
205	1896	41.76	3.09	1903	42.05	3.27	1906	41.95	3.41	1893	41.69	3.35	1887	43.51	3.39	1883	41.58	3.18
220	1887	41.56	2.89	1895	41.88	3.1	1899	41.8	3.26	1889	41.6	3.26	1883	43.41	3.29	1879	41.49	3.09
240	1874	41.27	2.6	1883	41.61	2.83	1891	41.62	3.08	1883	41.47	3.13	1879	43.32	3.2	1875	41.4	3
255	1868	41.14	Z47	1878	41.5	2.72	1886	41.51	2.97	1880	41.4	3.06	1877	43.28	3.16	1873	41.36	2.96
280	1872	41.23	2J6	1879	41.52	2.74	1887	41.53	2.99	1882	41.45	3.11	1879	43.32	3.2	1875	41.4	3
305	1871	41.21	Z54	1878	41.5	2.72	1886	41.51	2.97	1882	,41.45	3.11	1879	43.32	3.2	1876	41.42	3.U2
325	1867	41.12	2.45	1875	41.43	2.65	1884	41.47	2.93	1881	41.43	3.09	1879	43.32	3.2	1876	41.42	3.02
350	1866	41.1	2.43	1872	41.37	2.59	1882	41.42	2.88	1880	41.4	3.06	1879	43.32	3.2	1876	41.42	3.02
375	1857	40.9	2.23	1864	41.19	2.41	1876	41.29	2.75	1877	41.34	3	1876	43.25	3.13	1874	41.38	2.98

IRH = 4.23°C/hr TTR = 4.25°C

Table 4 Results of Adiabatic Oxidation Studies - Ryder Coal

b. According to Table 1, Bare Coal, Two Yard and Ryder Coal can be respectively classified as coal with very high risk, high risk, medium risk of spontaneous combustion.

Considering the mining methods being used at D Colliery and the above results, the following conclusions and recommendations can be reached:

1. The major spontaneous combustion problem would come from the upper section of the seam, especially when the Bare Coal and Two Yard are left in the goaf areas. This is in fact a usual practice for roof control at D Colliery and may cause heating trouble not only in the advancing longwall faces in the upper section, but also the longwall retreat faces in the lower section.

2. As indicated in the laboratory tests, it takes relatively less time for the Bare Coal to undergo full oxidation. This may imply that there will be a short incubation period necessary for normal oxidation to advance into the incipient heating stage and special attention must be given at the very beginning of the longwall face, particularly the set-off and finishing line. Any coal left in these areas could cause heatings if sufficient preventive actions are not taken in advance. The face must be planned to start and have relatively smooth run without interruption by holidays or geological disturbances.

3. The short incubation periods are critical requiring more rapid salvage techniques if all the equipment is to be recovered. Salvage has to be planned and organised to be completed as quickly as possible.

4. Rapid advance of the face is the most effective way of overcoming this type of heating, although some temporary control can be achieved by preventing air leakage from the main gate by use of fans and pressure chambers.

5. The laboratory tests confirm the fact that the Thick Coal is particularly liable to spontaneous combustion and Bare Coal is the most reactive part within the seam.

5. CURRENT RESEARCH

The ESSH system was designed to provide support for the engineers at the design and planning stage of new mine sites, stockpiles or shipping operations, by saving time in the task of early identification of potential spontaneous heating risk. The laboratory results play an important role in the correct assessment of a heating potential.

The adiabatic oxidation test has traditionally been conducted manually by experienced personnel. Due to the slow oxidation process of spontaneous combustion, the test requires a consistent level of 'expert' supervision and monitoring. An experiment normally takes 6 to 8 hours to complete, which is time consuming and labour intensive. Moreover, the reliability of the test heavily depends upon the provision of an adiabatic environment by the temperature control unit. It is therefore highly desirable that a computerised system be introduced which allows the experimental results to be automatically fed into the ESSH system during its inferencing process.

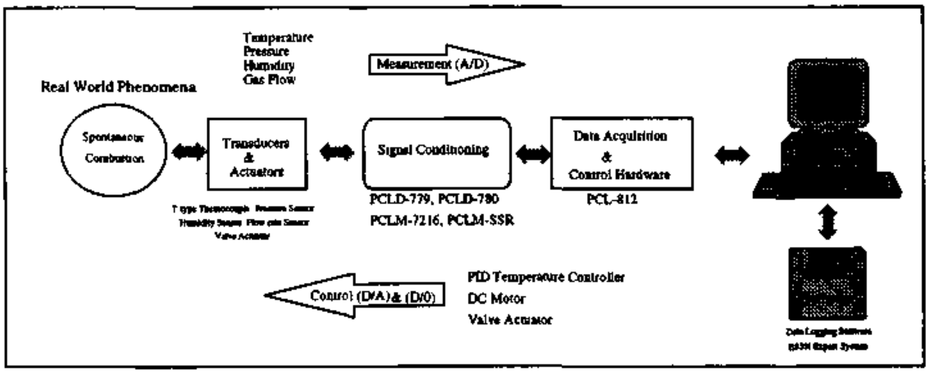

Figure 4. A computerised intelligent system for spontaneous combustion

Present research is therefore directed towards the development of a computerised intelligent system for the assessment of spontaneous combustion. Figure 4 shows an overview of the system. A high performance IBM PC is interfaced with the apparatus which allows real time data acquisition and control. A specialised IC (Integrated Circuit) element is used for signal conditioning, which provides high level linearised output signals with automatic cold junction compensation. A low level software has been developed for data acquisition and control using C++. The expert system ESSH is interfaced with the software and used as an intelligent front end to the apparatus, which enables simultaneous control, monitoring, data collection and storage of the tests. The system is currently under testing and refinement. A more detailed description of the system was given elsewhere (22).

The system could be further used to develop an Intelligent Mine Environmental Monitoring System. Today's Mine Operating Systems (MINOS) for fire detection and environmental monitoring in mines are capable of initiating an alarm. However, since the variation in normal condition for any part of the mine can be quite large, colliery staff are often required to respond to false alarm calls. The setting of alarm levels is clearly of critical importance and must take into account current knowledge of the normal environment.

The performance of the system could be further improved by the addition of Artificial Neural Networks, another technique of AI currently under exploitation in the mineral sector. By using a neural network to 'learn' what are normal combinations of ventilation rate, temperature, gas concentrations etc., for an individual location, such a situation could be avoided. The products of heating trom the adiabatic oxidation tests can be used as inputs to train a neural network to identify the occurrence of a heating at the earliest stage. By combining with a knowledge based system, an Intelligent Mine Environmental Monitoring System could be developed to provide more reliable early detection of spontaneous heatings and mine fires.

6. CONCLUSIONS

In order to minimise or avoid the risk from spontaneous combustion of coal, an important approach is to identify the liability of a coal to heating and thereafter take corresponding preventive actions. Study has demonstrated that the adiabatic oxidation test is able to provide such prior knowledge and assist the mining engineers to reduce the danger of self-heatings in mining operations.

The prediction of the spontaneous combustion potential in a mine requires the knowledge of the inherent liability of coal to self-heating, the geological conditions and mining design parameters. The development of a computerised intelligent system incorporating laboratory appraisal as well as field evidence greatly enhanced the reliability of the risk assessment.

Spontaneous combustion and mine fires continue to represent a major threat to mine safety. The use of monitoring and detection equipment for fire detection is still being developed and evaluated in its use and experience. The pace of technological change has been so rapid that there is no doubt that the adoption of new technology such as Artificial Intelligence into today's mine monitoring and control system will dramatically help the elimination the fire hazard underground.

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