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Experimental studies to evaluate spontaneous heating liabilities of coals: a case study

Spontaneous heating of coal is a major problem worldwide and has been a great concern due to its potential to destroy precious coal resources and cause fire accidents in coal mines. Majority of fires occurring in different coalfields are started by spontaneous combustion of coal. So, extensive research work is being done to characterize the nature and causes of spontaneous heating to prevent its occurrence. In this paper, different properties of coal samples obtained from coal mines under Central Coalfields Limited (CCL) have been evaluated based on: proximate and ultimate analysis, calorific value, FT-IR spectroscopy and DTA. The data obtained was used to compare characteristics of different seams with respect to their tendency towards spontaneous heating susceptibility. From the experimental investigations, it was found that, in general the CCL coals have high ash content, low in moisture (below 2%), and have higher calorific value. The CHNS analysis showed that the sulphur content of the coals is less than 1% in all the cases. Among organic compounds alkane was found to be the most abundant functional group. Based on the transition temperature, it could be inferred that, seam 2 of Sarubera is least susceptible whereas seam 8 of Pindra opencast mine is most susceptible to spontaneous heating.

1. Introduction

Spontaneous combustion is an oxidation reaction that occurs without an external heat source. Spontaneous heating of coal is a major problem worldwide and has been a great concern due to its potential to destroy precious coal resources and cause fire accidents in coal mines. Majority of fires occurring in different coalfields are started by spontaneous combustion of coal. The process leading to spontaneous combustion can be summarized as follows:

- Oxidation occurs when oxygen reacts with the fuel, in this case coal.
- The oxidation process produces heat.
- If the heat is dissipated, the temperature of the coal will not increase.
- If the heat is not dissipated then the temperature of the coal will increase.
- At higher temperatures the oxidation reaction proceeds at a higher rate.
- Eventually a temperature is reached at which ignition of coal occurs.

The nature of the coal must be extensively studied and its tendency to self-heating must be determined which can be used as an aid in preventing spontaneous combustion. In this paper, an attempt was made to carryout few experiments like proximate and ultimate analysis, calorific value, FT-IR spectroscopy and DTA to assess the spontaneous heating risk of CCL coals.

2. Study area

The location of sampling sites are shown in Fig.1

3. Experimental methodology

The proximate and ultimate analysis, calorific value, FT-IR spectroscopy and DTA studies were carried out to assess the spontaneous heating risk of CCL coals. For proximate analysis the guidelines described in Indian Standard IS-1350(part-I), 1984 was followed. In CHNS analysis the absolute percentage of carbon (C), hydrogen (H), nitrogen (N), sulphur (S) is determined. Vario EL model CHNS analyser was used (Fig.2). For determination of calorific value of coal Parr bomb calorimeter(Fig.3) was used. For DTA, SHIMAZDU make DTA-TG(Fig.4) instrument was used. For FT-IR analysis, Perkin Elmer FTIR spectrometer was used (Fig.5 (a) and (b)).

4. Results and discussions

In proximate analysis, the variations of moisture, ash, volatile matter and fixed carbon content of CCL coals is shown in Fig. 6. The variations of calorific value and CHNS in coal samples are presented in Figs.7 and 8 respectively. The variations of transition temperatures are presented in Fig.9. The results of FT-IR are summarized in Table 1.

The transition temperature obtained during DTA can be used as an indicator of spontaneous heating susceptibility of coal. According to previous investigations the spontaneous heating susceptibility of coal has an inverse

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Fig.1 Location of sampling sites

TABLE 1: ORGANIC COMPOUNDS PRESENT IN CCL COALS

Sample name	Alkane	Alkene	Alkyne	Aromatic rings	Phenol and alcohol	Carboxylic acids	Ketones	Aldehydes
Argada 1	Yes	Yes	No	No	No	No	No	No
Argada 2	Yes	Yes	No	No	No	Yes	Yes	No
Kedla 1	Yes	No	No	No	No	No	No	No
Kedla 2	Yes	Yes	No	No	Yes	No	No	No
Pindra 5	Yes	No	No	No	No	No	No	No
Pindra 6	Yes	No	No	No	No	Yes	Yes	No
Pindra 7B	Yes	Yes	No	No	No	No	No	No
Pindra 7C	Yes	No	No	No	No	Yes	Yes	No
Pindra 8	Yes	No	No	No	No	Yes	Yes	No
Pundi 4	Yes	No	No	No	No	No	No	No
Pundi 7	Yes	No	No	Yes	No	No	No	No
Sarubera 1	Yes	No	No	No	No	No	No	No
Sarubera 2	Yes	Yes	No	No	No	No	No	No
Tapeen 8A	Yes	Yes	No	No	No	Yes	Yes	No
Tapeen 8B	Yes	Yes	No	No	No	Yes	Yes	No
Tapeen 8C	Yes	Yes	No	No	No	No	No	No
Topa 4	Yes	No	No	No	No	No	No	No
Topa 5	Yes	No	No	No	No	No	No	No
Topa 6	Yes	Yes	No	No	No	No	No	No
Topa 7	Yes	No	No	No	No	No	Yes	No
Topa 8	Yes	Yes	No	No	No	No	No	No

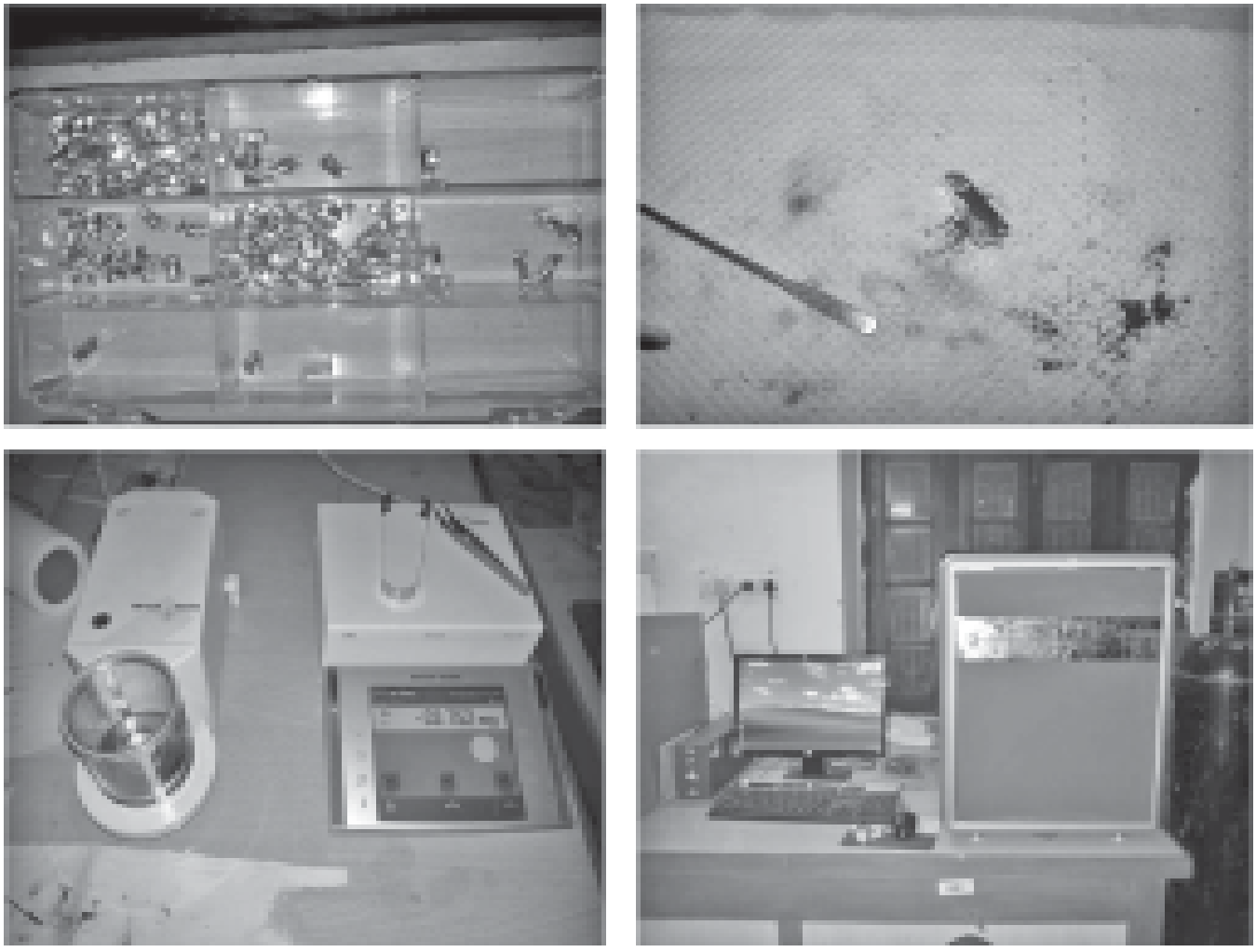

Fig.2 CHNS analyser (Model: Vario EL)

Fig.3 Parr digital bomb calorimeter

Fig.4 Shimazdu DTA equipment

relationship with transition temperature. Spontaneous heating susceptibility α 1/ T, where, T = transition temperature obtained from DTA

So, the lower the transition temperature more susceptible the coal to spontaneous heating [20]. Table 2 ranks the coals according to their spontaneous heating susceptibility.

Different organic functional groups has been identified from the FTIR spectra.

- Alkanes were found in all the coal samples.
- Alkenes were present in all samples except in some samples of Kedla, Pindra and Topa mines
- No alkynes were observed
- There was one occurrence of each of

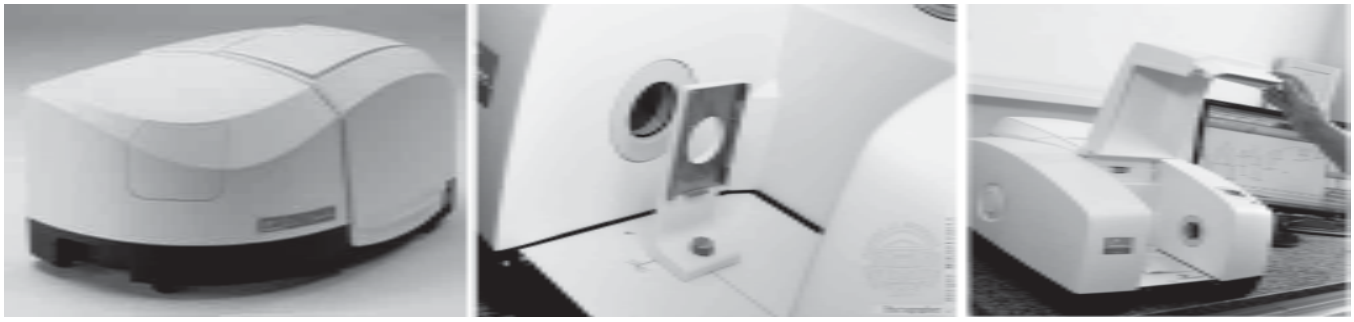

Fig.5(a) Perkin Elmer FTIR spectrometer

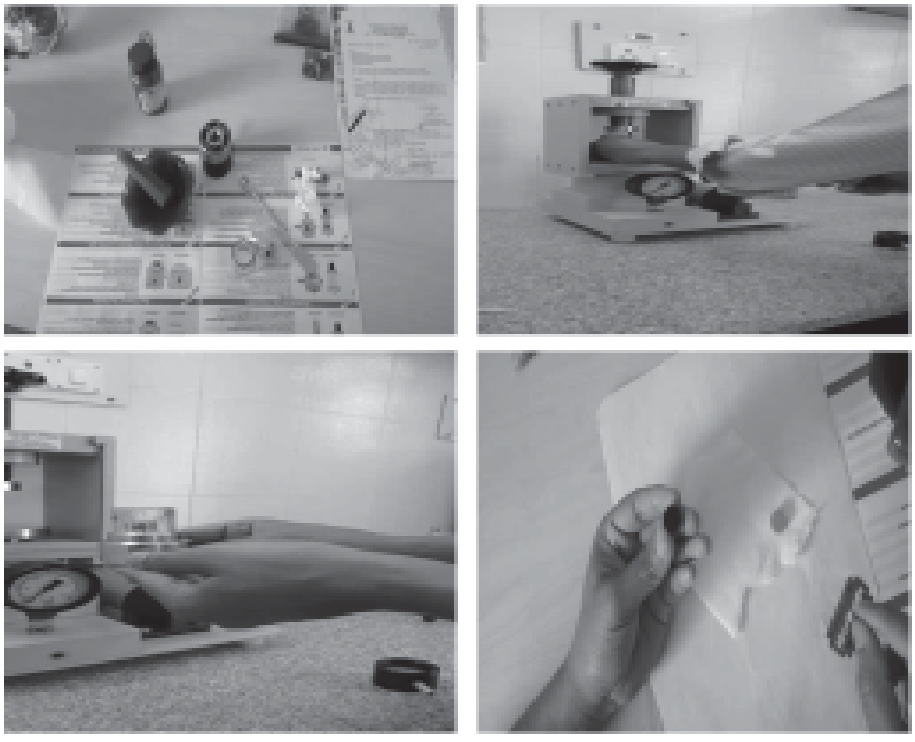

Fig.5(b) Pellet preparation before FTIR

aromatic ring and alcohol in Pundi 7 and Kedla 2 samples respectively.

- Six of the samples contained carboxylic acid and ketone groups from which 3 samples had the lowest values of transition temperature.

7. Conclusions

- From the proximate analysis done on CCL coal samples the following conclusions were derived:
  * The minimum percentage of moisture content was found in sample 'Kedla 1' with a value of 0.91%. The maximum percentage was recorded in case of sample 'Argada 2' with a value of 9.6%.
  * The lowest percentage of ash was 5.9% obtained in case of sample 'Pundi 7'. The highest

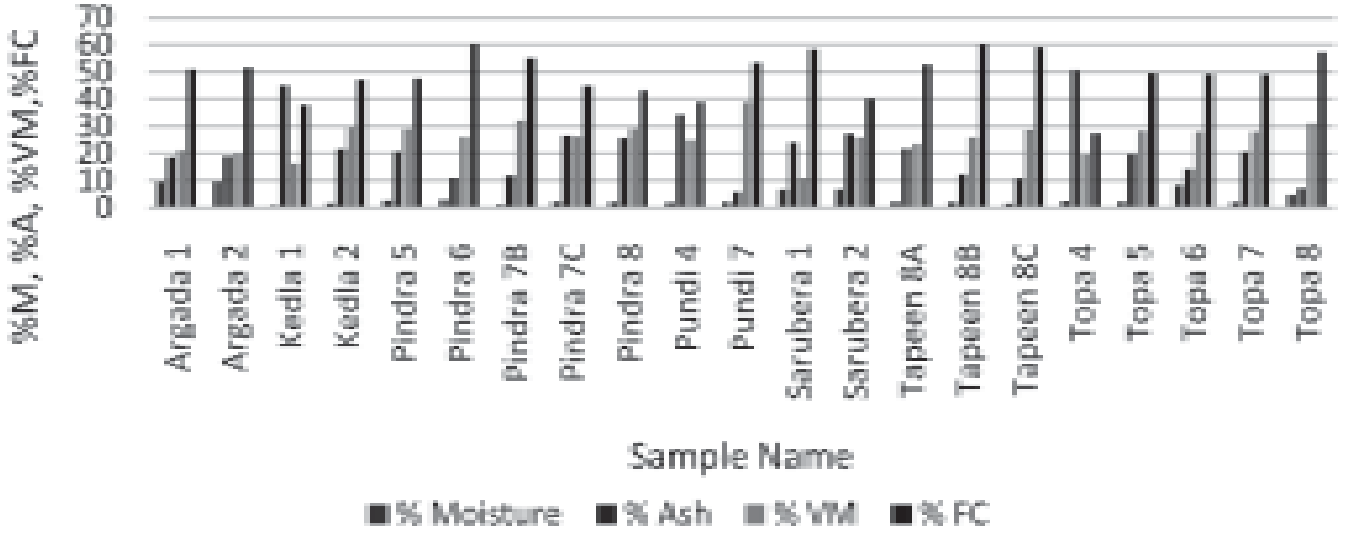

Fig.6 Variation of moisture, ash, volatile matter and fixed carbon content of CCL coals

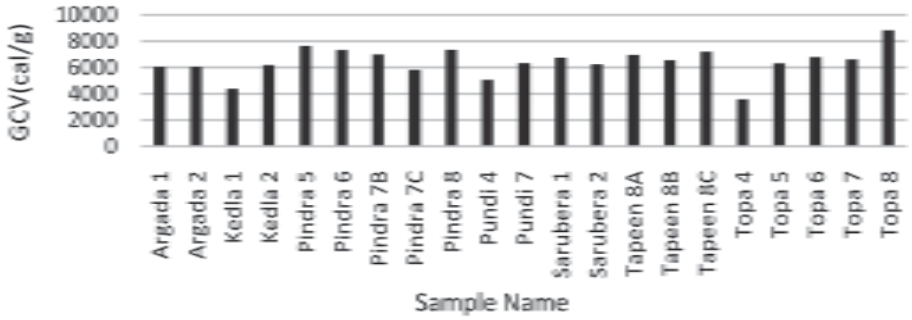

Fig.7 Variation of gross calorific value of CCL coals

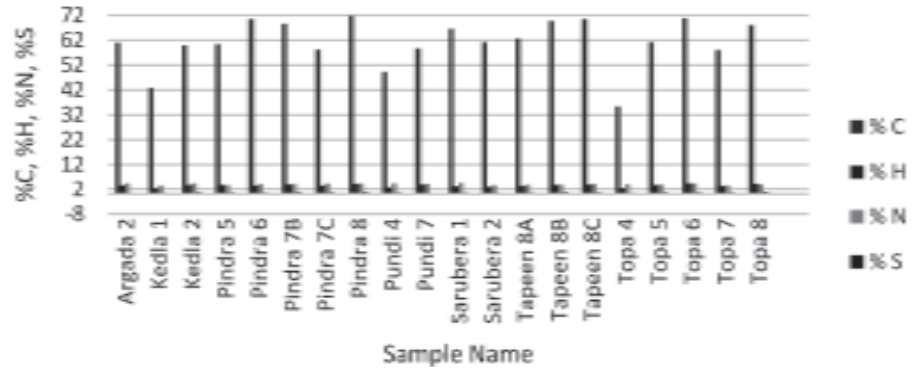

Fig.8 Variation of carbon, hydrogen, nitrogen and sulphur content of CCL coals

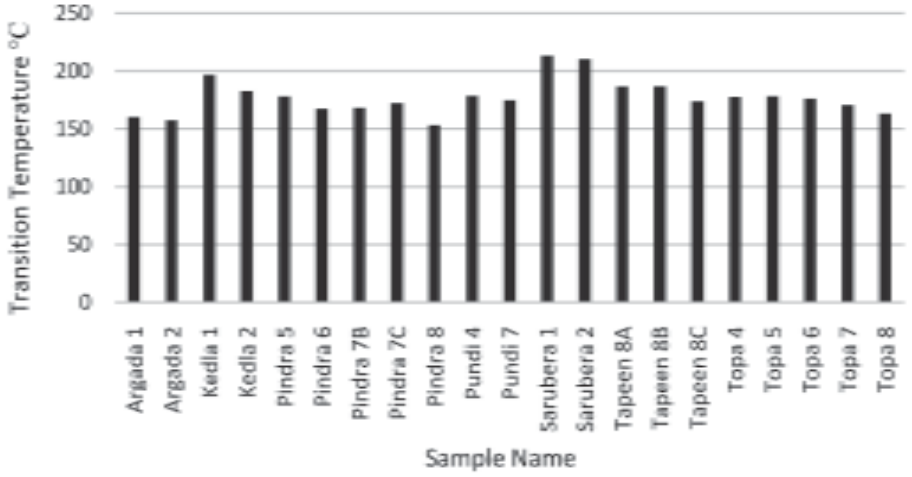

Fig.9 Variation of transition temperature (DTA) of CCL coals

percentage of ash was present in the sample 'Topa 4' with a value of 50.6%.

* The minimum percentage of volatile matter was recorded in case of sample ‘Sarubera 1’ with a value of 10.8% and the maximum value was found in case of 'Pundi 7' at 38.8%.
* The percentage of fixed carbon was found to be lowest at 27.6% in case of sample ‘Topa 4’ and the highest value was obtained to be 60.2% for sample ‘Pindra 6’.

◆ Calorific testing on CCL coal samples provide following conclusions:

* The lowest figure for gross calorific value was 3571.3 Cal/g for sample ‘Topa 4’. The highest figure for gross calorific value happened to be 8821.6 Cal/g in case of sample ‘Topa 8’.
* These figures are supported by proximate analysis as well. Because, at 50.6% ‘Topa 4’ has highest percentage of ash content among the samples with 19.4% volatile matter content and the lowest percentage of fixed carbon with a value of only 27.6%. Similarly, ‘Topa 8’ has only 7.3% ash content, 30.9% volatile matter and 57.2% fixed carbon content.
* So, the maximum gross calorific value in case of ‘Topa 8’ can be attributed to higher volatile matter, fixed carbon content and lower ash content. The opposite is true in case of ‘Topa 4’.

◆ CHNS analysis of coal gave following conclusions:

* The lowest and highest percentage of carbon content were found to be 35.4% in case of ‘Topa 4’ and 71.8% in case of ‘Pindra 8’.
* It was observed that in all the coal samples the percentage of carbon content is higher than the percentage of fixed carbon content. This is because the carbon content obtained from CHNS analysis also includes carbon which is not available for oxidation and does not take part in combustion e.g. carbon present in carbonate minerals.
* The minimum and maximum percentage of hydrogen content were 2.4% in case of ‘Kedla 1’ and 4.4% in case of ‘Topa 6’.
* The lowest value for nitrogen was 3.4% in case of ‘Kedla 1’ and the highest value was 4.8% in case of ‘Argada 1’.
* Percentage of sulphur content was found to be minimum at 0.4% in case of ‘Argada 1’ and maximum at 0.9% in case of ‘Topa 8’.

◆ The following inferences can be drawn from FTIR:

TABLE 2: RANKING OF CCL COALS ACCORDING TO SPONTANEOUS HEATING LIABILITY

Sample name	Transition temperature (C)	Highest susceptibility to spontaneous heating
Pindra 8	153.09	
Argada 2	157.43	
Argada 1	160.18	
Topa 8	163.12	
Pindra 6	167.51	
Pindra 7B	168.1	
Topa 7	170.59	
Pindra 7C	172.36	
Tapeen 8C	173.85	
Pundi 7	174.76	
Topa 6	176.06	
Topa 4	177.62	
Pindra 5	178.02	
Topa 5	178.23	
Pundi 4	178.63	
Kedla 2	182.65	
Tapeen 8A	186.67	
Tapeen 8B	186.81	
Kedla 1	196.66	Lowest susceptibility to spontaneous heating
Sarubera 2	210.36	
Sarubera 1	213.28	

* Alkanes were the most prevalent organic compounds found to be present in all of the coal samples.
* Only 10 samples indicated presence of alkanes.
* Alcohol was observed in 'Kedla 2' and aromatic ring was found in case of 'Pundi 7' samples.
* Six samples indicated presence of carboxylic acid and ketone groups including 'Argada 2', 'Pindra 6', 'Pindra 7C', 'Pindra 8', 'Tapeen 8A' and 'Tapeen 8B'.

- The following conclusions were adopted from the observation of differential thermal analysis:
  * The transition temperature value suggests that among the CCL coal samples 'Pindra 8' is most liable to spontaneous heating and 'Sarubera 1' is least liable to spontaneous heating.

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