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Spontaneous Combustibility Characterisation of the Chirimiri Coals, Koriya District, Chhatisgarh, India

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Abstract

Representative coal samples were collected from different coal seams of the Chirimiri coalfield which covered the entire stratigraphic sequence. These samples were tested for Chemical analysis, Crossing Point Temperature (CPT), Petrography, Infrared studies (IR) and Differential Thermal Analysis (DTA). All the test results vindicated that the aforesaid parameters had a definite relationship with the stratigraphic disposition or the ranks of coal. The low rank coals found as younger seams in the stratigraphic sequence were more prone to spontaneous combustion whereas the higher rank coals found at the bottom of stratigraphic sequence were less prone to spontaneous combustion. Through combustibility characterisation by different tests, it was found that the upper Duman and Kaperti seams placed as younger seams in the stratigraphic sequence are highly prone to spontaneous combustion whereas the lower Karakoh and Sonawani seams seem to be least prone to spontaneous combustion.

Keywords: Chirimiri Coalfield, Crossing Point Temperature (CPT), Infrared (IR) Studies, Differential Thermal Analysis (DTA), Spontaneous Combustion

1. Introduction

Spontaneous combustion of coal is a major hazard in coal mines. It not only causes huge loss of coal resources but also poses a great threat to the environment as well as life of the mine workers.

Fires in coal mines could be anthropogenic, induced from nearby fire affected seams or due to spontaneous combustion which is a common phenomenon. Oxidation of coal is an exothermic process and if the heat generated is allowed to accumulate, the accumulated temperature ignites the coal. This phenomenon is called spontaneous combustion. This is a perennial problem in coal mines everywhere. In India, spontaneous combustion is seen in all major coalfields like Raniganj, Jharia, Karanpura, Bokaro, Ib-valley, Talcher etc. Chirimiri coalfield of Chhatisgarh is no exception.

Fire gases are liberated due to oxidation of coal in sealed off mines. Monitoring fire gases is the main tool for determination of fire status. On that basis different fire indices can be determined for examining the extent of fire and for devising efficient combat methods [1].

Mishra [2] did some work to characterise the petrography of Chirimiri coals. Panigrahi and Sahu [3] contributed significantly on the nature of the spontaneous combustibility in coals and found that seams having crossing point temperature (CPT) in the range of 122˚C to 140˚C are highly susceptible to spontaneous combustion and between 140˚C to 170˚C are moderately susceptible to spontaneous combustion. Further they classified the Chirimiri coals with respect to their spontaneous heating susceptibility by neutral approach. Jain [4] made an assessment of spontaneous heating susceptibility by using Differential Thermal Analysis (DTA) method. Singh *et al*. [1] have devised some fire indices to be used for assessing the spontaneous heating susceptibility.

Many physical and chemical parameters are responsible for spontaneous combustion in coal mines. In this paper, an attempt has been made to characterise the Chirimiri coals for their susceptibility to spontaneous combustion by studying their geology, chemistry, CPT, petrography, IR studies and DTA.

2. General Geology

The Chirimiri coalfield in Koriya district of Chhatisgarh is a part of Son-valley basin. It falls within 23˚08'N and 23˚15'N latitudes and 82˚17'E and 82˚25'E longitudes and covers an area of 130 sq. km. This coalfield has a unique physiographic setting. Unlike other Gondwana basins, this coalfield is marked by high hills with steep scarp faces and deep gorges along the course of stream flows. The mean altitude is about 650 m above mean sea level (MSL) which is unique as compared with other Gondwana coalfields in India. This coalfield forms a plateau amidst the surrounding plains formed by Talchir sediments. The geological map of Chirimiri coalfield is shown in **Figure 1**.

2.1. Stratigraphic Formations

2.1.1. Precambrians

The Precambrian rocks do not crop out in the vicinity of the coalfield. These are found to the northwest side of the area and comprise granites, gneisses and few outcrops of quartzite.

2.1.2. Talchirs

Talchir Formation covers a large tract of the low lying plains surrounding the coalfield on the western, southern and eastern margins. Due to unevenness of the Precambrian basement, varying thickness of the Talchir sediments is preserved at different places. The Talchirs are composed of olive green shale and lemon yellow fine grained sand stone. The sand stone is usually compact with unaltered feldspars. Towards the top of the Talchirs, a transition zone is well defined. This zone is characterised by grey shales interbanded with green shales. The grey shales on weathering develop distinctive greenish shale and break into splintery fragments. The transitional zone contains thick units of light grey, fine to medium grained sandstones which at places are not distinguishable from the Barakar strata.

2.1.3. Barakars

The Talchirs grade upwards into the Barakar Formation which crops out on the highlands and occupies the central part of the basin. It is composed of light grey, coarse grained sandstones and the cement is normally kaolinized feldspar. Lenticular bands of pebbly sandstone are also common. The proportion of fine grained sandstone is less compared to coarse grained sandstone. Ripple drift laminated shales are also found. Coal seams, however, show prominent horizons within the sand stone dominated cycles.

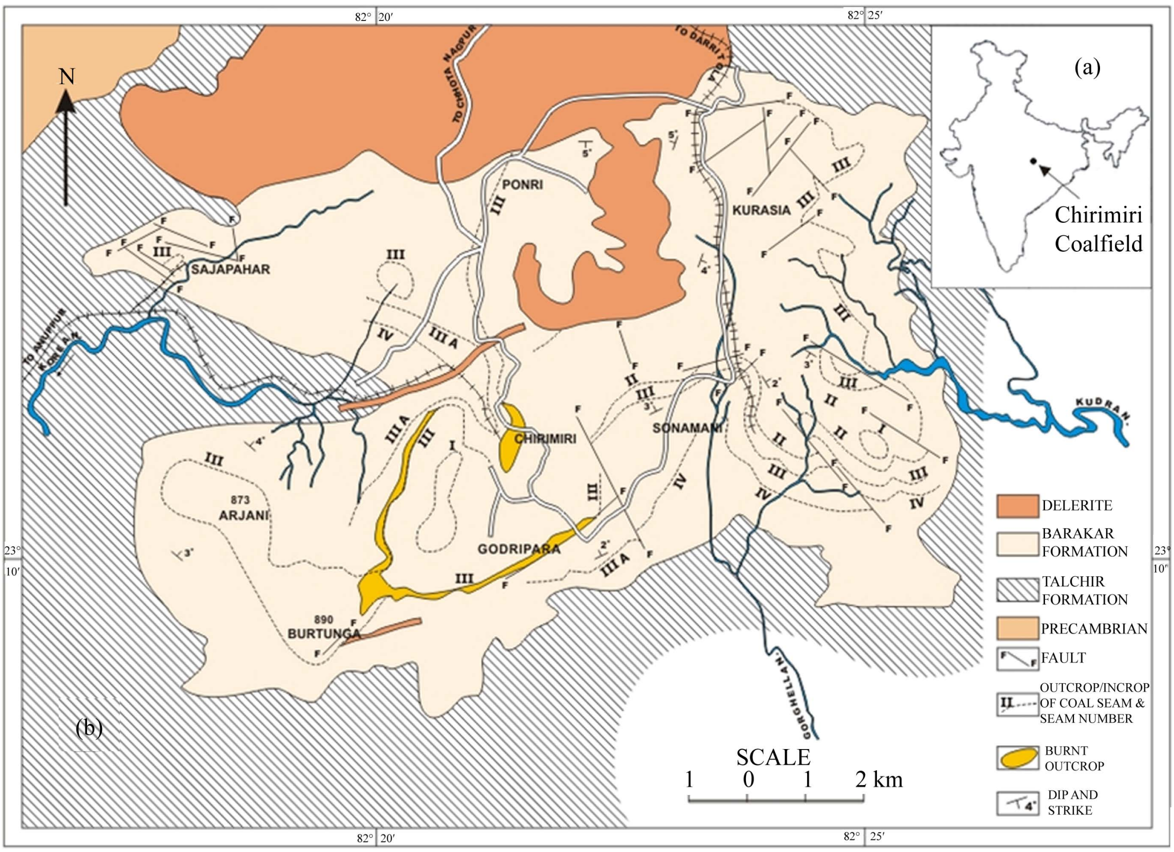

Figure 1. (a) Outline map of India with location of Chirimiri coalfield. (b) Geological map of Chirimiri coalfield (modified after Raja Rao [5]).

2.2. Basic Flows, Dykes and Sills

Basic flows overlie the Barakar sequence and occur on the tops of the hills giving rise to steep escarpments. A prominent sill of dolerite defines the northern boundary of the Chirimiri coalfield which continues further northward into the Sonhat coalfield. The maximum thickness of the sill is reported to be 100 m. A few dykes are also reported.

The stratigraphy of the area is shown in **Table 1**.

2.2.1. Geology of Coal Seams

Chirimiri coalfield is one of the best and extensively developed coalfields in Chhatisgarh. There are seven working collieries in this field, namely Kurasia, Chirimiri, New Chirimiri Pondi Hill (NCPH), West Chirimiri, Duman Hill, North Chirimiri and Koriya colliery.

The most important seam in Chirimiri basin is the Karakoh seam which is exposed in all the blocks. It is locally named as Bijora seam in Koriya colliery and Ghorghella seam in Duman Hill and North Chirimiri collieries. This is a marker seam and co relatable in all collieries. The other co relatable seam is the Sonawani seam which is the lower most seam in Chirimiri coalfield. It is also referred as Kotmi seam in Duman Hill and North Chirimiri collieries. The sequence of coal seams is reflected in **Table 2**.

2.2.2. Chemical Analysis

The chemical analysis of the Chirimiri coals (**Table 3**) reveals that the top most seam known as Duman seam is the lowest in rank whereas the Sonawani seam found at the bottom of the stratigraphic sequence shows highest rank of all seams. Similar results have been proved in Raniganj coalfield [6], Talchir coalfield [7] and Ib-valley coalfield [8]. Gradual decrease of moisture and volatile matter down the stratigraphic sequence is observed.

Table 1. Stratigraphy.

Age	Formation	Lithology
Upper Cretaceous to Eocene	Deccan Trap	Basic flows, dykes & sills (60 m. to 100 m)
Lower Permian	Barakar	Sandstones with subordinate shales and coal seams (230 m to 435 m)
Upper Carboniferous to Lower Permian	Talchir	Predominantly olive green shales and fine grained sand stones (+9 m)
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Precambrians		Granite, gneisses and quartzites

Table 2. Generalised sequence of coal horizons in Chirimiri coalfield.

Seam	Thickness (m)
Duman	0.2 to 2.3
Parting	6 to 50
Kaperti	0.2 to 8
Parting	12 to 44
Karakoh - Bijora - Ghorghella	1.5 to 19.8
Parting	7.0 to 60
Sonawani - Kotmi	0.1 to 7.8
Parting	90 to 130
Talchir Formation	

Table 3. Chemical analysis of the coals of the Chirimiri coalfield.

Sample No.	Name of coal seam	Proximate analysis (wt% air dried basis)				Ultimate analysis (wt% d.m.f. basis)				Calorific value(cal/g)
		Moisture	Ash	V.M.	F.C	C	H	N	O	
Du/4	Duman	7	10.7	34.0(40.5)	48.3(59.5)	77.1	6.4	1.48	15.02	6910
Du/3	Duman	7.6	10.4	32.2(38.5)	49.8(61.5)	81.16	6.5	1.73	10.61	7120
Du/2	Duman	8.4	8.4	30.0(35.4)	53.2(64.6)	80.38	6.74	1.46	11.42	6790
Du/1	Duman	6.7	15.3	30.1(37.4)	47.9(62.6)	81.26	7.18	1.7	9.86	7370
Ka/3	Kaperti	7.5	15.8	29.0(36.5)	47.7(63.5)	81.79	5.86	1.46	10.89	7160
Ka/2	Kaperti	5.1	10.8	28.2(32.7)	55.9(67.3)	85.45	5.46	1.56	7.53	7550
Ka/1	Kaperti	6.2	15.6	25.0(30.6)	53.2(69.4)	86.9	5.48	1.43	6.19	7480
Kk/6	Karakoh	6.6	5.5	30.0(33.7)	57.9(66.3)	82.93	5.62	1.72	9.73	7440
Kk/5	Karakoh	6.7	15.2	26.9(33.1)	51.2(66.9)	81.93	5.61	1.83	10.63	7225
Kk/4	Karakoh	6.3	13.4	27.6(33.3)	52.7(66.7)	82.04	5.09	1.77	11.1	7590
Kk/3	Karakoh	6.3	12.1	28.7(34.2)	52.9(65.8)	82.25	5.57	1.74	10.44	7805
Kk/2	Karakoh	6.5	14.6	29.0(35.6)	49.9(64.4)	84.58	4.78	1.81	8.83	7330
Kk/1	Karakoh	6.4	14.9	29.2(35.9)	49.5(64.1)	78.62	4.79	1.68	14.91	7210
So/3	Sonawani	6.5	10.4	26.3(30.8)	56.8(69.2)	85.15	5	1.83	8.02	7900
So/2	Sonawani	6.1	12.3	26.7(31.7)	54.9(68.3)	82.49	4.85	1.74	10.92	7375
So/1	Sonawani	6	16.1	25.6(31.5)	52.3(68.5)	86.77	4.98	1.83	6.42	8005

N.B. figures in parentheses ( ) indicate values on dry mineral free (d.m.f.) basis

The Duman seam coals are very rich in hydrogen, exceeding the upper limit of Seyler's band [9] by 0.7% to 1.5% (**Figure 2**). The coals of other seams show plottings within ±0.3% deviation from the Seyler's band as observed in other Indian coals [10]. The H/C vs. O/C diagram (**Figure 3**) suggests the formation of type-III Kerogen in terrestrial environment from which the Chirimiri coals have evolved. The evolutionary paths of maceral groups (**Figure 4**) show that normal vitrinites and perhydrous vitrinites along with matured exinites constitute the Chirimiri coals.

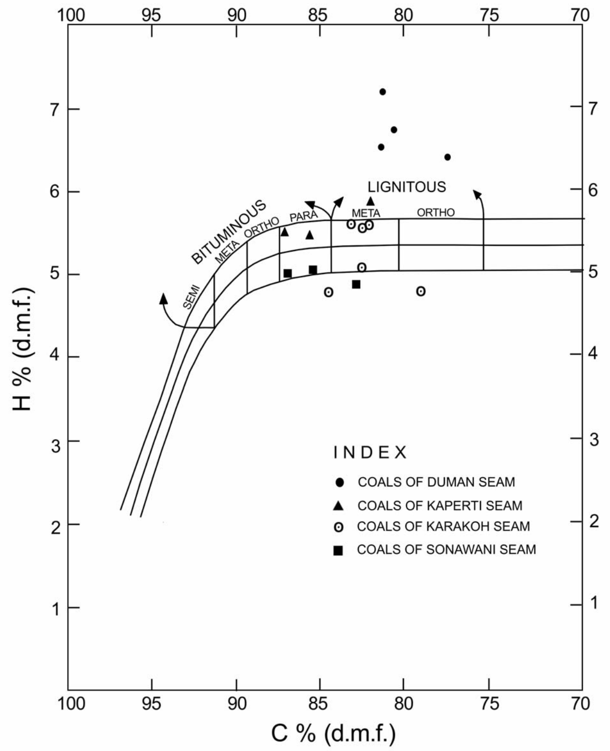

Figure 2. Plots of Chirimiri coals in Seyler's Chart [9].

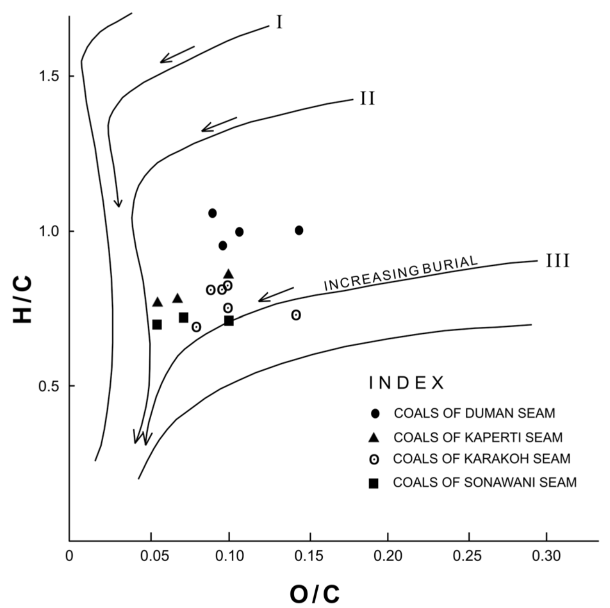

Figure 3. Depositional environment of Chirimiri coals (After VAN KREVELEN [11]).

2.3. Spontaneous Combustibility Characterisation of the Chirimiri Coals

Characterisation of coals towards proneness to spontaneous combustion can be done by measurement of crossing point temperature (CPT) index. The methodology or principle adopted here is heating of the coal sample in an oxidising atmosphere at a definite rate of temperature rise. The apparatus used was CPT apparatus. The coal samples of the Chirimiri coalfield were subjected for CPT index measurement and the results are shown in **Table 4**.

The CPT of all the samples of the Chirimiri coalfield show that the average value of Duman seam coals is 130.1˚C, Kaperti, 135˚C, Karakoh, 143.1˚C and Sonawani 151.3˚C. It is seen that the oldest seam Sonawani has highest CPT of 151.3˚C whereas the youngest Duman seam has CPT of 130.1˚C and there is gradual decrease of CPT from older seam to younger seam.

On the basis of parameters like V.M. and CPT, Chandra *et al*. [12], Niyogi [7] and Behera [8] have classified the coals as follows:

Volatile matter (V.M)	CPT (˚C)	Susceptibility of coal to spontaneous combustion
<36%	155 - 185	Least susceptible
36% - 41%	140 - 155	Moderately susceptible
41% - 46%	125 - 140	Highly susceptible

As per the above classification, the coals of the Chirimiri Coalfield are considered moderately to highly prone to spontaneous combustion.

2.4. Petrography and Its Relation with CPT

The Chirimiri coals were studied for the petrography (**Table 5**). It was found that vitrinite content varied from 12.2% to 76.2%, exinite from 4.6% to 17.0% and inertinite from 17.9% to 81.7% on mineral matter free basis. The average percentage of vitrinite was 44.4%, exinite 10% and inertinite 45.6%. It shows that the Chirimiri coals are inertinite rich.

On seam wise consideration, the top Duman seam contains more vitrinite which gradually decreases towards Sonawani seam. The exinite content does not show any variation in different seams. On the other hand, the inertinite content shows increasing trend towards the

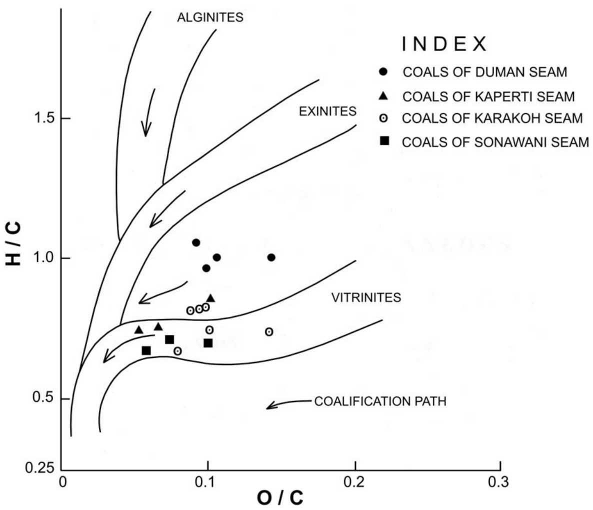

Figure 4. Evolution paths of macerals of Chirimiri coals (After VAN KREVELEN [11]).

Table 4. Crossing Point Temperature (CPT) of the coals of the Chirimiri Coalfield.

Name of the seam	Sample No.	CPT (˚C)	Average CPT (˚C)
Duman	Du/4	129	130.1
	Du/3	125.5	
	Du/2	132.0	
	Du/1	134.0	
Kaperti	Ka/3	135	135
	Ka/2	132	
	Ka/1	138	
Karakoh	Kk/6	137	143.1
	Kk/5	140	
	Kk/4	144	
	Kk/3	142	
	Kk/2	147	
	Kk/1	148.5	
Sonawani	So/3	151	151.3
	So/2	148	
	So/1	155	

Table 5. Maceral composition (volume%) and reflectance (Rm% and Rmax%) of vitrinite of the coals of the Chirimiri coalfield.

Sample No.	Name of coal seam	Vitrinite	Exinite	Inertinite	Mineral matter			Rm%	Rmax%
					Pyrite	Others	Total		
Du/4	Duman	57.3(61.0)	11.5(12.3)	25.0(26.7)	0.8	5.4	6.2	0.52	0.6
Du/3	Duman	58.2(62.4)	11.3(12.1)	23.7(25.5)	1	5.8	6.8	0.55	0.63
Du/2	Duman	59.1(69.2)	6.5(7.6)	19.8(23.2)	0.3	14.3	14.6	0.58	0.68
Du/1	Duman	57.1(60.3)	9.4(9.9)	28.3(29.8)	1.2	4	5.2	0.56	0.69
Ka/3	Kaperti	64.0(76.2)	5.0(5.9)	15.0(17.9)	3	13	16	0.56	0.65
Ka/2	Kaperti	17.4(18.7)	13.9(15.0)	61.5(66.3)	0.2	7	7.2	0.58	0.7
Ka/1	Kaperti	32.6(37.2)	12.7(14.5)	42.3(48.3)	2.8	9.6	12.4	0.6	0.72
Kk/6	Karakoh	42.7(47.3)	11.5(12.7)	36.0(40.0)	1.6	8.2	9.8	0.57	0.67
Kk/5	Karakoh	47.0(54.0)	4.0(4.6)	36.0(41.4)	3	10	13	0.56	0.65
Kk/4	Karakoh	16.3(19.9)	13.9(17.0)	51.6(63.1)	1.4	16.8	18.2	0.59	0.73
Kk/3	Karakoh	38.0(45.7)	6.0(7.2)	39.1(47.1)	1	15.9	16.9	0.58	0.73
Kk/2	Karakoh	25.4(27.6)	8.1(8.8)	58.4(63.6)	2.3	5.8	8.1	0.57	0.67
Kk/1	Karakoh	27.2(29.7)	6.2(6.8)	58.1(63.5)	0.8	7.7	8.5	0.58	0.75
So/3	Sonawani	37.0(41.6)	6.0(6.7)	46.0(51.7)	0.4	10.6	11	0.61	0.75
So/2	Sonawani	42.3(45.1)	11.4(12.2)	40.1(42.7)	0.8	5.4	6.2	0.6	0.75
So/1	Sonawani	10.0(12.2)	5.0(6.1)	67.0(81.7)	1.8	16.2	18	0.61	0.75

N.B. The figures in parentheses represent maceral composition on mineral matter free basis.

bottom seam. Pyrite and other mineral matter vary from 5.2% to 18.2% in which pyrite contributes to 0.2% to 3%.

Correlations have been drawn between vitrinite and CPT (**Figure 5**), exinite and CPT (**Figure 6**) and inertinite and CPT (**Figure 7**). It is seen that CPT decreases with increase of vitrinite and exinite. On the other hand, CPT increases with increase of intertinite. Thus susceptibility to spontaneous combustion of the Chirimiri coals increases with the increase of vitrinite and exinite whereas it decreases with increase of inertinite.

The mean reflectance (Rm%) of vitrinite varies between 0.52% and 0.61% which suggests the Chirimiri coals to be of low rank. The rank increases from the top Duman seam to bottom Sonawani seam in harmony with increasing reflectance value. The maximum reflectance (Rmax%) of vitrinite of the Chirimiri coals is correlated to volatile matter (**Figure 8**) and the elemental carbon

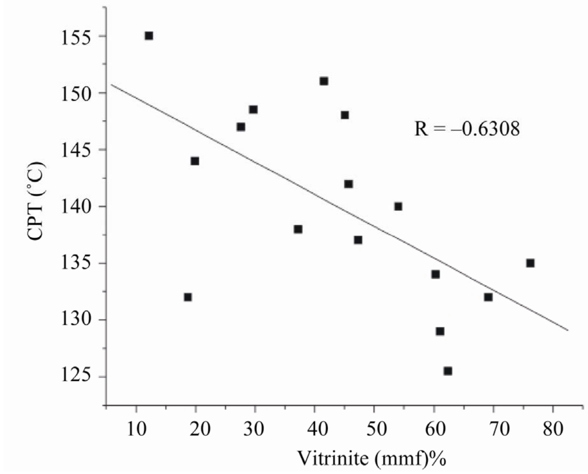

Figure 5. Correlation between vitrinite and crossing point temperature of Chirimiri coals.

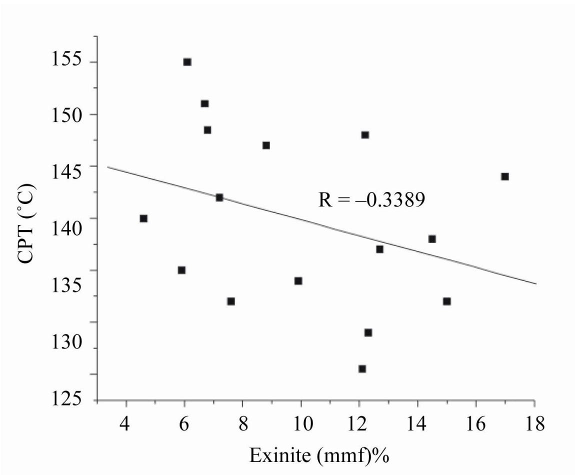

Figure 6. Correlation between exinite and crossing point temperature of Chirimiri coals.

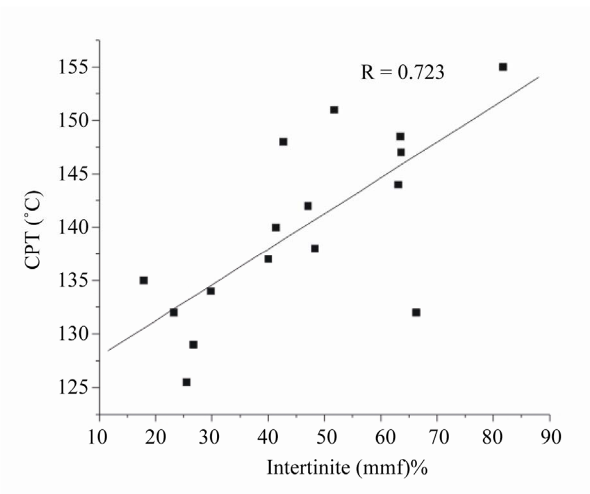

Figure 7. Correlation between inertinite and crossing point temperature of Chirimiri coals.

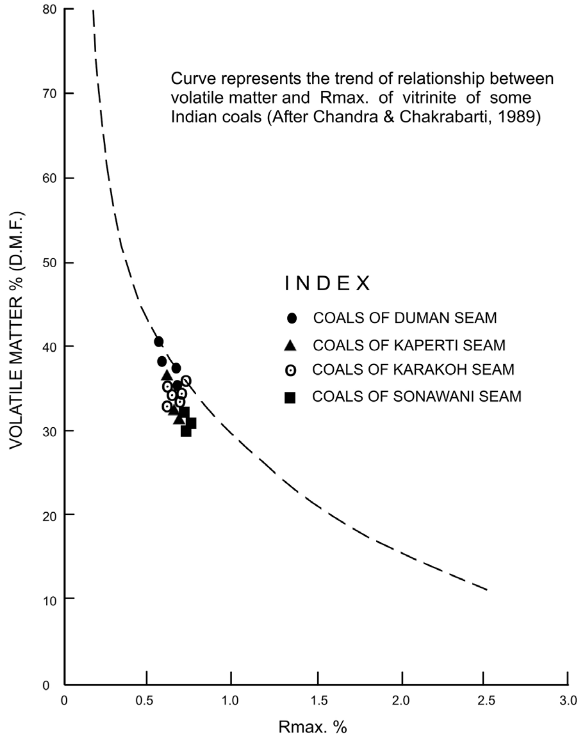

Figure 8. Relation between volatile matter and reflectance (Rmax%) of vitrinite of Chirimiri coals.

content (**Figure 9**). The plots were found plotted close to the curve drawn by Chandra & Chakrabarti [10] for other Indian coals.

2.5. Infrared Studies (IR)

The infrared spectra obtained from the coal samples of different seams of the Chirimiri coalfield were used to interpret the variation of functional groups with reference to spontaneous combustion. The spectra are shown in **Figure 10**.

The broad absorption band between 3700 cm^{-1} and 3000 cm^{-1} is due to the intermolecular hydrogen bonded OH group, present in the moisture content of coal. The broad peak is more prominent in case of Duman seam and Kaperti seam than the Karakoh and Sonawani seam. It indicates high moisture absorbing capacity of the Duman and the Kaperti seam. Nandi *et al*. [13] have concluded earlier that the amenability of a coal to self heating as indicated by lower crossing point temperature is due to hydroxyl groups of the coal structure. Thus (OH) content could play an active role for high susceptibility of spontaneous combustion of the Duman and the Kaperti seams. Main peaks are located around 3400 cm^{-1} in almost all samples. Hydrogen bonded NH group may also contribute partly to the intensity of the band at 3300 cm^{-1}.

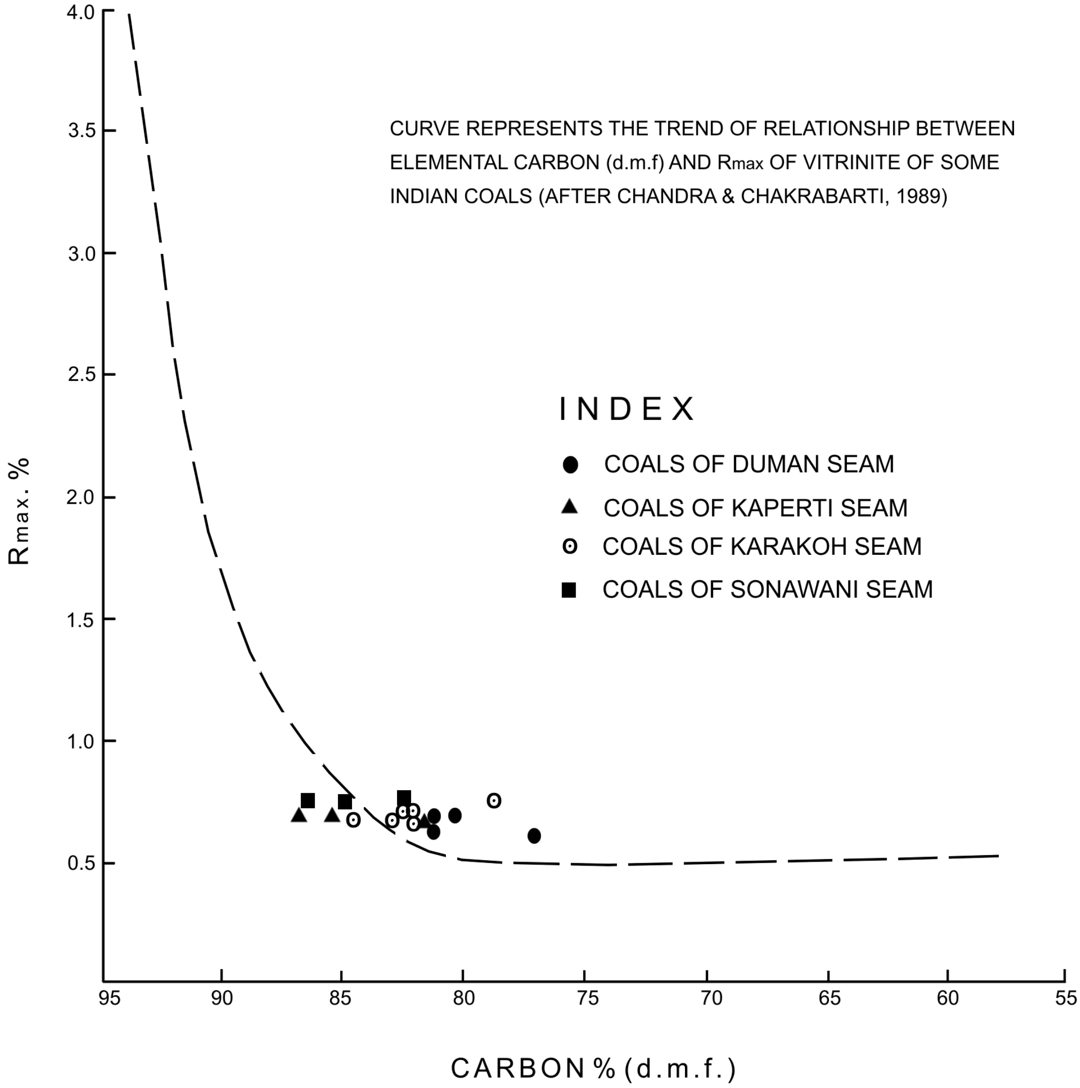

Figure 9. Relation between elemental carbon and reflectance (Rmax%) of vitrinite of Chirimiri coals.

Two sharp but small peaks appear in the region between 3000 cm^{-1} and 2800 cm^{-1}. Most of the coal samples show characteristic absorption at 2920 ± 10 cm^{-1} and 2850 ± 10 cm^{-1}. These spectral bands indicate the presence of aliphatic CH, CH_2 and CH_3 groups [14]. These aliphatic absorption bands are stronger in Duman and Kaperti seams and less intense in Karakoh and Sonawani seams. This type of aliphatic chains also occurs at 1450 ± 10 cm^{-1}. The intensities of these bands in different seams vary in the same fashion as mentioned above.

The 1600 ± 10 cm^{-1} absorption band corresponding to the double bond stretching variation of aromatic C = O, is the most spectacular among all the spectra. The coals of Duman and Kaperti seams show stronger absorbance than the coals of other seams. Choudhury *et al*. [15] established that higher the aromatic content, the faster is the rate of auto-oxidation; hence lower the crossing point temperature. Thus a higher content of aromatic C = O could be responsible for susceptibility to spontaneous combustion of Duman and the Kaperti seams.

The peaks at 1020 ± 10 cm^{-1} occur due to presence of kaolinite or clay minerals containing large amount of kaolinite. Sharp peaks at 600 cm^{-1}, 530 cm^{-1}, 460 cm^{-1} and 340 cm^{-1} are also indicative of the presence of mineral matter.

2.6. Differential Thermal Analysis

The Differential Thermal Analysis (DTA) technique has been proved to be useful to assess the proneness of coal to spontaneous combustion. It is the rate of rise of the heat evolution of coal during aerial oxidation which otherwise controls the proneness to spontaneous combustion.

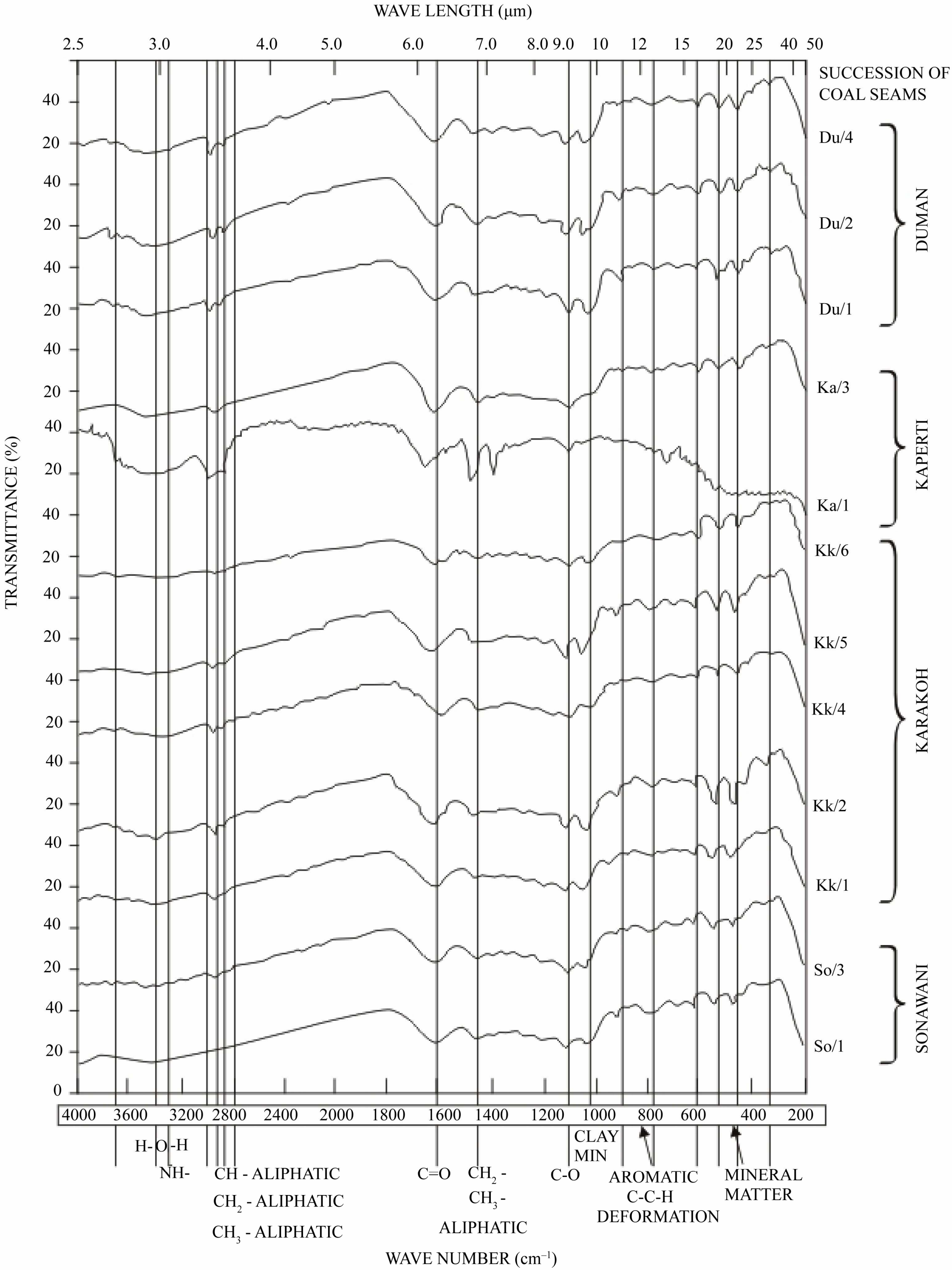

Figure 10. Infrared spectra of Chirimiri coals.

Chandra *et al*. [12] used this technique to assess the degree of proneness to spontaneous combustion in Raniganj coals. Stott & Baker [16] observed that in DTA, initial stage of spontaneous heating of coal is due to evaporation which leads to cooling effect, but the exothermic reaction due to oxidation soon gains ground. Banerjee & Chakraborty [17] studied DTA on coal and found that at stage-I, the reaction is predominantly endothermic due to the release of moisture, but after sometime the reaction becomes exothermic at stage-II due to oxidation. The rate of rise of heat evolution in stage-II process is much lower if the coal is poorly combustible. Banerjee [18] further observed that in DTA the degree of cooling in stage-I is directly proportional to inherent moisture content, but subsequent exothermic reaction follows due to oxidative heating. Banerjee *et al*. [19] further concluded that oxidation kinetics in DTA studies facilitates air entry due to opening up of active centres in the surface of coal. Chandra *et al*. [12] and Behera & Chandra [20] applied DTA technique to evaluate the degree of proneness to spontaneous heating of coal in Raniganj and Ib-valley coalfields respectively.

The experimental results of the DTA of the Chirimiri coals are shown in **Table 6**. The thermograms are shown in **Figure 11**. The DTA reveals that phase transformation due to dehydration of the coal samples of the Sonawani seam and Karakoh seam numbered as So/1, So/3, Kk/2, Kk/4 and Kk/6 showed endothermic peaks in temperature range of 104˚C to 116˚C, but the coal samples of the Kaperti seam and the Duman seam numbered as Ka/1, Ka/3, Du/1, Du/3 and Du/4 showed peak maxima between 100˚C and 106˚C.

A close scrutiny of the thermograms shows that there is gradual variation in the bulging nature of these endothermic peaks vis-a-vis the stratigraphic sequence. The bulging in case of Sonawani and Karakoh is greater compared to those of Kaperti and Duman seams. The second endothermic peaks are due to the combustion of volatiles or degasification. For Sonawani and Karakoh, the peak maxima are found between 400˚C and 415˚C, whereas for the samples of the Kaperti and the Duman, the peak maxima are in between 390˚C and 410˚C. The exothermic peaks due to the combustion of fixed carbon are found in the temperature range of 455˚C to 490˚C in the samples of Sonawani seam and the Karakoh seam whereas for the samples of Kaperti and the Duman seams, the peaks range from 455˚C to 495˚C.

A comparison of DTA peak temperatures and the corresponding crossing point temperatures is also shown in **Table 6**. A graphical relation between the CPT and the first DTA endothermic peak temperature is shown in **Figure 12**.

2.7. Correlation Co-Efficient for DTA and CPT

The correlation co-efficient between two parameters such as DTA and CPT was calculated and the best fit line was drawn (**Figure 12**). The r value of these two parameters was found to be 0.9192 and the‘t’ value was calculated by using the formula t = r $\frac{\sqrt{(n-2)}}{\sqrt{(1-r^2)}}$ where t = test for significance, r = correlation co-efficient and n = number of samples used. The calculated t value was found to be 6.6023 which is greater than the tabulated value (2.4469 at 5% level of significance). This vindicated that the relation between these two parameters is significant. As the CPT increases so also the DTA endothermic peak temperature.

2.8. Correlation Co-Efficient for Vitrinite and CPT

Correlation between vitrinite and CPT has been shown in **Figure 5**. The t value was calculated to be 3.0418 which is greater than the tabulated value (2.1448), hence significant.

Table 6. Comparison of DTA vis-a-vis CPT of the coals of the Chirimiri coalfield.

Sample No.	Name of coal seam	DTA - Peak Temperature (˚C)			CPT (˚C)
		Endothermic 1st	Endothermic 2nd	Exothermic	
Du/4	Duman	106	390	470	129
Du/3	Duman	100	390	460	125.5
Du/1	Duman	100	410	475	134
Ka/3	Kaperti	105	400	495	135
Ka/1	Kaperti	106	400	455	138
Kk/6	Karakoh	104	400	455	137
Kk/4	Karakoh	110	415	490	144
Kk/2	Karakoh	112	410	480	147
So/3	Sonawani	114	410	485	151
So/1	Sonawani	116	410	460	155

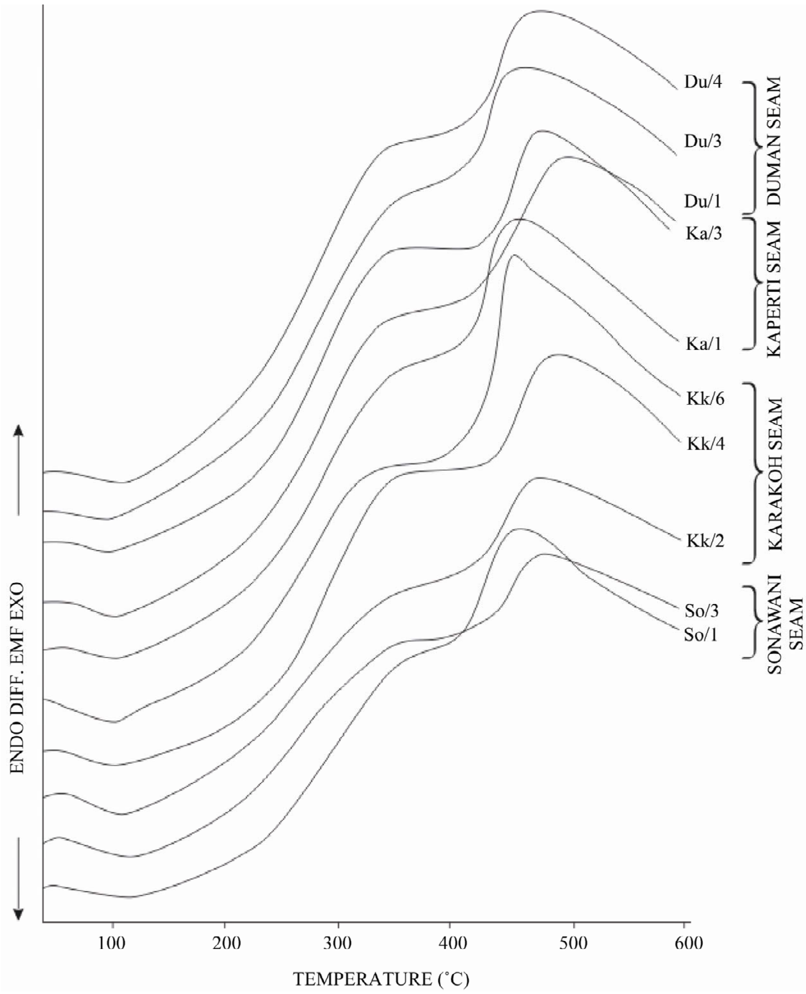

Figure 11. DTA thermograms of Chirimiri coals.

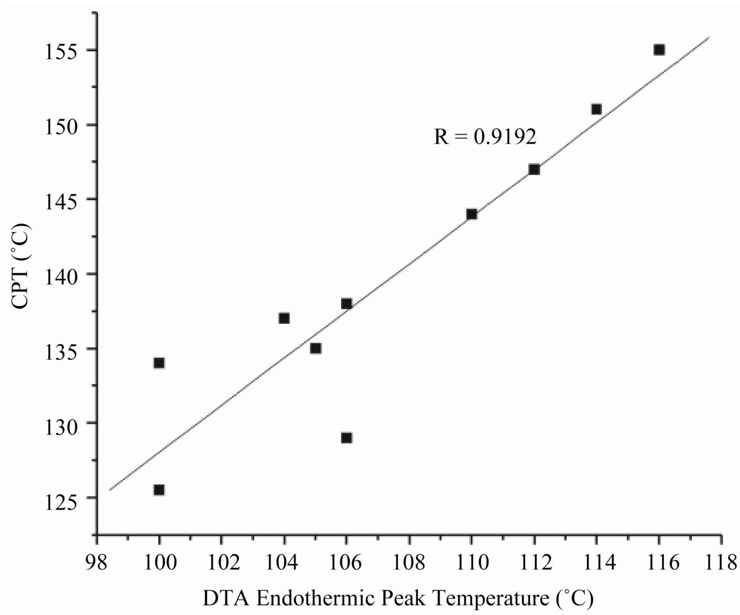

Figure 12. Correlation between DTA endothermic peak temperature and crossing point temperature of Chirimiri coals.

2.9. Correlation Co-Efficient for Exinite and CPT

Correlation between exinite and CPT has been shown in **Figure 6**. The calculated value of t was found to be 3. 6381 and the tabulated value for t is 2.1448, hence significant.

2.10. Correlation Co-Efficient for Inertinite and CPT

Correlation between inertinite and CPT was drawn in **Figure 7**. The calculated value of t was found to be 3.9157 and the tabulated value for t is 2.1448, hence significant.

3. Conclusions

From the foregoing discussions, the following conclusions are drawn.

1) Unlike other lower Gondwana coalfields, the Chirimiri coalfield is located in a different physiographic set up, i.e., at an elevation of 650 m from MSL.

2) The degree of proneness to spontaneous combustion of the coals is related to stratigraphy or rank of the coal which was proved by the study of different parameters.

3) The study of volatile matter and crossing point temperature reveal that the Chirimiri coals are moderate to highly prone to spontaneous combustion.

4) Petrographic study proves that the degree of proneness to spontaneous combustion increases with the increase of vitrinite and exinite, but decreases with the increase of inertinite content.

5) Infrared studies prove that the top Duman and Kaperti seam coals show stronger absorbance than the coals of other seams. Hence, these seams are relatively more prone to spontaneous combustion as compared to the bottom Karakoh and Sonawani seams.

6) The DTA studies used to assess the spontaneous combustibility character show that the first endothermic peak temperature range for Karakoh and Sonawani seams is 104˚C to 116˚C whereas that for Kaperti and Duman seams is 100˚C to 106˚C. Hence, the Kaperti and Duman seam coals are highly prone to spontaneous combustion.

7) Correlation co-efficients of CPT with DTA, CPT with vitrinite, CPT with exinite and CPT with inertinite were found to be significant. Therefore, lower the CPT, higher is the tendency to spontaneous heating susceptibility.

8) All parametrical tests suggest that the proneness to spontaneous heating is related to the rank of coal.

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