R. P. SINGH
S. K. RAY
A. K. SINGH
N. K. VARMA
and
N. SAHAY

Studies on spontaneous heating behaviour of coal

Spontaneous heating of coal may endanger the safe operation of underground and opencast coal mines. In India, statistical data indicates that about 70 per cent of mine fires/heating are caused due to spontaneous heating. To deal with spontaneous heating problems in mines, sufficient knowledge about the oxidation characteristics of coal on laboratory scale is essential. Based on the above fact, present study has been carried out in the laboratory using coal samples of four different Indian coal seams. 40 gram coal sample of -40 mesh size was heated in a reaction vessel at a constant airflow rate of 90 cc/min under the temperature range from 40 to 300°C. Gas samples were collected from reaction vessel and were analysed in a microprocessor based gas chromatograph. The analysis results indicate that the emission of CO started from 40°C in all the coal samples and concentration of CO increases with increase in temperature and the O_2 concentration follow the opposite trend. Emission of hydrocarbons started only after a temperature of 120°C. Emission of C1-C4 hydrocarbons may be utilised to assess the status of fire in the sealed panels. The study also revealed that CO is the best indicator for early detection of spontaneous heating for Indian coals.

Introduction

Spontaneous combustion of coal is one of the important factors, which may endanger the safe operation of underground and opencast coal mines. In India, statistical data indicates that about 70 per cent of mine fires/heating are caused due to spontaneous combustion of coal which may lead to huge loss of property and some times precious lives.

Spontaneous combustion is a very complicated phenomenon and governed by several factors like temperature, airflow, moisture, oxygen concentration, strata condition, chemical composition and coal structure. Generally, it occurs during extraction, highpressure differential across pillars, sluggish ventilation and storage of coal in large quantity.

Messrs. R. P. Singh, S. K. Ray, A. K. Singh, N. K. Varma and N. Sahay, Scientists, Central Mining Research Institute, Barwa Road, Dhanbad 826 001, Jharkhand

To deal with early detection and control/combat of such endogenous fires sufficient knowledge about spontaneous heating property of coal is required on laboratory scale.

The process of oxidation that occurs in coal seam are accompanied with emission of various gases like CO, CO_2, H_2, CH_4 and higher hydrocarbons and all are temperature dependent. Emission of various gases at varied temperature may give the adequate information about the various stages of spontaneous heating and state of fire also.

The chromatographic analysis of gases emitted during externally heated coal samples in the temperature range between 40°C to 300°C under airflow may be able to define the spontaneous heating property of coal.

Four coal samples from different seams were selected to study the spontaneous heating property of coal. Each coal sample separately heated in a reaction vessel made of brass at constant airflow rate of about 90 cc/min under the temperature range between 40 to 300 °C. The gas samples were collected from the reaction vessel and analysed in microprocessor based gas chromatograph. The paper highlights the instrumentation system, experimental procedure and important findings and its interpretation.

Instrumentation

The instrumental set-up to perform the above study may be explained into following heads.

1. Device for thermal oxidation of coal
2. Chromatographic analysis of gas samples

Device for thermal oxidation of coal

The device consist of microprocessor based electrical furnace having heating chamber of 450 x 400 x 400 mm (H x W x D) internal cross section. A 150mm long 37.5mm (ID) 4mm-thickness reaction vessel made of brass was fitted in the heating chamber of electric furnace. A net less than 0.2 mm dia. pore size for stabilising the air flow through the vessel was fitted at the lower end of the vessel which was connected with copper tube for air inlet fitted with air flow meter to measure the air flow rate. The upper end of the vessel was connected to a copper tube and the other end was connected through a suction pump fitted with two-way stop cork to regulate the airflow and for collection of gas samples. The coal sample to be studied was placed in the reaction vessel and a thermocouple was inserted in the coal to measure the coal temperature. The vessel was placed inside the heating chamber for heating purpose. The temperature of heating chamber can be measured with thermocouple and regulated through programmable temperature controller. The heating chamber temperature and coal temperature can be displayed on the programmable controlled panel. The complete system is shown in Fig. 1.

CHROMATOGRAPHIC ANALYSIS OF GAS SAMPLES

Chromatographic method for analysis of gas samples is widely accepted technique.

The main advantage of the technique is that it can analyse number of samples within short span of time up to PPB range with optimum accuracy. Only 5-10 cc gas sample is required for complete analysis. Gas chromatograph model-9100 was used for the purpose and complete analysis has been done in three different mode using FID and TCD detector. It is worthwhile to mention here that the gases like nitrogen, hydrogen and zero air required to run the chromatograph were supplied from gas generators. The analysis of gases like CO, CO_2, H_2, O_2, CH_4, and C1-C4 hydrocarbons were done in three different analytical modes of gas chromatography. Details for all three modes are given below.

Mode-I for analysis of CO, CO_2 and CH_4

Detector	- Flame Ionisation detector with catalytic converter (methaniser)
Column	- Porapoque-N
Carrier gas	- Hydrogen
Flow rate	- 20 cc/min
Flame generation	- Hydrogen + zero air
Oven temperature	- 40°C

Mode-II for analysis of hydrogen and oxygen

Detector	- Thermal conductivity detector
Column	- Molecular sieve
Carrier gas	- Nitrogen
Flow rate	- 30 cc/min
Oven temperature	- 30°C

Mode-III for analysis of C1 to C4 Hydrocarbons

Detector	- Flame Ionisation detector
Column	- Porapoque-N + porapoque-Q (joint column)
Carrier gas	- Hydrogen
Flow rate	- 20 cc/min
Flame generation	- Hydrogen + zero air
Oven temperature	- 80°C

Methodology for experimentation

40 gm coal sample of (- 40 mesh) size was kept in the reaction vessel and it was placed in the heating chamber vertically. The lower portion of the vessel was connected with 6 mm dia copper tube fitted with flow meter to supply required quantity of fresh air through the coal sample. The upper end of the vessel was connected to another copper tube of same diameter and the other end of this tube was connected with a suction pump fitted with a T shaped stop cork to regulate the air flow and collect the gas samples.

After fitting the vessel filled with coal sample in the heating chamber and establishing the airflow to the extent of 90-cc/ min through the vessel, heating was started at the rate of 1°C/min. Collection of gas samples was started from 40°C to 300°C at every 10°C interval.

Analytical techniques

The analysis of gas samples were carried out with the help of gas chromatograph model-9100 having Netwin computer software for graphical representation. Before conducting the sample analysis standardization of gas chromatograph is being carried out by creating a standard method file with the help of calibration gases. It may be noted here that for each mode of analysis as mentioned earlier, standard method files are to be created separately. The analysis may be interrupted due to power failure or any breakdown of any parts of the set up. In such cases a fresh calibration of the system often calls for otherwise it will lead to erroneous result.

After creating a standard method file for a particular mode the samples were analysed by injecting the gas samples through the injection loop of the chromatograph.

Results and discussion

Four coal samples from different coal seams of the country were tested in the laboratory. Methodology adopted for oxidation of coal samples and its analysis has already been discussed in earlier paragraphs. The results have been depicted through Figs. 2-5 and Tables 1-5. Figs. 2, 3, 4 and 5 represent the variation of CO, CO_2 and O_2 concentration with temperature from coal samples of Jambad seam, Dobrana seam, King seam and MVK-5 incline mine respectively. From Fig. 2 it is evident that the CO emission started at a very low temperature (40°C) and gradually increases to a value of about 1% at a temperature of 200°C. The CO_2 concentration also increases with temperature and at 200°C its value was about 12.50%. The sharp increase in CO concentration was noticed from a temperature of 140°C. The oxygen concentration decreases with temperature and came down to 6% at 200°C. The value of O_2 and CO_2 becomes equal (9.5%) at a temperature of about 170°C. Fig. 3 indicates that the emission of CO started at 40°C and gradually increases with temperature. The emission of CO becomes faster at a temperature of 120°C. The concentration of CO and CO_2 was very low in comparison with earlier experiment. After a temperature of 280°C, CO concentration starts decreasing. In this case O_2 concentration decreases to a value of about 6%. Fig.4 indicates that CO started emitting at very beginning and increases sharply after 140°C. Further the CO concentration starts decreasing after 240°C. The maximum CO and CO_2 concentration increased to a value of 1.1% and 5%

respectively. The oxygen concentration follows the same trend, as earlier and minimum concentration of O_2 recorded was about 8%. The value of O_2 and CO_2 concentration becomes equal (8%) at about 190°C temperature. Fig.5 shows the same trend as earlier but sharp increase in CO concentration at about 160°C temperature was noticed. The maximum concentration of CO and CO_2 recorded was 2.5 and 17% respectively. The value of O_2 and CO_2 becomes equal (about 9%) at a temperature of 170°C.

Tables 1-4 represent the emission of hydrocarbons from above coal seams during oxidation of coal samples. The emission of hydrocarbons started only after 120°C

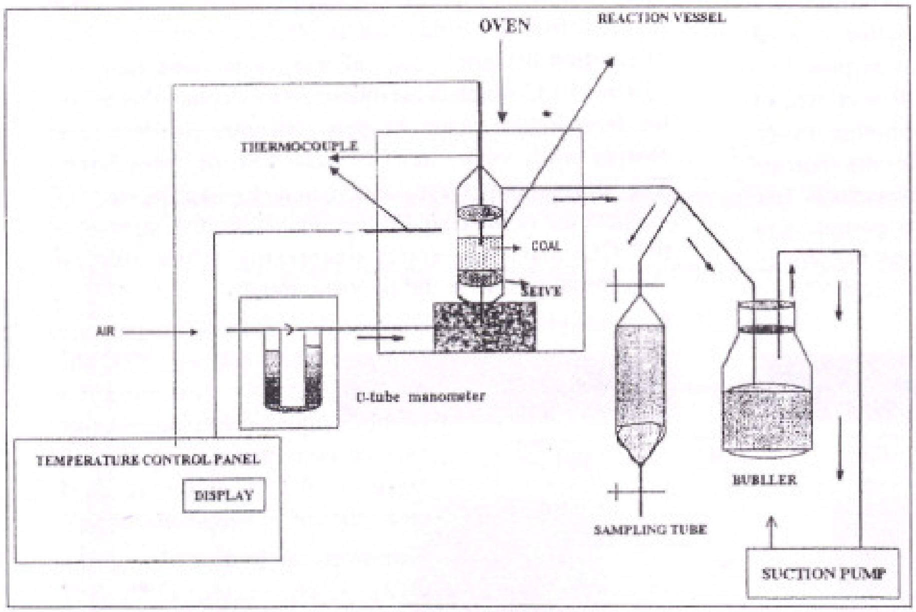

Fig.1 Device for thermal oxidation

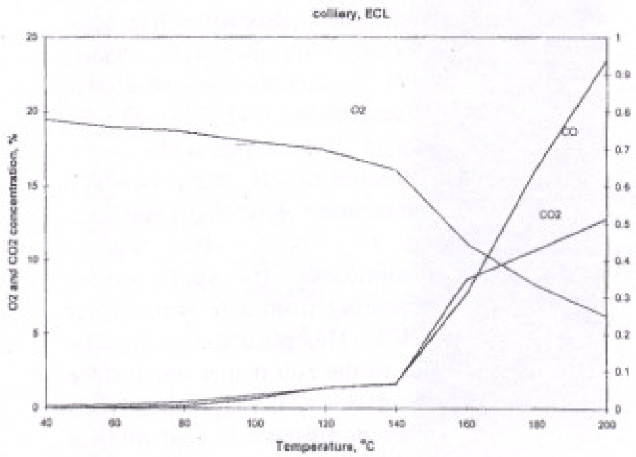

Fig.2 Emission of CO and CO_2 with temperature from coal sample of Jambad seam, Madhujore colliery, ECL

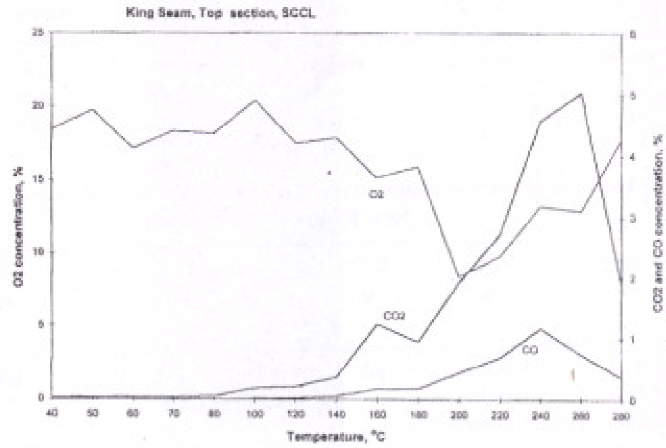

Fig.4 Emission of CO and CO_2 with temperature from coal sample of VK 7 incline, king seam, top section, SCCL

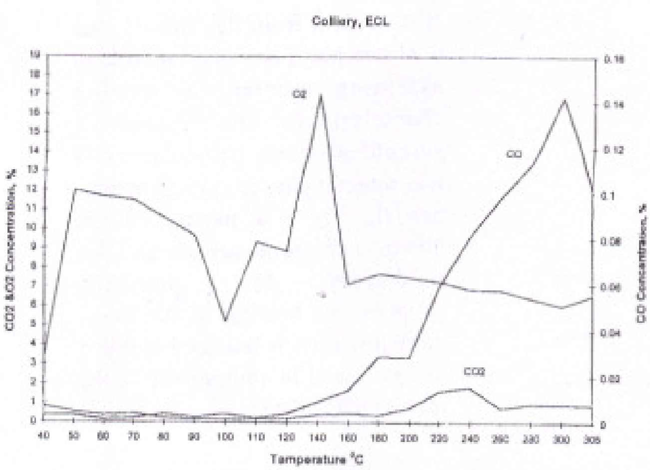

Fig.3 Emission of CO and CO_2 with temperature from coal sample of Dobrana seam, New Kenda colliery, ECL

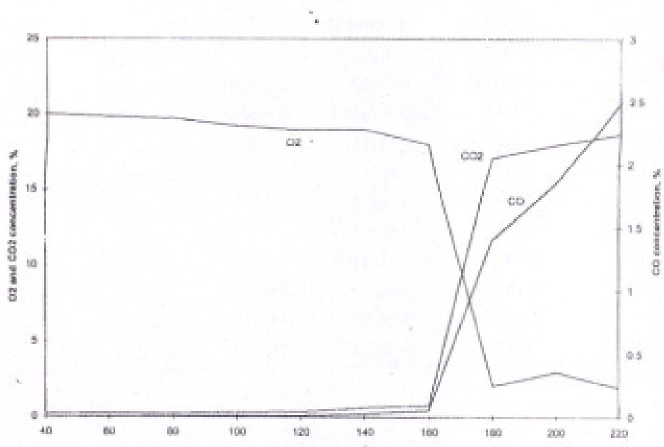

Fig.5 Emission of CO and CO_2 with temperature from coal sample of MVK-5 incline, SCCL

and the concentration of emitted hydrocarbons was very low. Critical analysis of the tables reveals that the hydrocarbons C1-C4 emits at varied temperature range and few of them like C_2H_2 emits at about 260°C.

The Table 5 shows the effect of size variation of coal sample on emission of CO and CO_2. For the purpose two experiments have been conducted on two different size of same coal samples, one on -72 mesh size and another on -40 mesh size under same experimental set up. Results indicate that the concentration of CO and CO_2 in small particle size coal was much higher in comparison to larger particle size coal. This phenomenon can be explained in a way that due to smaller particle size more surface area was available for oxidation.

TABLE 1: EMISSION OF HYDROCARBONS WITH TEMPERATURE FROM COAL SAMPLE OF JAMBAD SEAM, MADHUIORE COLLIERY, ECL

	Temp. °C	C_2H_4 %	C_2H_6 %	C_2H_2 %	C_3H_8 %	n-C_4H_{10}+ I-C_4H_{10} %
1	40.0	nil	nil	nil	nil	nil
2	60.0	-	-	-	-	-
3	80.0	-	-	-	-	-
4	100.0	-	-	-	-	-
5	120.0	0.0029	0.0090	0.00015	0.0019	0.01395
6	140.0	0.0035	0.0100	0.00016	0.0050	0.01866
7	160.0	0.0174	0.0104	0.0007	0.0150	0.0435
8	180.0	0.0286	0.1328	0.0019	0.0330	0.1663
9	200.0	0.1103	0.2430	0.0080	0.1290	0.4903

TABLE 2: EMISSION OF HYDROCARBONS WITH TEMPERATURE FROM COAL SAMPLE OF DOBRANA SEAM, NEW KENDA, COLLIERY, ECL

	Temp. °C	CH_4 %	C_2H_4 %	C_2H_6 %	C_2H_2 %	C_3H_8 %	n-C_4H_{10}+ I-C_4H_{10} %
1	40.0	0.0061	nil	nil	nil	nil	nil
2	50.0	0.0036	-	-	-	-	-
3	60.0	0.0030	-	-	-	-	-
4	70.0	0.0013	-	-	-	-	-
5	80.0	0.0006	-	-	-	-	-
6	90.0	0.0013	-	-	-	-	-
7	100.0	Nil	-	-	-	-	-
8	110.0	0.0035	0.0004	-	-	-	-
9	120.0	0.0015	nil	-	0.0018	-	-
10	140.0	0.0019	0.0003	0.0005	nil	-	-
11	160.0	ND	4.8097×10^{-5}	0.0004	0.0022	-	-
12	180.0	ND	0.0011	nil	nil	-	-
13	200.0	0.0011	ND	-	0.0017	-	-
14	220.0	0.0006	0.0003	-	ND	-	-
15	240.0	ND	0.0001	-	ND	-	-
16	260.0	0.0020	5.045×10^{-5}	-	0.0009	-	0.0024
17	280.0	0.0030	0.0052	0.0044	0.0029	-	ND
18	300.0	0.0032	0.0032	0.0015	0.0003	-	0.0015
19	305.0	0.0035	0.0029	0.0019	0.0010	-	ND

ND = Not detected

The following points emerged from the investigation:

1. In majority of coal samples, CO emission starts at a temperature of about 40°C. The CO concentration increases with increase in temperature. It has been revealed from the study that in all the experiments, rate of reaction becomes faster after a temperature range of 120 to 140°C which is corroborated by the fact that under the temperature range oxygen concentration decreases sharply while emission of CO and CO_2 becomes faster. The above temperature range may be said as critical temperature of the coal. Further above 260°C temperature the CO and CO_2 starts decreasing while oxygen concentration follow the opposite trend.
2. It can also be seen from the results that in the temperature range between 160 to 190°C the oxygen and CO_2 concentration becomes equal which indicate that rate of consumption of O_2 and emission of CO_2 is almost equal under the above temperature range.
3. Emissions of hydrocarbons like C_2H_4, C_2H_6, C_2H_2, C_3H_8 and C_4H_{10} start only after a temperature of 120°C. In most cases the hydrocarbon like C_2H_2 liberates only after 260°C (Tables 1-4). As such, the concentration of hydrocarbons was observed very low in all the experiments.
4. Emission of CH_4 starts even at a temperature of 40°C and continues up to 100°C, after that it disappears. It again starts appearing from a temperature of 120°C. This phenomenon may be due to the fact that at initial stage i.e. up to 100°C CH_4 emited for its inherent presence in coal while at higher temperature (after 120°C) it again appears because of thermal oxidation.
5. It is evident from the Table 5 that coal size plays an important role in assessing spontaneous heating characteristics. The emission of gaseous products particularly CO was much higher in case of smaller particle size (-72 mesh). This is due to increase in surface area for oxidation. For detecting spontaneous heating in the mine, more attention is required in fallen or loose coal in comparison to the intact coal pillars.

Table 3: Emission of hydrocarbons from coal sample of King Seam top section, VK-7 incline mine, SCCL

	Temp. °C	CH_4 %	C_2H_4 %	C_2H_6 %	C_2H_2 %	C_3H_8 %	n-C_4H_{10} %
1	40.0	0.0096	nil	nil	nil	nil	nil
2	50.0	nil	-	-	-	-	-
3	60.0	nil	-	-	-	-	-
4	70.0	0.0002	-	-	-	-	-
5	80.0	6.39×10^{-5}	-	-	-	-	-
6	100.0	0.0004	-	-	-	-	-
7	120.0	nil	-	-	-	-	-
8	140.0	0.0016	0.0002	0.0001	-	-	-
9	160.0	nil	0.0005	0.0003	-	-	-
10	180.0	nil	0.0007	0.0004	-	-	-
11	200.0	nil	0.0022	0.0011	-	-	0.0011
12	220.0	0.0007	0.0005	0.0004	-	7.02×10^{-6}	nil
13	240.0	0.0041	0.0041	0.0015	-	nil	-
14	260.0	nil	0.0018	0.0009	-	8.71×10^{-5}	-
15	280.0	nil	0.0029	0.0015	1.6674×10^{-5}	9.77×10^{-5}	0.0011

Table 4: Emission of hydrocarbons with temperature from coal sample of MVK-5 incline mine, Balampalli, SCCL

	Temp. °C	CH_4 %	C_2H_4 %	C_2H_6 %	C_2H_2 %	C_3H_8 %
1	40.0	nil	nil	nil	nil	nil
2	60.0	-	-	-	-	-
3	80.0	-	-	-	-	-
4	100.0	-	-	-	-	-
5	120.0	-	-	-	-	-
6	140.0	-	0.0040	-	-	-
7	160.0	-	0.0026	-	0.0016	4.57809×10^{-5}
8	180.0	0.0465	0.2464	-	0.0368	0.0014
9	200.0	0.1511	0.5010	0.0918	0.0612	0.0023
10	220.0	0.6162	1.1167	0.1213	0.3289	0.0130

Table 5: Comparative study of CO2 & CO concentration at different mesh size of coal sample of King Seam top section VK-7 incline mine, SCCL

Temp. °C	CO_2 concentration (%)		CO concentration (%)	
	- 40 mesh	- 72 mesh	- 40 mesh	- 72 mesh
40	0.03	0.0099	0	0
50	0.0328	0.0187	0	0.002
60	0.0385	0.0596	0	0.0077
80	0.522	0.0811	0.0004	0.008
100	0.1875	0.4687	0.0104	0.0108
120	0.2101	0.1062	0.0251	0.0383
140	0.3609	0.7813	0.058	0.1687
160	1.2311	1.9662	0.1726	0.5112
180	0.9389	11.5346	0.1771	5.3234
200	1.9291	19.531	0.4397	7.9138
220	2.7183	19.309	0.6809	6.8954
240	4.5743	13.66	1.17	5.2238
260	5.0376	12.353	0.733	5.0978
280	1.9155	15.543	0.3685	6.1218

Conclusion

- The study reveals that CO is the best indicator for early detection of spontaneous heating of coal.
- Emission of various hydrocarbons at varied temperature range may be helpful in assessing the temperature and status of fire in the fire affected sealed off areas.
- For Indian coal the hydrocarbons cannot be used as a tool for early detection of spontaneous heating of coal as reported in other parts of the world.
- Size of the coal is a very important aspect in respect of spontaneous heating behaviour of coal. Smaller the size more susceptible is the coal towards spontaneous heating. For detection of spontaneous heating in the mine more attention is required in fallen or loose coal in comparison to the intact coal pillars.

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Mining industry update

New guidelines on mine allotments in the offing

The Union Government is reported to considering implementation of new guidelines on the allotment of iron ore mines as the current system is ridden with anomalies. It is pointed out that while some steel companies have no access to mines, steel trading companies with no steel plants of their own are exporting iron ores. Keeping this in view, the Ministry of Mines has constituted an expert group under the chairmanship of the former secretary to the government, Mr. R.K. Dang. The group is to form national guidelines on the criteria for grant and approval of mining leases relating to iron, manganese and chrome ores under the Minerals and Mines Development Regulations (MMDR) Act 1957.

Higher FDI in coal sector

The Union Ministry of Coal has virtually given its nod to the proposal for raising the foreign direct investment (FDI) limit for captive coal mines in steel and cement sector to 100% from the present level of 74%. The proposal will now go to the Cabinet for its approval.

The proposal was mooted by the Department of Industrial Policy and Promotion under the the Commerce Ministry and sought the approval of the coal ministry on raising FDI for captive mines in the two sectors. It can be recalled that the government has already approved 100% FDI in captive mines in the power sector. The Ministry has already allotted around 90 coal blocks for purposes of captive coal mining. Taken together these are estimated to have total reserves of 180 million tonnes. Along with power, the steel and cement sector account for the bulk of coal sales in the country.

Ministry awaits report on CIL revamping and coal sector reforms

The Coal Ministry is looking forward to the Shankar Committee interim report on Coal India revamping and coal sector reforms by the end of June 2005 while the final report is expected to be received in another two months time. The Committee is looking into issues like restructuring of Coal India, short-term gap in demand and supply of coal and how to augment overall coal supplies and converting the Central Mine Planning and Design Institute Ltd into a center of excellence.

Steps are also being taken to augment domestic coal supplies by 40-50 million tonnes to meet the shortfall in coal supplies. With a combination of new projects and capacity expansion of existing mines, the overall gap is estimated to be around 25-30 million tonnes in the next few years, based on the current consumption level.

Jharkhand plans special mining zones

The State Government of Jharkhand is contemplating to set up a special mining zone (SMZ) in the State based on a study and its recommendation on the mineral sector in eastern India carried out jointly by Confederation of Indian Industries and McKinsey.

The report "Turning the metals and mining potential of Eastern India into a goldmine" suggests a SMZ for quick clearance of mining projects. This new concept is likely to help the State's economic growth. The State Government is planning several initiatives to realize the potential of the mineral sector. It is planning to develop mineral rich areas as SMZ.

The mines and geology department is setting up a mineral information system to ascertain the distribution of minerals in the state. A geomagnetic survey would be undertaken to map the mineral deposits, helping prospective investors to quickly make decisions.

Coaljunction launched

The first electronic platform for trading coal has recently been launched in the country by the largest online steel trading company, Metaljunction in Kolkata. It is hoped that this platform would help in transforming the e-marketplace for coal. Over the next one or two years, it is expected that spot purchase of coal would account to 20% in case of Coal India's total sales which joined the platform offering around 10 million tonnes of coal to start with. The prices offered in these spot deals would expectedly serve as a benchmark for setting prices in the long-term contracts.

Incidentally, it is to be noted that CIL has already started e-auction through its subsidiary company Bharat Coking Coal Ltd. using MSTC's trading platform. BCCL hopes to continue trading using both MSTC and Coaljunction platforms.