

Chapter 3

Analysis of Coal

3.1 Inorganic Constituents in Coal

More than 95% of inorganic constituents in coal consists of minerals like kaolinite (Al-silicate), calcite (calcium carbonate) and pyrite (iron sulfide) - containing mainly alumina, silica, iron oxide, lime and sulfur. The remaining 5% consist mainly of magnesia (MgO), sodium and potassium oxides, titanium oxide as basic radical; and sulfates, chlorides and phosphates as acidic radicals¹⁰⁸.

Besides the above commonly occurring inorganic constituents, coal ash also contains elements of widely varying properties - of course to a relatively smaller concentration; the more important among them being - Be, Sr, Ba, B, Sc, Y, lanthanides, Zr, V, Co, Ni, Mo, U, Cu, Zn, Ga, Ge, As, Sb, Cd, Sn, I, Pb, Bi, Ag, Au, Rh, Pd, Pt, Th, Se and Te. Their distribution and abundance depend on the type and the history of coal, as well as the mode of ash making¹⁰⁹.

Vanadium is present in reasonably high concentration in coal ashes. As early as 1892 Kyle noted the presence of V in a lignite deposit in Argentina¹¹⁰. Low ash Australian coals have been reported to contain even 25% V (in the ash). Clarainvitrain type coals in Hungary contain 0.3-4.92% V¹⁰⁹. Headlee and Hunter observed V to remain at much higher proportion near the shale partings than in the main body of certain

U.S. coals¹¹⁰. Ashes of Indian lignite (Verkala) have been found to contain nearly 2% vanadium oxide¹¹¹.

3.2 Determination of Mineral Matter in Coal at High Temperature Ashing

The mineral matter of coal can be determined either qualitatively or quantitatively from the ash that is formed when coal is oxidized. Normal high temperature ashing of coal at 750°C, the temperature designated by ASTM standards¹¹², results in a series of reaction in all of the mineral groups in the coal except quartz.

All the clay minerals (Kaolinite, illite and montmorillonite) in coal contain lattice bound water which is lost during high temperature ashing. The iron sulfide minerals are oxidized to Fe_2O_3 and SO_2 . Some of the SO_2 may remain in the ash in combination with calcium, but much is lost. During high temperature ashing if all of SO_2 were emitted, then 33% of the weight of pyrite or of marcasite in the original sample could be lost. The CaCO_3 is calcined to lime (CaO) with a loss of CO_2 resulting in 44% reduction in the weight of the original calcite.

A number of workers have suggested schemes for calculating the true amount of mineral matter from the determinations made during the chemical analyses of coal. One of the first schemes and still the most widely used, was developed by Parr¹¹³, who

considered only the total sulfur and ash contents in developing the conversion formulas. A more sophisticated method was suggested by King, Maries and Crossley¹¹⁴, the 'KMC' method takes into account the loss of CO₂ for carbonates and decomposition of chlorides in addition to the variables considered by the Parr formula. The problem of converting raw data from chemical analyses to a pure coal basis by subtracting the calculated mineral matter has recently been investigated by Given et al^{115,116}.

3.3 Low Temperature Ashing

During the past decade the technique of electronic (radio frequency) low temperature ashing has been applied to investigations of mineral matter in coal. In a low temperature asher, O₂ is passed through a radio frequency field and a discharge takes place. Activated O₂ in this way passes over the coal sample, and the organic matter oxidizes at relatively low temperature usually less than 150°C¹¹⁷. The effects of low temperature ashing and of the oxidizing gas stream upon mineral in coal are minimal. No oxidation of mineral phases present has been reported, and the only phase changes observed were those to be expected at a temperature of 150°C and a pressure of 1 torr. Therefore, most of the major mineral constituents of coals, including pyrite, kaolinite, illite, quartz and calcite, are unaffected by radio frequency ashing. The results of studies of mineral matter in coal by this method

can be found in Gluskoter¹¹⁸, Estep, Kovach and Karr¹¹⁹, Wolfe¹²⁰, O'Gorman and Walker¹²¹ and Ward¹²².

After the low temperature mineral matter residue has been obtained by radio frequency ashing, a variety of instrumental techniques can be applied to identify the minerals and to determine their concentrations. The best developed, most inclusive and probably most reliable method for identifying minerals in coal is X-ray diffraction analysis^{117,120,121,122,123}. The other methods which have been less commonly employed include IR spectra^{119,121}, DTA¹²⁴⁻¹²⁶, SEM¹²⁷⁻¹³⁰, Electron probe¹³¹ and Mossbauer spectroscopy¹³².

3.4 Determination of Major and Trace Elements

In the recent years chemical analysis of mineral matter and trace elements in coal have been progressed from the "wet chemical" methods to sophisticated instrumental methods. The major elements in the mineral constituents of coal: Si, Al, Ti, Ca, Mg, Fe, P, S, Na, K usually associated with silicates are most frequently determined by X-ray fluorescence spectroscopy¹³³⁻¹³⁶ and flame photometry¹³⁷. The most popular technique used to determine minor and trace elements in coals are optical emission and atomic absorption spectroscopy¹³⁸⁻¹⁴². Neutron activation analysis is also an excellent technique for determining many elements. Its use is limited by the need of neutron source (usually an atomic reactor)¹⁴³⁻¹⁴⁴.

EXPERIMENTAL

3.5 Analysis of Coal

Nine different grades of coal from Raniganj coalfield (Bihar, India) were selected for coal ash deposit corrosion studies of steels and superalloys. The proximate analysis of coal was carried out by the procedure recommended by [ISI:1350 (1969) Part I]. The coals were powdered and analyzed for moisture, volatile, ash and fixed carbon. The ash residues were analyzed for metallic and non-metallic constituents, soluble and insoluble constituents and silica and silicates using a wide variety of techniques, chemical analysis, flame photometry, atomic absorption spectrometry, thermogravimetry, X-ray diffraction analysis and infrared spectroscopy.

The details of the procedures are described in the following sections.

3.6 Proximate Analysis

3.6.1 Milling of coal

Coal samples were milled to fine powder and passed through 150 mesh sieve.

3.6.2 Moisture determination

Moisture in the coal samples was determined by heating the coals at 110°C for 1 hour in an oven.

3.6.3 Volatile matter determination

The powder coal samples were kept at 900°C for 7 minutes in a muffle furnace to determine volatile matter. The amount of moisture present as determined earlier was deducted to get correct volatile matter contents.

3.6.4 Ash determination

The powdered coal samples were kept in an open silica crucible at 750°C until a constant weight of residue is obtained. The results of proximate analysis are given in Table 3.1.

3.7 Analysis of Ash

3.7.1 Determination of soluble constituents

The soluble constituents in the ash samples were determined by taking a weighed amount of ash (about 0.5g) and extracting it with a litre of water. The mixture was heated near to boiling followed by filtration through a Whatman filter paper. The filter paper was dried and the dried material was transferred to a weighed silica crucible. The filter paper was burnt to ash. The amount of the insoluble constituent was determined by subtracting the weight of filter paper ash. The insoluble material consists of silica and some insoluble silicates.

3.7.2 Determination of silica in an 'insoluble' silicate

The amount of silica in an 'insoluble' silicate was determined by fusing the insoluble ash residue (obtained from the residue of water extract) with sodium carbonate in a platinum crucible. The fused mass was extracted with minimum amount of warm water followed by small additions of concentrated hydrochloric acid and then heated till evolution of carbon dioxide ceases. The acidic solution is evaporated to dryness on the water bath when insoluble silica separates out. The residue is extracted with dil. HCl to remove salts of Fe, Al & other metals which may be present and filtered. The residue contains mainly SiO_2 which is weighed.

3.7.3 Determination of sulfur

The ash was mixed with the fusion mixture (1:2) and fused in a platinum crucible. The fused mixture was extracted with hot water and boiled followed by the addition of 10-20 ml of conc. HCl. The sulfur is precipitated as BaSO_4 from the solution on adding a solution of BaCl_2 . The precipitate is then transferred on a Whatman 40 filter paper, the filter paper was dried and ignited on a silica crucible. The crucible is heated on an oxidizing flame till a constant weight is obtained. The percentage of sulfur was calculated by using a conversion factor of 0.13735.

3.7.4 Determination of chloride

All the combined chlorine was precipitated as AgCl on addition of AgNO₃ solution to an acidic solution (HNO₃) of fused ash. The precipitate was transferred on a sintered crucible and washed with dil. HNO₃ several times. The crucible was then dried in an oven at 110°C and weighed as AgCl. The % chlorine was found out by using a conversion factor of 0.24737.

3.7.5 Determination of magnesium

Magnesium was determined by complexometric titration. The fused ash was extracted with hot water followed by filtration. The calcium present in the filtrate was precipitated as calcium oxalate on addition of ammonium oxalate in the alkaline medium. The precipitate was filtered on a sintered crucible and the filtrate was collected. The amount of magnesium in the solution (filtrate) was determined by titrating it with a standard solution of sodium versenate (sodium salt of EDTA) using Eriochrome Black T as an indicator and maintaining a pH of about 10 (using NH₄Cl-NH₄OH buffer). The sharp change in colour from deep red to blue indicates end point.

3.7.6 Determination of sodium, potassium and calcium by flame photometer

The amount of sodium, potassium and calcium was determined by flame photometric method. A Systronic India Ltd. flame photometer was used for the measurements. Cooking gas

was used as a fuel.

Standard solution of NaCl, KCl and CaCl₂ of varying concentrations ($1 \times 10^{-1} \text{M}$ to $1 \times 10^{-3} \text{M}$) were prepared and their absorbances were measured on the flame photometer. Calibration curves for Na⁺, K⁺ and Ca⁺⁺ were drawn.

A weighed amount of ash (0.5g) was extracted with water followed by the addition of 20 ml of Anal R HCl, the mixture was boiled, cooled and filtered. The filtrate was transferred to a 100 ml standard flask and the volume was made up to 100 ml on addition of demineralized water. The amount of Na⁺, K⁺ and Ca⁺⁺ was determined in this solution by flame photometer using the calibration curves.

Table 3.2 gives the results of the major elements present in the coal ash samples.

3.7.7 Spectrophotometric determination of iron, chromium and vanadium

The amount of iron, chromium and vanadium in the ash was determined by colorimetric methods of analysis. The spectrophotometric determinations were made with the help of Bausch and Lomb Spectronic '20' spectrophotometer in the range of 350 to 800 nm.

(i) Determination of iron

Standard ferric ammonium sulfate solutions were prepared by dissolving weighed amount of ferrous ammonium

sulfate in water followed by boiling with conc. HNO_3 . To each solution 10 ml of 1.0% ammonium thiocyanate was added so as to provide ferric concentrations in the range of 1 to 5 mg/litre. The λ_{max} of the red coloured complex was found at 500 nm and the Beer Lambert's law obeys in the said concentration range. The absorbances of the complex solutions (containing known concentrations of Fe(III)) were measured and the calibration curves were drawn.

10 ml of 10% ammonium thiocyanate solution was added to 100 ml of fused ash solution (containing 0.5 g of ash) and the absorbance was noted at 500 nm. The calibration curve gives the concentration of iron present in the ash.

(ii) Determination of chromium

The diphenyl carbazide reagent used for the spectrophotometric determination of chromium was prepared as follows:

4 g of phthalic anhydride and 0.25 g of diphenyl carbazide were dissolved in 95% ethanol. The acidity of the approximately neutral solution was adjusted by adding 3.3 ml of 1:5 H_2SO_4 and making up the volume to 100 ml.

To the standard potassium dichromate solutions, 1 ml of the reagent was added so as to give chromium concentrations in the range of 0.1-0.4 mg/litre. The λ_{max} of the violet coloured complex was observed at 540 nm. The concentration/

absorbance curve (calibration curve) indicates that the Beer Lambert's law is followed in this concentration range.

To the fused ash solutions (containing 0.7% ash) 1 ml of the reagent was added and the absorbance was recorded at 540 nm. The concentration of chromium in the ash was determined from the calibration curve.

(iii) Determination of vanadium

Standard sodium vanadate solutions were prepared by dissolving weighed amount of salt. To each solution, 1.5 ml of the reagent (1.0 ml of 1:8 H_2SO_4 + 0.3 ml of 85% H_3PO_4 + 0.2 ml of 5% sodium tungstate) was added so as to give vanadium concentrations in the range of 0.5-2 mg/litre. The λ_{max} of the yellow coloured complex was found at 400 nm and the Beer Lambert's law obeys in the said concentration range. The absorbances of the yellow coloured complex solutions (containing known concentration of vanadium) were measured and calibration curve was drawn.

1.5 ml of the reagent (composition given above) was added to 100 ml of fused ash solutions (containing 0.7 g ash) and the absorbance of the solution was measured. The calibration curve gives the concentration of vanadium in different ash solutions.

3.7.8 Determination of trace elements

The determination of trace elements in the ash was carried out by atomic absorption spectrophotometry. A Perkin Elmer model 303 (303-0073) atomic absorption spectrophotometer (by the courtesy of Central Drug Research Institute, Lucknow) was used to determine the concentration of Li, Mo, Cu, Zn, Mn and Pb in the ash. High purity acetylene was used as the fuel and appropriate Perkin Elmer hollow cathode lamps were chosen for the determination of the trace elements. Table 3.3 gives the results of various trace elements present in the ashes of the coals.

3.8 Infrared Spectra

The technique of infrared spectroscopy was used to identify some of the constituents present in the ash. The infra spectra of the ash samples were recorded with a Perkin Elmer '621' infrared spectrophotometer in the frequency range of $800-200\text{ cm}^{-1}$ using CsBr prism and nujol as a mulling agent. Table 3.4 gives the characteristic peaks in the far infrared spectra of coal ash samples.

3.9 Thermogravimetric and Differential Thermal Analysis

The methods of TGA and DTA were used to determine the thermal behaviour of different constituents of coals in the temperature range of $50-800^{\circ}\text{C}$.

The thermogravimetric analysis apparatus was assembled by R. R. L. Hyderabad, India. It consists of Mettler semi micro-analytical balance, model B 6 (capacity 100 g, accuracy ± 0.2 mg) with a hook fixed underside the pan. A platinum furnace with an inside diameter of 25 mm, open at both ends supported vertically below the pan is used for heating. A quartz glass bucket containing the sample is suspended freely from the hook of the balance pan by means of a fine platinum wire. The lower end of the furnace is plugged with an insulation refractory material to prevent convection current. The temperature in the furnace is regulated by a program controller and the temperature at the sample bucket is read with the aid of a multivoltmeter type potentiometer. The temperature is varied by changing input current to the furnace.

A Leeds and Northrup apparatus was used for DTA measurements.

The following are the specifications:

Sample holder and cells	: Grim and Shaw pattern ceramic sample holder and cells.
Thermocouple	: Pt - (Pt - 10% Rh)
Range	: 200 for full scale deflection
Rate of heating	: $10^{\circ}\text{C}/\text{min}$
Weight of sample	: 0.20 g
Reference and diluent	: Quartz

3.10 X-Ray Diffraction Analysis

A Philips X-ray diffraction assembly was used. Debye-Scherrer X-ray diffraction patterns of the powdered ash were taken using an appropriate $K\alpha$ radiation (usually Cu $K\alpha$ or Fe $K\alpha$). Table 3.5 lists the constituents, present in the ash residues, as identified by X-ray diffraction analysis.

RESULTS

3.11 Infrared Spectra

Figure 3.1 shows the infrared spectra of the ash samples obtained by the combustion of different grades of coals at 750°C. The spectra of the samples indicate a medium intensity band at 460 cm^{-1} which could be assigned to metal sulfur stretching vibrations. The weak intensity bands at 360 cm^{-1} and 380 cm^{-1} most probably arising from metal chloride stretches. The medium intensity bands at 730, 780, 810 cm^{-1} may be assigned to metal-oxygen, silica-oxygen and sulfur-oxygen stretching vibrations, respectively and are present invariably in the spectra of all the ash samples. In general, the infrared spectra of the coal ash samples contain relatively a few bands, the medium and strong intensity bands are mainly concentrated in the region: 800 - 300 cm^{-1} .

3.12 Thermogravimetric Studies

Figure 3.2 shows TGA plots of some coal samples. Thermograms throw some light regarding the mode of combustion

of coals when the sample are heated from room temperature to about 1000°C .

Coal sample No. 2 (high moisture - low ash selected B) shows gradual loss in weight up to a temperature of 110°C followed by a plateau in the temperature range of $110\text{--}300^{\circ}\text{C}$. Above 300°C , there is a steep loss in weight up to a temperature of 700°C , corresponding to a total loss of 86%; henceforth there is no further loss (Figure 3.2a).

Coal sample No. 4 (high moisture - low ash grade I) shows a weight loss of about 6.0% up to 60°C followed by a region of no loss extending to a temperature of 250°C . In the temperature range of 250° to 350°C there is a region of very low weight loss followed by very rapid weight loss up to 700°C corresponding to a total weight loss of 85%. No weight loss is observed above 700°C (Figure 3.2b).

Sample No. 5 (low moisture - high ash grade I) shows practically no weight loss up to a temperature of 350°C followed by a gradual loss in weight and at 900°C a total loss of 56% is observed (Figure 3.2c).

Sample No. 8 (low moisture - high ash grade III A) does not show any weight loss up to a temperature of 370°C , above this temperature there is a steep loss in weight and a total weight loss of about 47% is observed at 700°C (Figure 3.2d).

Sample No. 9 (low moisture - high ash grade III B) shows no weight loss up to 375°C. Above 400°C the weight loss/temperature plot (Figure 3.2e) indicates a gradual loss up to a temperature of 1000°C. The total weight loss at this temperature corresponds to 68.5%.

3.13 Differential Thermal Analysis

Figure 3.3 presents the DTA curves of some coal samples. Coal sample No. 2 (high moisture - low ash selected B), coal sample No. 5 (low moisture - high ash grade III A) and sample No. 9 (low moisture, grade III B) do not show any peak in the DTA curves. The curves may be conveniently divided into four regions: a flat portion (ab) up to a temperature of 150°C, curves (bc) indicating steep loss in weight between 150°C and 300°C, a flat portion (cd) between 300°C and 500°C and a curvature (de) above 500°C, again indicating a steep loss in weight.

3.14 X-Ray Diffraction Analysis

X-ray diffraction analysis of coal ash samples indicates the presence of silica and silicates, the oxides of calcium, magnesium and iron, and sulfates of sodium and magnesium. The trace elements are likely to be present in the form of oxides, chlorides and sulfates but could not be detected.

DISCUSSION

The proximate analysis of various grades of coal indicate the presence of high ash (11.1 to 38.4%) and high volatile contents (23.4 to 40.4%). The mineral rich ash samples were found to have the following major elements concentrations : sulfur (2.1×10^3 to 10.7×10^3 ppm), sodium (0.9×10^3 to 19.8×10^3 ppm), potassium (0.2×10^3 to 6.2×10^3 ppm), calcium (48×10^3 to 360×10^3 ppm), magnesium (10.7×10^3 to 75.3×10^3 ppm) and chlorine (0.9×10^3 to 1.0×10^3 ppm). The ash mineral contents should include chloride and sulfates of Ca^{++} , Mg^{++} , Na^+ , K^+ and trace elements (water soluble portion) and silicate and silica (water insoluble portion constituting 97.7 to 99.7% of the ash).

The infrared spectra of coal ash residues show several medium intensity bands in the region: $800-300 \text{ cm}^{-1}$. The medium intensity band at 460 cm^{-1} has been assigned to metal-sulfur stretching vibrations and indicates the presence of metal sulfates or sulfides in the ash. The weak intensity bands at 360 and 290 cm^{-1} probably result from metal chloride stretching vibration and show the presence of metal chlorides in the ash. The medium intensity bands at 730 , 780 and 810 cm^{-1} are respectively assigned to M-O, Si-O and S-O stretches and give evidence of the presence of metallic oxides, silica, silicates and sulfates in the ash residues.

The thermogravimetric studies of the coal samples provide some interesting information regarding the thermal decomposition of various constituents present in the coal. The high moisture coals (sample 1 to 4) invariably lose moisture in the temperature range of 100-150°C which is indicated by a gradual loss in weight up to 150°C. Above 300°C there is a rapid weight loss in high moisture coals and practically all the volatile matter is eliminated at 700°C corresponding to a total weight loss of 85-89% leaving ash residue comprising 15-11% weight of the coal samples, this mainly comprises of silicates and little silica. These figures are in reasonably good agreement within the values obtained during proximate analysis of the coals.

The low moisture coal (sample 5 to 9) show slightly different behaviour - there being practically no weight loss up to temperature of 350-400°C indicating the presence of little or no moisture in the coals. Above 400°C, there is a gradual loss in weight and unlike low moisture coals it does not complete at temperatures up to 1000°C. The thermogravimetric studies thus indicate the presence of other constituent in the low moisture coal which do not decompose even at 1000°C and not present in high moisture coals. Therefore, the mineral composition of the ash samples obtained from low moisture coals should be different from those of high moisture coals.

The DTA traces of high moisture coal samples show endothermic peaks in the temperature range of 100-150°C followed by regions of constant heat absorptions. A peak is observed near about 450°C followed by steep increase in heat absorptions. In low moisture coal samples, alternate regions of no heat change and heat absorption are observed. An endothermic peak is observed at about 575°C. The peak at 150°C and 450°C in the DTA traces of high moisture coals correspond to water and volatile matter losses respectively, whereas in low moisture coals a single peak at 575°C indicates volatile matter losses.

Results of chemical analyses of X-ray diffraction studies indicate the presence of much higher concentration of SiO_2 in the ash in low moisture coal (sample 1 to 4).

The ash residues of coals contain appreciably high concentrations of trace elements as indicated by the results of colorimetric method of analysis and atomic absorption spectrophotometry. Surprisingly Zn (698 to 3763 ppm), Mo (1960 to 3700 ppm), and Pb (395 to 4450 ppm) are present in abnormally high concentrations. The concentrations of other elements are: V (100 to 230 ppm), Cr (40 to 74 ppm), Fe (100 to 330 ppm), Li (\approx 100 ppm), Cu (151 to 310 ppm) and Mn (229 to 594 ppm). These elements do not found to play any important role as far as oxidation or hot corrosion behaviour is concerned as will be followed from the results of the proceeding chapters.

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Table 3.1
Moisture, Volatile Matter and Ash Contents of
Different Grades of Coal

Sample No.	Source	Grade	Moisture %	Volatile Matter %	Ash %
1.	Dhemonain Colliery R. B. Seam	High Moisture Selected B	6.2	31.5	11.7
2.	Kumardihi Jambad Seam	High Moisture Grade II	11.1	30.2	13.1
3.	Harmondia Colliery Disergarh Seam	High Moisture Selected A	6.3	29.7	11.1
4.	Bankola Colliery Jambad Seam	High Moisture Grade I	4.2	38.6	15.2
5.	Badjna Seam	Low Moisture Grade I	2.1	30.3	15.0
6.	Chenakuria 1 & 2 Pit Disergarh Seam	Low Moisture Selected B	1.8	40.7	15.5
7.	Badjna Colliery Singhpur Seam	Low Moisture Grade II	2.2	25.6	18.6
8.	Mandman Colliery Kalimati Seam	Low Moisture Grade IIIA	0.5	23.4	27.0
9.	Chapapur II Colliery Brendabanpur Seam	Low Moisture Grade IIIB	0.1	24.1	38.4

Table 3.2
Some Major Elements Present in Coal Ash

Sample No.	Soluble %	Insoluble %	$\times 10^3$ ppm					
			Na	K	Ca	Mg	S	Cl
1.	0.9	99.1	19.8	6.2	360	75.3	6.4	1.8
2.	1.1	98.9	5.5	3.1	176	43.7	5.4	1.4
3.	0.6	99.4	2.8	2.3	128	72.0	3.5	3.0
4.	0.7	99.3	1.4	1.6	88	31.0	5.4	1.0
5.	0.4	99.6	0.9	0.8	80	58.3	2.1	1.2
6.	2.3	97.7	7.3	3.1	176	40.3	10.7	2.6
7.	0.6	99.4	11.0	3.9	248	18.5	2.5	2.7
8.	2.4	97.6	3.7	2.3	104	80.2	4.0	0.9
9.	0.3	99.7	2.3	1.6	48	10.7	7.5	2.5

Table 3.3
Trace Elements Present in Coal Ash (in ppm)

Sample No.	V	Cr	Fe	Li	Mo	Cu	Zn	Mn	Pb
1.	130	63	100	95	2831	200	1307	297	1722
2.	120	54	330	95	1959	260	2203	351	2633
3.	130	52	160	95	-	155	723	459	1705
4.	145	71	280	95	3700	200	698	594	1310
5.	148	74	130	95	3700	155	1280	590	2230
6.	140	52	150	95	3700	151	3763	478	4450
7.	180	63	270	95	1960	310	1071	590	1720
8.	230	42	320	95	2830	200	929	229	2655
9.	100	40	160	95	1960	155	799	243	395

Table 3.4
 Characteristics Peak in the Infrared
 Spectra of Coal Ash Samples

Band, cm^{-1}	Assignment
460 (s)	M - S stretches
360 and 390 (m)	M - Cl stretches
730 (m)	M - O stretches
780 (m)	Si - O stretches
810 (m)	S - O stretches

Table 3.5
 Identification of the Constituents by X-ray
 Diffraction

Material	Constituents identified
Ash residues of high and low mois- ture coals (sample no. 1 to 9)	Oxides of Ca, Mg, K, Na, sulfates of Ca, Mg, K, Na, silica and silicates

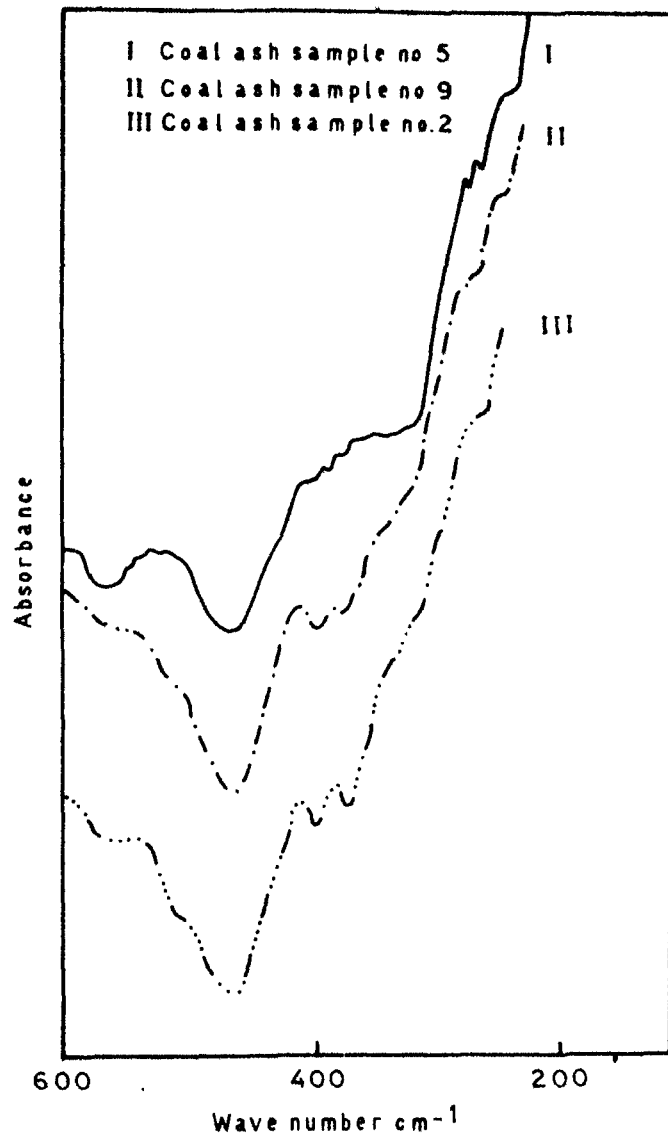


Fig. 3.1 Infrared spectra of coal ash samples

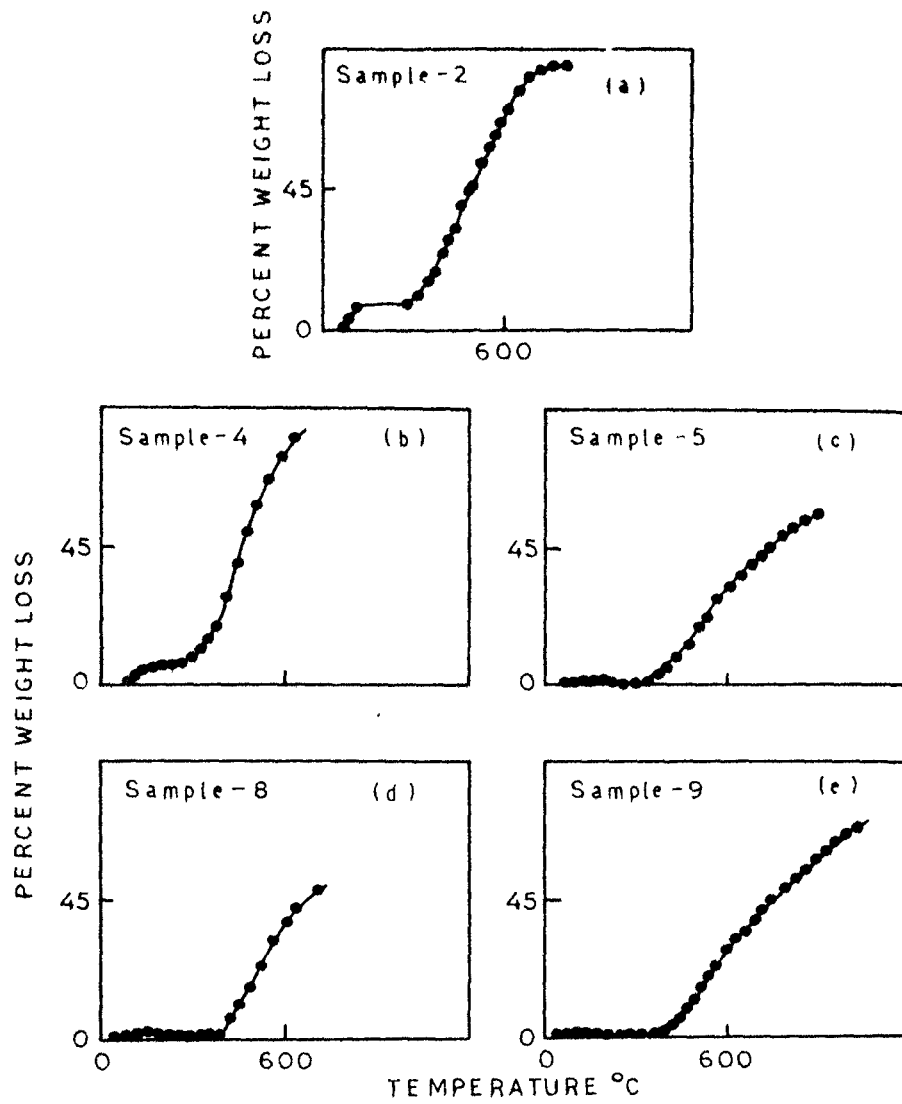


Fig. 3.2 TGA plots of coal samples

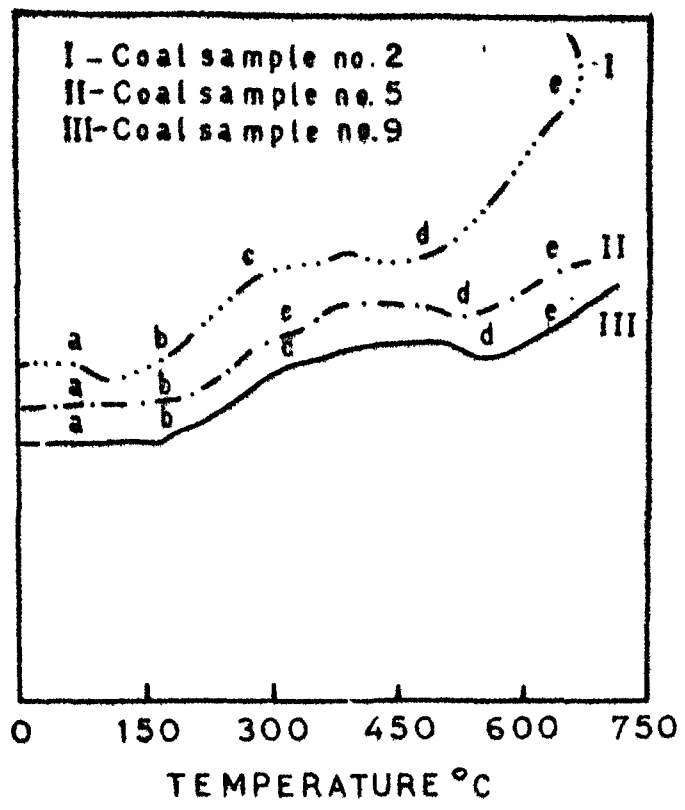


Fig. 3.3 DTA traces of coal samples