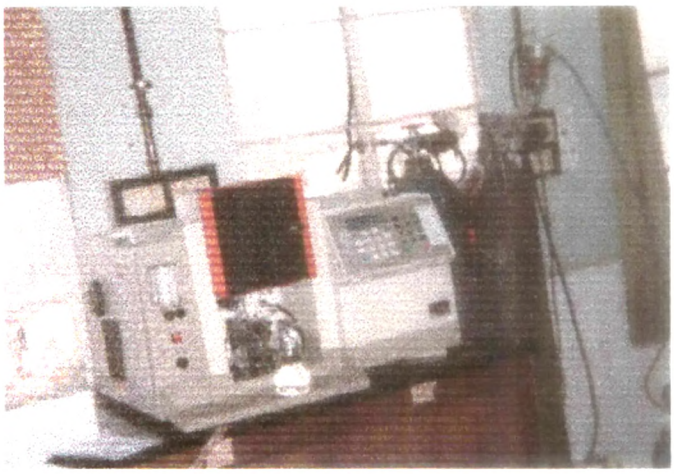


Chapter 6

PHYSICO-CHEMICAL CHARACTERS OF THE COAL

6

6.1 MACROSCOPIC APPEARANCE

The Bapung coal is black to dark black in colour. Generally, the coal of this field is hard and compact. But soft and friable varieties are also not uncommon. The coal lacks banded structure and appears to be entirely made up of vitrain. The coals break with cubical fracture, but the hard ones break with sub-conchoidal to conchoidal fracture. Most of the coal, when exposed to the sun,

easily disintegrate into small chips, indicating the high per cent of volatile matter in them. Sometimes very thin pyrite bands are observed. The coal shows dull to glossy lustre. On weathering, the coal breaks parallel to the bedding plane.

6.2 SPECIFIC GRAVITY

The specific gravity of the coal varies from 1.21 to 1.41 with an average value of 1.30 (Table 6.1).

6.3 PROXIMATE ANALYSIS

Proximate analysis deals with the determination of moisture content, ash, volatile matter and fixed carbon of the coal. It gives the measure of the relative amount of volatile and non-volatile matters in coal.

6.3.1 Moisture content

In the present study the moisture content of coal is found to range between 1.5 and 2.1% in air dried basis (Table 6.2) with an average value of 1 7%.

The moisture content of the top seam varies from 1.5 to 2.1% with an average value of 1.81%. In the middle seam the moisture content varies from 1.5 to 2% with an average value of 1.8%. In the bottom seam it varies from 1.5 to 1 9% with an average value of 1.64%.

6.3.2 Ash content

The ash content of the coal is found to range from 1.1 to 4.2% in air dried basis with an average value of 2.4% (Table 6.2). The ash content of the top seam varies from 1.5 to 2.7% with an average value of 2.2%. In the middle seam the ash content varies from 1.5 to 3.4% with an average value of 2.3%. The ash content of bottom seam varies from 1.5 to 4.2% with an average value of 2.6%.

In dry moisture free basis it ranges from 1.12 to 4.27% with an average value of 2.40% (Table 6.3).

The ash contents of the coal shows different shades of colour. The common colours are white, grey, pink and brown (Table 6.6).

6.3.3 Volatile matter content

The volatile matter content of coal ranges from 40.02 to 45.25% in air dried basis with an average value of 42.50% (Table 6.2). The volatile matter content of the top seam varies from 40.10 to 45.25% with an average value of 42.36%. In the middle and bottom seams volatile matter varies from 40 02 to 43.07% and 40.02 to 44 70% with an average values 41.85% and 43.19% respectively.

In dry moisture free, dry ash free and dry mineral matter free basis it varies from 40.63 to 46.22%, 41 34 to 47.53% and 41.52 to 47.82% with an average values of 43 26%, 44.33% and 44.53% respectively (Tables 6.3, 6.4 and 6.5).

The nature of the coke beads are not uniform in all the samples.

They form non-swelling and swelling beads which are hard in nature (Table 6.6).

6.3.4 Fixed carbon content

The fixed carbon content of coal ranges from 49.95 to 56.78% in air dried basis with an average value of 53.39% (Table 6 2). The fixed carbon content of the top seam varies from 49.95 to 55.7% with an average value of 53.65%. In the middle and bottom seams, the fixed carbon varies from 52.35 to 56.78% and 50.00 to 56.78% with an average values 54.10% and 52.57% respectively.

In dry moisture free basis the fixed carbon ranges from 50.86 to 57.76% with an average of 54.42% (Table 6.3). In dry ash free basis it ranges in between 52.47 and 58.66% having an average value of 55.71% (Table 6.4). In dry mineral matter free basis it ranges from 52.78 to 58.96% with an average value of 55 96% (Table 6.5).

The proximate analyses data are represented in stacked bar diagrams in Fig 6 1 – 6.4.

6.3.5 Fuel ratio

The fuel ratio of the coal is computed using the values of volatile matter and fixed carbon contents in dry mineral matter free basis. The fuel ratio is found to range 1 10 to 1 42 with an average value of 1.26 (Table 6.5)

6.4 ULTIMATE ANALYSIS

6.4.1 Carbon

The carbon content of coal varies from 71.36 to 75.67% in air dried basis with an average value of 73.44% (Table 6.7). In dry mineral matter free basis, the percentage of carbon ranges from 74.30 to 79.65 and the average percentage is 77.07 (Table 6.8).

6.4.2 Hydrogen

The hydrogen content of coal ranges from 5.13 to 5.86% in air dried basis. The average percentage is 5.52 (Table 6.7). In dry mineral matter free basis, it varies from 5.32 to 6.15% with an average value of 5.79% (Table 6.8).

6.4.3 Nitrogen

The nitrogen content of coal varies from 1.32 to 2.80% in air dried basis with an average value of 2.24% (Table 6.7). In dry mineral matter free basis it varies from 1.39 to 2.95% with an average value of 2.35% (Table 6.8).

6.4.4 Oxygen

The oxygen content of coal varies from 8.10 to 13.70% in air dried basis with an average value of 10.86% (Table 6.7). In dry mineral matter free basis it ranges from 8.55 to 14.01% with an average value of 11 39% (Table 6.8)

The ultimate analyses data are represented in stacked bar diagrams in Fig. 6.5 & 6.6.

The H/C ratio of coal varies from 0.07 to 0.08 (0.08 in average) and the O/C ratio varies from 0.11 to 0.19 (0.15 in average) in dry mineral matter free basis (Table 6.8). Low H/C ratio and a high O/C atomic ratio as seen by plotting in 'Van Krevelen Diagram' (Fig. 6.7) indicates that the Bapung coal was derived essentially from continental plants, whose microbial degradation in the basin of deposition was limited due to sedimentation and rapid burial.

6.4.5 Sulphur

The sulphur content of the Bapung coal varies from 3.58 to 5.03% in air dried basis with an average value of 4 31% (Table 6.9).

6.4.6 Forms of sulphur

Sulphur occurs in three different forms – sulphate, pyritic and organic. The amount of sulphate sulphur of coal varies from 0 27 to 0.78% with an average value of 0.48%, pyritic sulphur varies from 0.28 to 1.21% with an average value of 0.61% and organic sulphur varies from 2.27 to 4.20% with an average value of 3.07% in air dried basis (Table 6.9).

In per cent of total sulphur, the organic sulphur is the dominant form of sulphur in coal which varies from 60.44 to 88.42% with an average value of 74 83% (Table 6 10). The pyritic sulphur varies from

8.22 to 24.06% with an average value of 14.16% (Table 6.10). The sulphate sulphur content varies from 8.68 to 15.51% with an average value of 11.03% (Table 6.10).

The sulphur compositions are also represented in stacked bar diagrams in Fig. 6.8 & 6.9.

The percentage of different forms of sulphur are plotted in a triangular diagram (Figure 6.10) with the three end members of organic, pyritic and total sulphur (Ahmed, 1991a) and most of the plots fall in sub-triangle 1 representing more than 50% organic sulphur. Thus, the coal can be said organo-sulphur coal according to this classification.

6.5 CALORIFIC VALUE

6.5.1 Bomb calorimeter

The calorific value of coal is determined in the laboratory using Bomb calorimeter. Air dried samples of coal liberate 6712.8 to 7592.5 cal/gm (12083.34 to 13666.50 B.Th.U/lb) calorific value (Table 6.11). The average calorific value of coal is 7326.2 cal/gm (13197.12 B.Th.U/lb).

6.5.2 Goutal's formula

The calorific value of coal calculated from the proximate analyses using the Goutal's formula ranges from 7082.42 to 7817.54 cal/gm (12748.36 to 14071.57 B.Th.U/lb) with an average of 7423.22

cal/gm (13361.79 B.Th.U/lb) (Table 6.12) in air dried basis. In dry moisture free basis the calorific value ranges from 7221.00 to 7952.51 cal/gm (12997.80 to 14314.33 B.Th.U/lb) with an average value of 7556.51 cal/gm (13601.70 B.Th.U/lb) (Table 6.13). In dry ash free basis it ranges from 7439.52 to 8075.98 cal/gm (13391.14 to 14536.76 B.Th.U/lb) with an average value of 7741.82 cal/gm (13935.27 B.Th.U/lb) (Table 6.13) and in dry mineral matter free basis it ranges from 7484.08 to 8109.88 cal/gm (13471.34 to 14597.78 B.Th.U/lb) with an average value of 7782.03 cal/gm (14007.65 B.Th.U/lb) (Table 6.13).

6.5.3 Useful heat value

The useful heat value of coal calculated from the proximate analyses data ranges from 7185.8 to 7627.4 cal/gm (12934.44 to 13729.32 B.Th.U/lb) with an average of 7433.63 cal/gm (13380.53 B.Th.U/lb) in air dried basis (Table 6.14). In dry moisture free basis the useful heat value ranges from 7310.07 to 7751.42 cal/gm (13158.13 to 13952.56 B.Th.U/lb) with an average value of 7565.65 cal/gm (13618.17 B.Th.U/lb) (Table 6.15). In dry ash free basis it ranges from 7636.34 to 7839.05 cal/gm (13745.41 to 14110.29 B.Th.U/lb) with an average value of 7751.34 cal/gm (13952.41 B.Th.U/lb) (Table 6.15). In dry mineral matter free basis it ranges from 7702.65 to 7861.68 cal/gm (13864.77 to 14151.02 B Th.U/lb) with an average value of 7793.79 cal/gm (14028.82 B.Th.U/lb) (Table

6.15).

The calorific values determined in the laboratory are compared with the calculated values using Goutal's formula and useful heat value formula (Table 6.16). The calculated values are in general higher than the determined values which ranges (in air dried basis) from 7.1 to 107.1 cal/gm (12.78 to 196.06 B.Th.U/lb) and the average is 43.86 cal/gm (92.62 B.Th U/lb). It is observed from the correlation table (Table 6.16) that the calculated values by Goutal's formula are higher than the determined values (bomb calorimeter) and the values found by applying useful heat values formula are mostly higher than the determined and calculated values in air dried basis.

6.6 TRACE ELEMENTS IN COAL

Concentration of trace elements in coal are shown in Table 6.17. Measured metals are lead, copper, manganese, zinc, chromium, nickel, cobalt, calcium, magnesium and selenium. Concentration of trace elements were measured in parts per million (ppm) of the total coal. The concentration ranges of the trace elements in coal are lead from 0.1 to 1.4 ppm, copper from 1.2 to 3.5 ppm, manganese from 0.1 to 0.4 ppm, zinc from 0.6 to 1.6 ppm, chromium from 0.1 to 1.4 ppm. The concentration of nickel is detectable from samples 4, 3 and 24 only. The concentration of nickel is 0 1 to 0.4 ppm. Cobalt concentration is also detectable from sample no. 4, 10, 17. The concentration of cobalt is 0.1 ppm The cadmium concentration is not

detectable in the coal. The rich concentration of Se from 105.7 to 139.2 ppm in coal appear to be due to post burial enrichment by circulating ground water containing the elements (Table 6.17). The concentration of the elements lead, copper, manganese, zinc and chromium are plotted against the ash per cent of the coal samples (Figures 6.11, 6.12, 6.13, 6.14 and 6.15). From the figures it is seen that concentration of lead, copper, zinc and chromium increases with increasing ash content of the coal and concentration of manganese decreases with increasing ash content of the coal. It indicates that copper, zinc, chromium and cobalt are concentrated mainly in the inorganic fractions of the coal and manganese are concentrated mainly in the organic fractions of the coal.

6.7 ANALYSIS OF MINE WATER

Due to mining of coal and subsequent utilisation of coal, water is polluted in various ways. The stagnation of mine water leads to health hazards. Besides the ponds, rivers are polluted due to discharge of ash or coal fines from nearby power stations or washeries.

The coal mining area of Bapung is characterised by various streams and rivulets. Analysis of such water, flowing through the rocks, leaching ionic species including metals provide a huerestic approach to the geochemical study of the area

The seepage water from various coal mines of Bapung area

were analysed. The water samples were obtained from five strategically selected sites and the results are furnished in Table 6.18. From the table it is evident that pH value of sites 1, 2, 4 and 5 is *ca.* 3 which indicates that seepage water from coal mines are quite acidic and the corresponding conductivity varies from 287 to 976 μs/cm and the TDS varies from 143 to 487 mg/L. The higher TDS in the water indicates that ions are mostly in the form of dissolved sulphates. In site 3 where pH of water recorded was 6 is consistent with the low TDS and conductivity.

Atomic Absorption Spectroscopic (AAS) study reveals the presence of as many as six heavy metals viz., iron, cobalt, zinc, manganese, lead and copper (Table 6.19). Cadmium and chromium were not detected. Calcium and magnesium expectedly were found in all the samples analysed. Se detected from site 4 is a noteworthy feature and is characteristic of NE region and is thus of concern from toxicity viewpoint. A high concentration of Fe in site 4 presumably indicates greater leaching of Fe from the pyrites of original coal which contains significant amount of iron disulphates in the form of pyrites.

The results of the analysis suggest that the water is highly acidic with large quantity of dissolved ions. Presence of heavy metals renders the water unsuitable and unsafe for drinking and other domestic uses.

Table 6.1 Specific gravity of Bapung coal

Sample No.	Specific gravity
1	1.27
2	1.31
3	1.41
4	1.17
5	1.21
6	1.22
7	1.35
8	1.25
9	1.33
10	1.22
14	1.34
15	1.37
16	1.27
17	1.29
18	1.40
19	1 28
20	1.27
21	1.29
22	1.39
23	1.29
24	1.30
Average	1.30
Maximum	1.41
Minimum	1.21

Table 6.2 Results of proximate analysis of Bapung coal in air dried basis (in weight per cent)

Sample No.	Moisture	Ash	Volatile matter	Fixed carbon
1	1.8	1.5	42.15	54.55
2	2.0	1.6	40.25	56.15
3	1.9	2.8	41.20	54.10
4	2.0	1.6	42.30	54.10
5	1.7	2.7	44.70	50.90
6	1.8	2.4	44.25	51.55
7	1.6	1.5	43.70	53.20
8	1.8	2.4	40.10	55.70
9	1.5	2.2	42.75	53.55
10	1.7	4.2	44.10	50.00
11	2.0	2.4	40.25	55.35
12	1.9	3.4	42.35	52.35
13	1.6	1.1	44.20	53.10
14	1.5	1.6	42.23	54.67
15	1.7	1.5	40.02	56.78
16	1.5	1.7	40.02	56.78
17	1.7	2.2	42.32	53.78
18	1.6	2.1	42.02	54.28
19	1.7	2.5	43.67	52.13
20	2.1	2.7	45.25	49.95
21	1.8	2.5	43.07	52.63
22	1.6	3.7	44.25	50.45
23	1.9	3.1	42.02	52.98
24	1.5	3.2	42.87	52.43
Average	1.7	2.4	42.50	53.39
Maximum	2.1	4.2	45.25	56.78
Minimum	1.5	1.1	40.02	49.95

Table 6.3 Results of proximate analysis of coal in dry moisture free basis (in weight per cent)

Sample No.	Ash	Volatile matter	Fixed carbon
1	1.53	42.92	55.55
2	1.63	41.07	57.29
3	2.85	41.99	55.14
4	1.63	43.16	55.20
5	2.74	45.47	51.78
6	2.44	45.06	52.49
7	1.52	44.41	54.06
8	2.44	40.83	56.72
9	2.23	43.40	54.37
10	4 27	44 86	50.86
11	2.45	41.07	56.48
12	3.46	43.17	53.36
13	1.12	44.92	55.96
14	1.62	42.87	55.50
15	1.52	40.71	57.76
16	1.73	40.63	57.64
17	2.24	43.05	54.71
18	2.13	42.70	55.16
19	2.54	44.43	53.03
20	2.76	46.22	51.02
21	2.55	43.86	53.59
22	3.76	44.97	51.27
23	3.16	42.83	54.01
24	3.25	43.52	53.23
Average	2.40	43.26	54.42
Maximum	4.27	46.22	57.76
Minimum	1.12	40 63	50.86

Table 6.4 Results of proximate analysis of coal in dry ash free basis (in weight per cent)

Sample No.	Volatile matter	Fixed carbon
1	43.69	56.41
2	41.75	58.25
3	43.23	56.77
4	43.88	56.12
5	46.76	53.24
6	46.18	53.81
7	45.09	54.90
8	41.85	58.14
9	44.39	55.60
10	46.86	53.13
11	42.10	57.89
12	44.72	55.28
13	45.43	55.57
14	43.58	56.42
15	41.34	58.66
16	41.34	58.66
17	44.04	55.96
18	43.63	56.37
19	45.58	54.42
20	47.53	52.47
21	45.00	55.00
22	46.73	53.27
23	44.23	55.77
24	44.98	55.02
Average	44.33	55.71
Maximum	47.53	58.66
Minimum	41.34	52.47

Table 6.5 Results of proximate analysis of coal in dry mineral matter free basis

Sample No.	Volatile matter (wt. %)	Fixed carbon (wt. %)	Fuel ratio (FC/VM)
1	42.73	56.59	1.32
2	41.90	58.46	1.40
3	43.47	57.08	1.31
4	44.03	56.32	1.28
5	46.99	53.50	1.14
6	46.46	54.13	1.15
7	45.28	55.12	1.21
8	42.12	58.50	1.39
9	44.64	55.91	1.25
10	47.27	53.59	1.13
11	42.37	58.26	1.38
12	45.06	55.69	1.24
13	45.56	54.73	1.20
14	43.74	56.63	1.29
15	41.52	58.90	1.42
16	41.56	58.96	1.42
17	44.29	56.28	1.28
18	43.85	56.64	1.29
19	45.89	54.51	1.19
20	47.82	52.78	1.10
21	45.17	55.19	1.22
22	47.21	53.82	1.14
23	44.56	56.18	1.26
24	45.25	55.34	1.22
Average	44.53	55.96	1.26
Maximum	47.82	58.96	1.42
Minimum	41.52	52.78	1.10

Table 6.6 Colour of the ash and character of the coke beads of Bapung coal

Sample No.	Colour of ash	Character of the coke beads
1	Light brown	Fissured, non-swelling, porous and medium hard
2	Brown	Black, metallic lustre, after heating it swells and becomes porous
3	Light brown	Colour in carbon-black with reddish lustre, after heating it swells and becomes porous
4	Pink	Fissured, non-swelling, black, porous and medium hard
5	Light pink	Grey, non-porous, fissured and slightly swelling
6	Pink	Grey, non-porous, fissured and slightly swelling
7	Deep brown	Grey, non-porous, fissured and slightly swelling
8	Brown	Black, metallic lustre, swells and porous
9	Light brown	Black, metallic lustre, swells and porous
10	Reddish	Black, metallic lustre, after heating it swells and becomes porous
11	Greyish brown	Fissured, non-swelling, porous
12	Violet	Grey, non-porous, fissured, swells
13	Deep brown	Grey, non-porous, fissured, swells
14	Brown	Grey, non-porous, fissured, swells
15	Greyish brown	Grey, non-porous, fissured, swells
16	Brown	Grey, non-porous, fissured, swells
17	Greyish brown	Black, metallic lustre, after heating it swells and becomes porous
18	Deep brown	Grey, non-porous, fissured and slightly swelling
19	Light yellow	Black in colour, porous and non-swelling
20	Brown	Black, metallic lustre, after heating it swells
21	Light pink	Grey, fissured and shows slightly swelling
22	Light brown	Colour is black, reddish lustre, porous
23	Light yellow	Black in colour, porous and non-swelling
24	Greyish white	Black in colour, porous and non-swelling

Table 6.7 Elemental composition of Bapung coal in air dried basis (in weight per cent)

Sample No.	Moisture	Mineral matter	Carbon	Hydrogen	Nitrogen	Sulphur (organic)	Oxygen
1	1.8	1.81	74.28	5.62	2.56	3.36	10.57
2	2.0	1.96	71.36	5.13	2.71	3.38	13.46
3	1.9	3.32	75.02	5.39	2.80	3.47	8.10
8	1.8	2.98	74.58	5.86	1.68	3.14	10.24
9	1.5	2.73	73.34	5.14	2.11	2.44	12.74
10	1.7	5.01	72.89	5.70	1.79	3.57	9.34
11	2.0	3.00	75.67	5.65	1.32	3.37	8.99
12	1.9	4.11	72.02	5.55	2.10	3.43	10.89
13	1.6	1.38	74.56	5.57	2.72	3.64	10.53
17	1.7	2.75	71.36	5.60	1.90	2.99	13.70
18	1.6	2.56	72.59	5.57	2.56	3.24	11.88
19	1.7	3.13	74.68	5.53	2.70	2.27	9.99
24	1.5	3.77	72.36	5 47	2.23	3.95	10.72
Average	1.7	2.96	73.44	5.52	2.24	3.25	10.86
Maximum	2.0	5.01	75.67	5.86	2.80	3.95	13.70
Minimum	1.5	1.38	71.36	5.13	1.32	2.27	8.10

Table 6.8 Elemental composition of coal in dry mineral matter free basis

Sample No.	Carbon (wt. %)	Hydrogen (wt. %)	Nitrogen (wt. %)	Sulphur (organic) (wt. %)	Oxygen (wt. %)	H/C	O/C
1	77.06	5.83	2.66	3.49	10.97	0.08	0.14
2	74.30	5.32	2.82	3.52	14.01	0.07	0.19
3	79.15	5.69	2.95	3.66	8.55	0.07	0.11
8	78.32	6.15	1.76	3.29	10.75	0.08	0.14
9	76.58	5.37	2.20	2.55	13.30	0.07	0.17
10	78.13	6.11	1.92	3.83	10.01	0.08	0.13
11	79.65	5.95	1.39	3.55	9.46	0.07	0.12
12	76.63	5.90	2.23	3.65	11.59	0.08	0.15
13	76.85	5.74	2.80	3.75	10.85	0.07	0.14
17	74.68	5.86	1 99	3.13	14.34	0.08	0 19
18	75.74	5.81	2.67	3.38	12.39	0.08	0.16
19	78.47	5.81	2.84	2.39	10.49	0 07	0.13
24	76.39	5.77	2.35	4.17	11.32	0.08	0 15
Average	77.07	5.79	2.35	3.41	11.39	0.08	0.15
Maximum	79.65	6.15	2.95	4.17	14.01	0.08	0.19
Minimum	74.30	5.32	1.39	2.39	8.55	0.07	0.11

Table 6.9 Sulphur content of Bapung coal in air dried basis (in weight per cent)

Sample No.	Total sulphur	Sulphate sulphur	Pyritic sulphur	Organic sulphur
1	4.11	0.41	0.34	3.36
2	4.25	0.45	0.42	3.38
3	4.45	0.43	0.55	3.47
4	4.31	0.52	0.38	3.41
5	3.76	0.46	0.45	2.85
6	4.27	0.42	0.68	3.17
7	4.38	0.57	0.48	3.33
8	4.40	0.54	0.72	3.14
9	3.58	0.50	0.64	2.44
10	5.02	0.59	0.86	3.57
11	4.69	0.58	0.74	3.37
12	4.71	0.48	0.80	3.43
13	4.38	0.38	0.36	3.64
14	4.39	0.42	0.41	3.56
15	4.45	0.52	0.52	3.41
16	3.60	0.47	0.66	2.47
17	4.20	0.53	0.68	2.99
18	4.27	0.49	0.54	3.24
19	3.37	0.32	0.78	2.27
20	4.09	0 27	0.63	3.19
21	4.75	0.27	0.28	4.20
22	5.03	0.78	1.21	3.04
23	4.08	0.55	0.84	2.69
24	4.97	0.45	0.57	3.95
Average	4.31	0.48	0.61	3.07
Maximum	5.03	0.78	1.21	4.20
Minimum	3.58	0.27	0.28	2.27

Table 6.10 Forms of sulphur of coal (in weight per cent of total sulphur)

Sample No.	Sulphate sulphur	Pyritic sulphur	Organic sulphur
1	9.98	8.27	81.75
2	10.59	9.88	79.53
3	9.66	12.36	77.98
4	12.06	8 82	79.12
5	12.23	12.00	75.79
6	9.84	15.93	74.24
7	13.01	10.96	76.03
8	12.27	16.36	71.36
9	13.97	17.88	68.16
10	11.75	17.13	71.12
11	12.37	15 78	71.86
12	10.19	16.99	72.82
13	8.68	8.22	83.11
14	9.57	9.94	81.09
15	11.69	11.69	76.63
16	13.06	18.33	68.61
17	12 62	16.19	71.19
18	11.48	12.65	75.88
19	9.49	23.15	67.36
20	6.60	15.40	77.99
21	5.68	5.89	88.42
22	15.51	24.06	60.44
23	13.48	20.59	65.93
24	9.05	11.47	79.48
Average	11.03	14.16	74.83
Maximum	15 51	24 06	88.42
Minimum	8.68	8.22	60 44

Table 6.11 Calorific value of Bapung coal in air dried basis (determined in Bomb calorimeter)

Sample No.	Cal/gm	B.Th.U/lb
1	7254.6	13058.28
2	6809.2	12256.56
3	7461.9	13431.42
4	7474.7	13454.46
5	7106.3	12791.34
6	6712.8	12083.04
7	7390.8	13303.44
8	7546.6	13583.88
9	7341.2	13214.16
10	7021.5	12638.70
11	7489.4	13480.92
12	7230.2	13014.36
13	7420.3	13356.54
14	7510.7	13519 26
15	7592.5	13666.50
16	7592.5	13666.50
17	7423.6	13542 48
18	7492.4	13486.32
Average	7326.2	13197.12
Maximum	7592.5	13666.50
Minimum	6712.8	12083.34

Table 6.12 Calorific value of coal in air dried basis (calculated using Goutal's formula)

Sample No.	Volatile matter (wt.% in air dried basis)	Fixed carbon (wt. % in air dried basis)	Volatile matter (wt% in DMMF basis)	α	Calorific value	
					Cal/gm	B.Th.U/lb
1	42.15	54.55	43.59	73	7550.05	13590.09
2	40.25	56.15	41.75	76	7623.05	13721.49
3	41.20	54.10	43.23	74	7485.00	13473.00
4	42.30	54.10	43.88	74	7481.80	13467.24
5	44.70	50.90	46.76	68	7213.40	12984.12
6	44.25	51.55	46.18	69	7280.35	13104.63
7	43.70	53.20	45.09	70	7421.40	13358.52
8	40.10	55.70	41.85	76	7615.00	13707.00
9	42.75	53.55	44.39	70	7383.60	13290.48
10	44.10	50.00	46.86	68	7098.80	12777.84
11	40.25	55.35	42.10	75	7557.45	13603.41
12	42.35	52.35	44.72	70	7257.20	13062.96
13	44.20	53.10	45.43	70	7448.20	13406.76
14	42.23	54.67	43.58	73	7565.73	13618.31
15	40.02	56.78	41.34	79	7817.54	14071.57
16	40.02	56.78	41.34	79	7817.54	14071.57
17	42.32	53.78	44.04	71	7414.68	13346.42
18	42.02	54.28	43.63	73	7518.42	13533.15
19	43.67	52.13	44.20	72	7418.90	13354.02
20	45.25	49.95	47.53	66	7082.42	12748.36
21	43.07	52.63	45.00	70	7330.56	13195.01
22	44.25	50.45	46.73	69	7190.15	12942.27
23	42.02	52.98	44.23	70	7285.76	13114.37
24	42.87	52.43	44.98	70	7300.16	13140.29
Average					7423.22	13361.79
Maximum					7817.54	14071.57
Minimum					7082.42	12748.36

Table 6.13 Calorific value in different basis

Sample No.	Calorific value (dry moisture free basis) cal/gm (B.Th.U/lb)	Calorific value (dry ash free basis) cal/gm (B.Th.U/lb)	Calorific value (dry mineral matter free basis) cal/gm (B.Th.U/lb)
1	7688.26 (13838.86)	7807.69 (14053.84)	7802.40 (14044.32)
2	7819.10 (14074.38)	7949.50 (14309.10)	7978.12 (14360.61)
3	7628.74 (13731.73)	7854.16 (14137.49)	7897.34 (14215.21)
4	7633.92 (13741.05)	7761.20 (13970.16)	7788.40 (14019.12)
5	7337.92 (13208.25)	7545.36 (13581.65)	7582.32 (13648.17)
6	7413.32 (13343.97)	7598.84 (13677.91)	7644.40 (13759.92)
7	7541.62 (13574.91)	7658.10 (13784.58)	7689.44 (13840.99)
8	7754.12 (13957.41)	7948.08 (14306.54)	7998.12 (14396.61)
9	7496.34 (13493.41)	7666.50 (13799.70)	7709.42 (13876.95)
10	7221.00 (12997.8)	7543.14 (13577.65)	7608.74 (13695.73)
11	7711.61 (13880.89)	7904.48 (14228.06)	7955.07 (14319.12)
12	7397.42 (13315.35)	7663.36 (13794.05)	7720.78 (13987.40)
13	7569.12 (13624.41)	7654.84 (13778.71)	7677.06 (13818.70)
14	7680.51 (13824.91)	7807.78 (14054.00)	7836.68 (14106.02)
15	7952.41 (14314.33)	8075.98 (14536.76)	8109.88 (14597.78)
16	7936.25 (14285.25)	8075.98 (14536.76)	8117.96 (14612.32)
17	7542.77 (13576.98)	7715.56 (13888.01)	7759.55 (13967.19)
18	7640.22 (13752.39)	7807.33 (14053.19)	7845.53 (14121.95)
19	7547.42 (13585.36)	7744.20 (13939.56)	7773.90 (13993.02)
20	7234.16 (13021.49)	7439.52 (13391.14)	7484.08 (13471.34)
21	7464.58 (13436.24)	7660.00 (13788.00)	7687.48 (13837.46)
22	7307.07 (13152.73)	7592.51 (13666.52)	7670.73 (13807.31)
23	7426.92 (13368.46)	7669.24 (13804.63)	7725.96 (13906.73)
24	7411.26 (13340.27)	7660.24 (13788.43)	7705.38 (13869.68)
Average	7556.51 (13601.70)	7741.82 (13935.27)	7782.03 (14007.65)
Maximum	7952.51 (14314.33)	8075.98 (14536.76)	8109.88 (14597.78)
Minimum	7221.00 (12997.80)	7439.52 (13391.14)	7484.08 (13471.34)

Table 6.14 Useful heat value of coal in air dried basis

Sample No.	Ash (wt. % in air dried basis)	Moisture (wt. % in air dried basis)	138 (A+M)	Useful heat value Cal/gm (B.Th.U/lb)
1	1.5	1.8	455.4	7544.6 (13580.28)
2	1.6	2.0	496.8	7503.2 (13505.76)
3	2.8	1.9	648.6	7351.4 (13232.52)
4	1.6	2.0	496.8	7503.2 (13505.76)
5	2.7	1.7	607.2	7392.8 (13307.04)
6	2.4	1.8	579.6	7420.4 (13356.72)
7	1.5	1.6	427.8	7572.2 (13629.96)
8	2.4	1.8	579.6	7420.4 (13356.72)
9	2.2	1.5	510.6	7489.4 (13480.92)
10	4.2	1.7	814.2	7185.8 (12934.44)
11	2.4	2.0	607.2	7392.8 (13307.04)
12	3.4	1.9	731.4	7268.6 (13083.48)
13	1.1	1.6	372.6	7627.4 (13729.32)
14	1.6	1.5	427.8	7572.2 (13629.96)
15	1.5	1.7	441.6	7558.4 (13605.12)
16	1.7	1.5	441.6	7558.4 (13605.12)
17	2.2	1.7	538.2	7461.8 (13431.24)
18	2.1	1.6	510.6	7489.4 (13480.92)
19	2.5	1.7	579.6	7420.4 (13356.72)
20	2.7	2.1	662.4	7337.6 (13207.68)
21	2.5	1.8	593.4	7406.6 (13331.88)
22	3.7	1.6	731.4	7268.6 (13083.48)
23	3.1	1.9	690.0	7310.0 (13158.00)
24	3.2	1.5	648.6	7351.4 (13232.52)
Average				7433.6 (13380.48)
Maximum				7627.4 (13729.32)
Minimum				7185.8 (12934.44)

Table 6.15 Useful heat value in different basis

Sample No.	Useful heat value (dry moisture free basis) cal/gm (B.Th.U/lb)	Useful heat value (dry ash free basis) cal/gm (B.Th.U/lb)	Useful heat value (dry mineral matter free basis) cal/gm (B.Th.U/lb)
1	7682.89 (13829.20)	7802.07 (14043.73)	7827.16 (14088.89)
2	7656.33 (13781.39)	7783.40 (14010.12)	7812.58 (14062.64)
3	7493.38 (13488.08)	7713.96 (13885.13)	7756.28 (13961.30)
4	7656.33 (13781.39)	7783.40 (14010.12)	7810.14 (14058.25)
5	7520.65 (13537.17)	7733.05 (13919.49)	7771.26 (13988.27)
6	7556.42 (13601.56)	7745.72 (13942.29)	7791.26 (14024.27)
7	7695.33 (13851.59)	7814.45 (14066.01)	7845.21 (14121.38)
8	7556.42 (13601.56)	7745.72 (13942.29)	7792.90 (14027.22)
9	7603.45 (13686.21)	7777.15 (13998.87)	7820.19 (14076.34)
10	7310.07 (13158.13)	7636.34 (13745.41)	7702.65 (13864.77)
11	7543.67 (13578.60)	7733.05 (13919.49)	7781.89 (14007.40)
12	7409.37 (13336.87)	7675.29 (13815.22)	7733.38 (13920.08)
13	7751.42 (13952.56)	7839.05 (14110.29)	7861.68 (14151.02)
14	7687.51 (13837.52)	7814.45 (14066.01)	7843.59 (14118.46)
15	7689.11 (13840.39)	7808.26 (14054.87)	7841.48 (14114.66)
16	7673.50 (13812.30)	7806.26 (14054.87)	7848.81 (14127.86)
17	7590.84 (13663.51)	7764.62 (13976.31)	7809.31 (14056.76)
18	7611.18 (13700.12)	7777.15 (13998.87)	7814.48 (14066.06)
19	7548.73 (13587.71)	7745.72 (13942.29)	7796.99 (14034.58)
20	7494.99 (13490.98)	7707.56 (13873.61)	7753.99 (13957.18)
21	7542.36 (13576.25)	7739.39 (13930.90)	7767.80 (13982.04)
22	7386.79 (13296.22)	7675.39 (13815.70)	7754.83 (13958.69)
23	7451.58 (13412.84)	7694.74 (13850.53)	7752.68 (13954.82)
24	7463.35 (13434.03)	7713.96 (13885.13)	7760.37 (13968.67)
Average	7565.65 (13618.17)	7751.34 (13952.41)	7793.79 (14028.82)
Maximum	7751.42 (13952.56)	7839.05 (14110.29)	7861.68 (14151.02)
Minimum	7310.07 (13158.13)	7636.34 (13745.41)	7702.65 (13864.77)

Table 6.16 Correlation of calorific value of coal in air dried basis

Sample No.	Goutal's formula cal/gm (B.Th.U/lb)	Bomb calorimeter cal/gm (B.Th.U/lb)	Useful heat value cal/gm (B.Th.U/lb)
1	7550.05 (13590.09)	7254.6 (13058.28)	7544.6 (13580.28)
2	7623.05 (13721.49)	6809.2 (12256.56)	7503.2 (13505.76)
3	7485.00 (13473.00)	7461.9 (13431.42)	7351.4 (13232.52)
4	7481.80 (13467.24)	7474.7 (13454.46)	7503.2 (13505.76)
5	7213.40 (12984.12)	7106.3 (12791.34)	7392.8 (13307.04)
6	7280.35 (13104.63)	6712.8 (12083.04)	7420.4 (13356.72)
7	7421.40 (13358.52)	7390.8 (13303.44)	7572.2 (13629.96)
8	7615.00 (13707.00)	7546.6 (13583.88)	7420.4 (13356.72)
9	7383.60 (13290.48)	7341.2 (13214.16)	7489.4 (13480.92)
10	7098.80 (12777.84)	7021.5 (12638.70)	7185.8 (12934.44)
11	7557.45 (13603.41)	7489.4 (13480.92)	7392.8 (13307.04)
12	7257.20 (13062.96)	7230 2 (13014.36)	7268.6 (13083.48)
13	7448.20 (13406.76)	7420.3 (13356 54)	7627.4 (13729.32)
14	7565.73 (13618.31)	7510.7 (13519.26)	7572.2 (13629.96)
15	7817.54 (14071.57)	7592.5 (13666.50)	7558.4 (13605.12)
16	7817.54 (14071.57)	7592.5 (13666.50)	7558.4 (13605.12)
17	7414.68 (13346.42)	7423.6 (13542.48)	7461.8 (13431.24)
18	7518.42 (13533.15)	7492.4 (13486.32)	7489.4 (13480.92)
Average	7474.96 (13454.92)	7326.2 (13197.12)	7461.8 (13431.24)

Table 6.17 Trace element contents of Bapung coal in ppm of the total coal

Sample No.	Ash (wt. %)	Trace elements (ppm)										
		Pb	Cu	Mn	Zn	Cr	Ni	Co	Cd	Ca	Mg	Se
1	1.5	0.1	1.8	0.4	0.8	0.1	ND	ND	ND	ND	ND	105.7
4	1.6	0.3	2.5	0.3	1.2	0.5	0 2	0.1	ND	0.3	2.6	124.2
10	4.2	0.4	2.9	0.2	1.6	1 4	ND	0.1	ND	1.8	2.9	118.2
13	1.1	0.3	1.3	0.4	1.0	0.2	0.4	ND	ND	0.1	4.7	124.6
15	1.5	0.5	1.5	0.2	1.2	0.3	ND	ND	ND	4.0	2.3	124.8
17	2.2	1.4	3.5	0.4	1.3	0.3	ND	0.1	ND	6.2	5.3	132.9
18	2.1	0.1	1.2	0.4	0.6	0.2	ND	ND	ND	0.3	4.7	139.2
20	2.7	0.4	1.2	0.2	0.9	0.3	ND	ND	ND	3.9	4.2	132.0
24	3.2	0.4	1.5	0.1	0.9	0.6	0.1	ND	ND	2.5	4.7	130.7
Maximum		1.4	3.5	0.4	1.6	1.4	0.4	0.1	ND	6.2	5.3	139.2
Minimum		0.1	1.2	0 1	0 6	0.1	0.1	0.1	ND	0.1	2.3	105.7

Table 6.18 Results of mine water analyses of Bapung coal

Site No.	pH	TDS (in mg/L)	Conductivity (in µs/cm)
1	2.99	366	743
2	2.82	487	976
3	6	22	43
4	3.18	402	805
5	3.46	143	287

Table 6.19 Heavy metals in mine water (in ppm)

Site No.	Pb	Cd	Fe	Ni	Cr	Cu	Mn	Co	Ca	Mg	Se	Zn
1	0.3	ND	1.8	ND	ND	0.2	0.8	ND	0.7	1.3	ND	1.1
2	0.1	ND	1.6	0.1	ND	0.3	0.1	0.1	0.1	1.5	ND	2.1
3	0.2	ND	1.7	ND	ND	0.4	0.9	ND	0.9	2.1	ND	1.1
4	0.4	ND	17.6	0.3	ND	0.3	4.4	0.2	0.2	1.1	0.1	3.4
5	0.3	ND	1.8	ND	ND	0.3	0.2	0.1	0.2	ND	ND	1.3

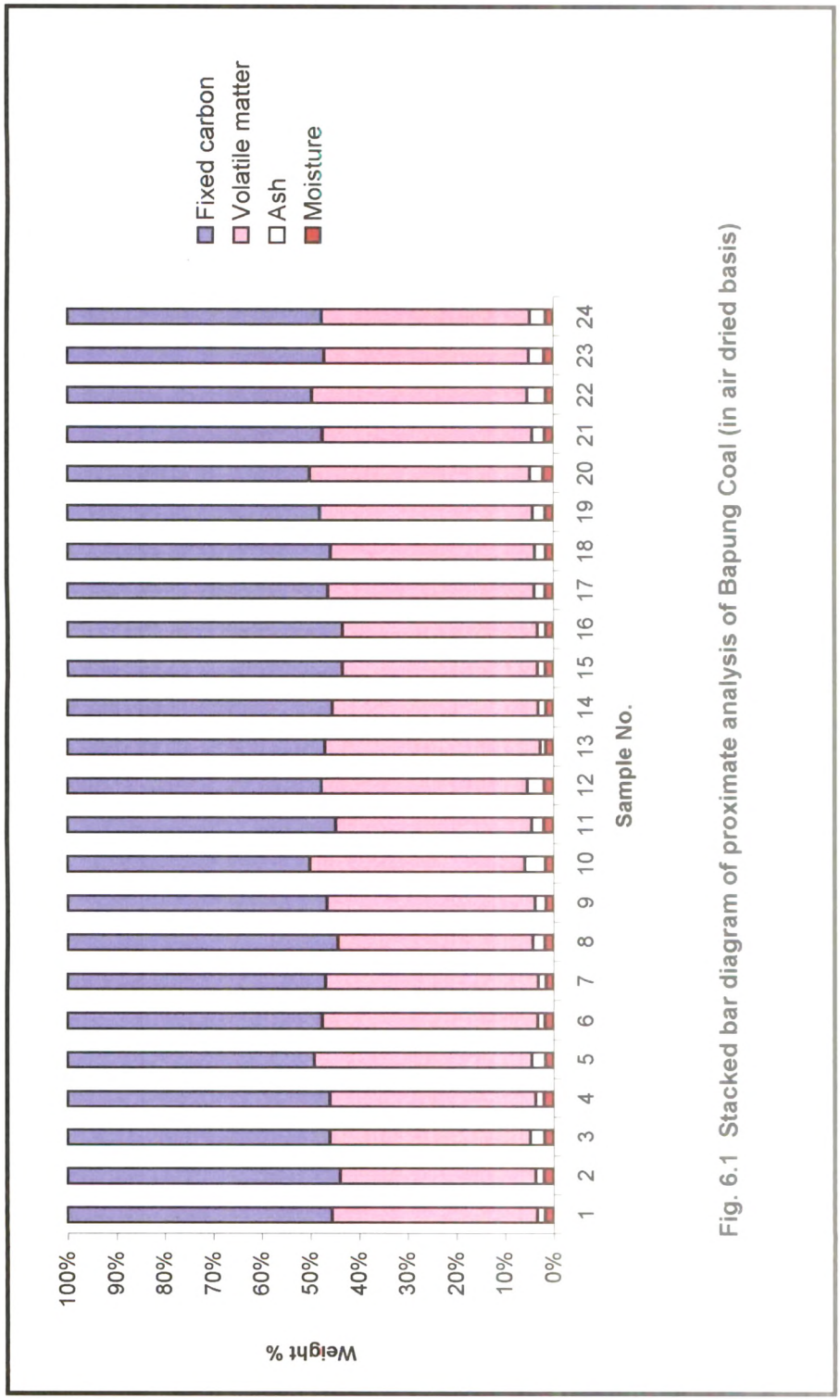


Fig. 6.1 Stacked bar diagram of proximate analysis of Bapung Coal (in air dried basis)

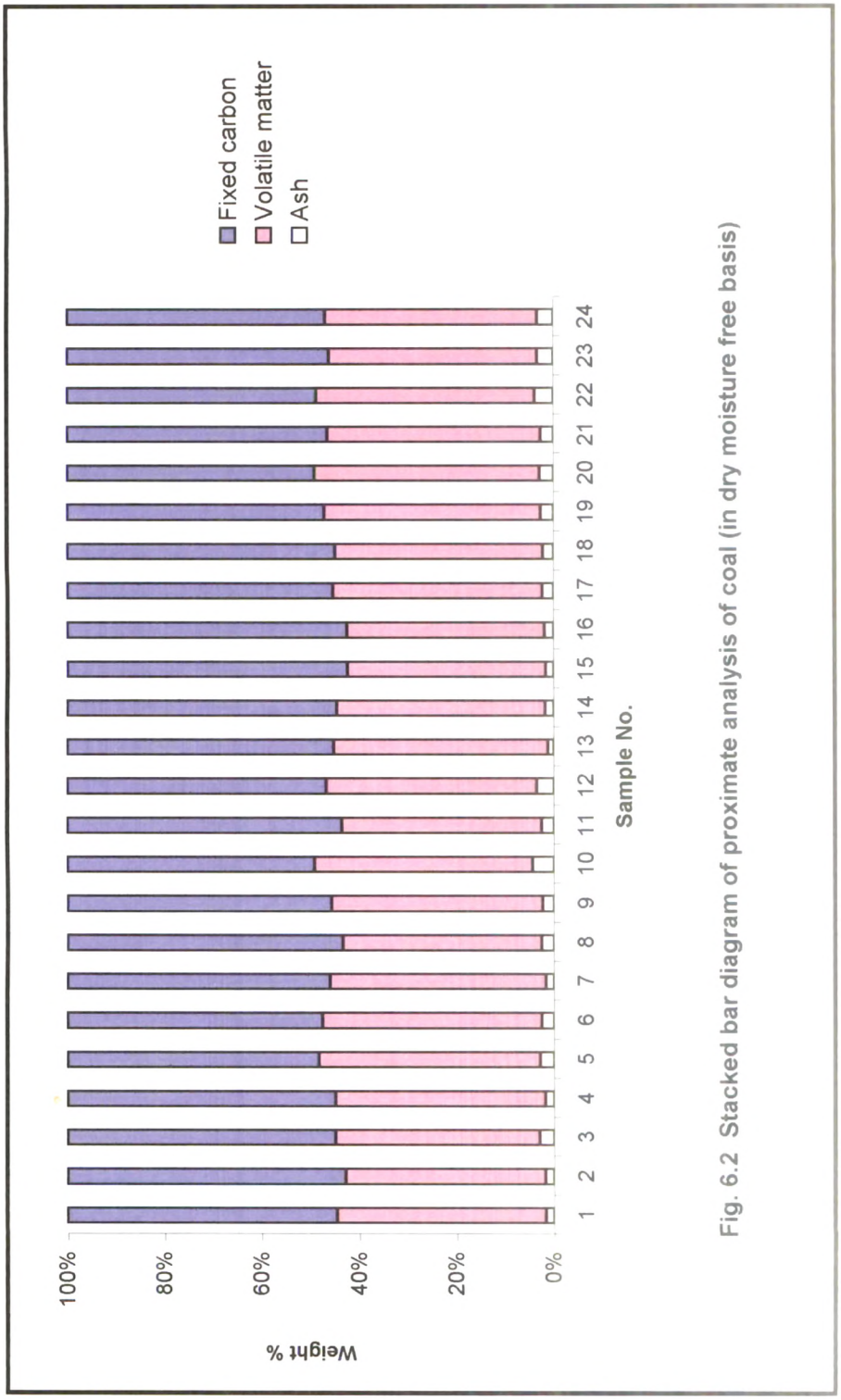


Fig. 6.2 Stacked bar diagram of proximate analysis of coal (in dry moisture free basis)

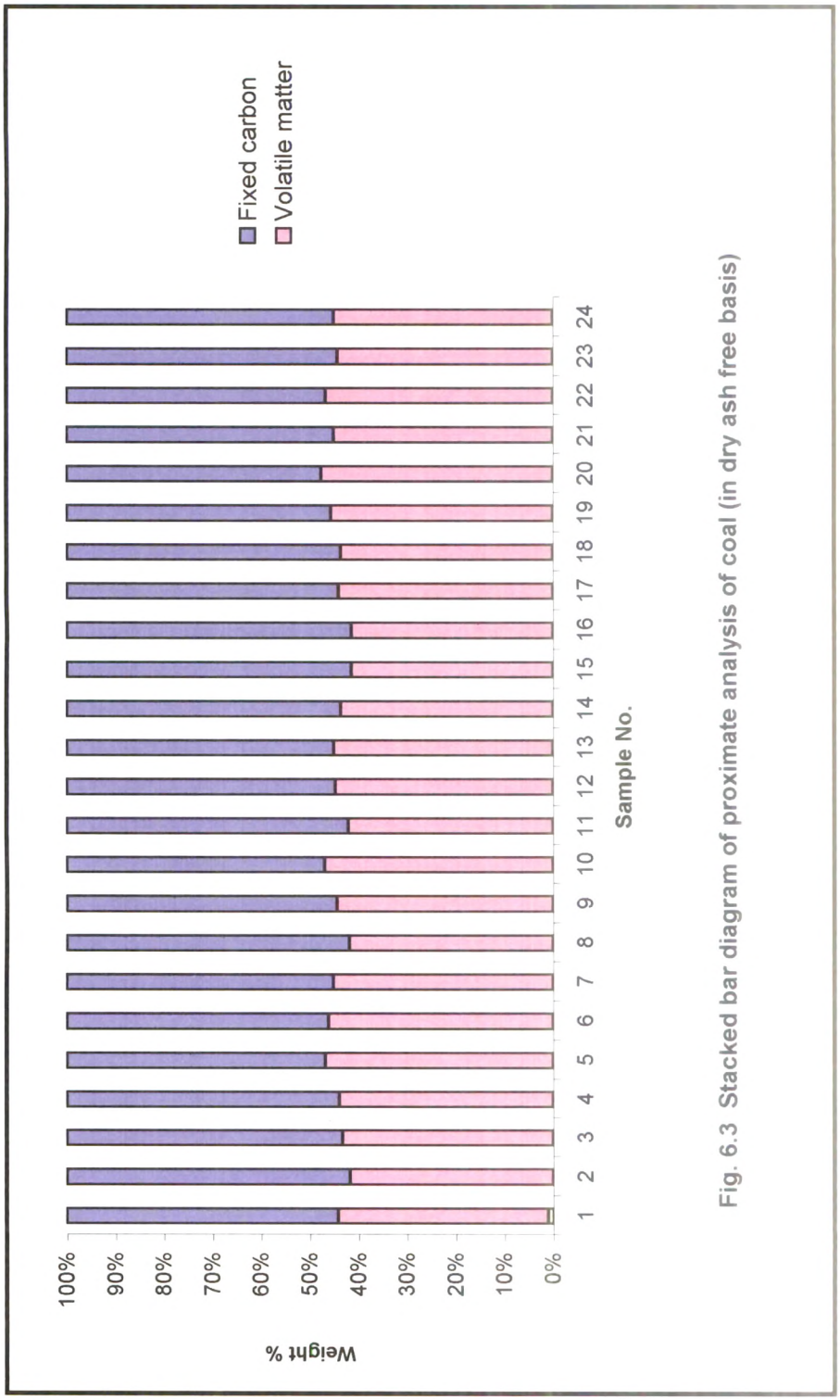


Fig. 6.3 Stacked bar diagram of proximate analysis of coal (in dry ash free basis)

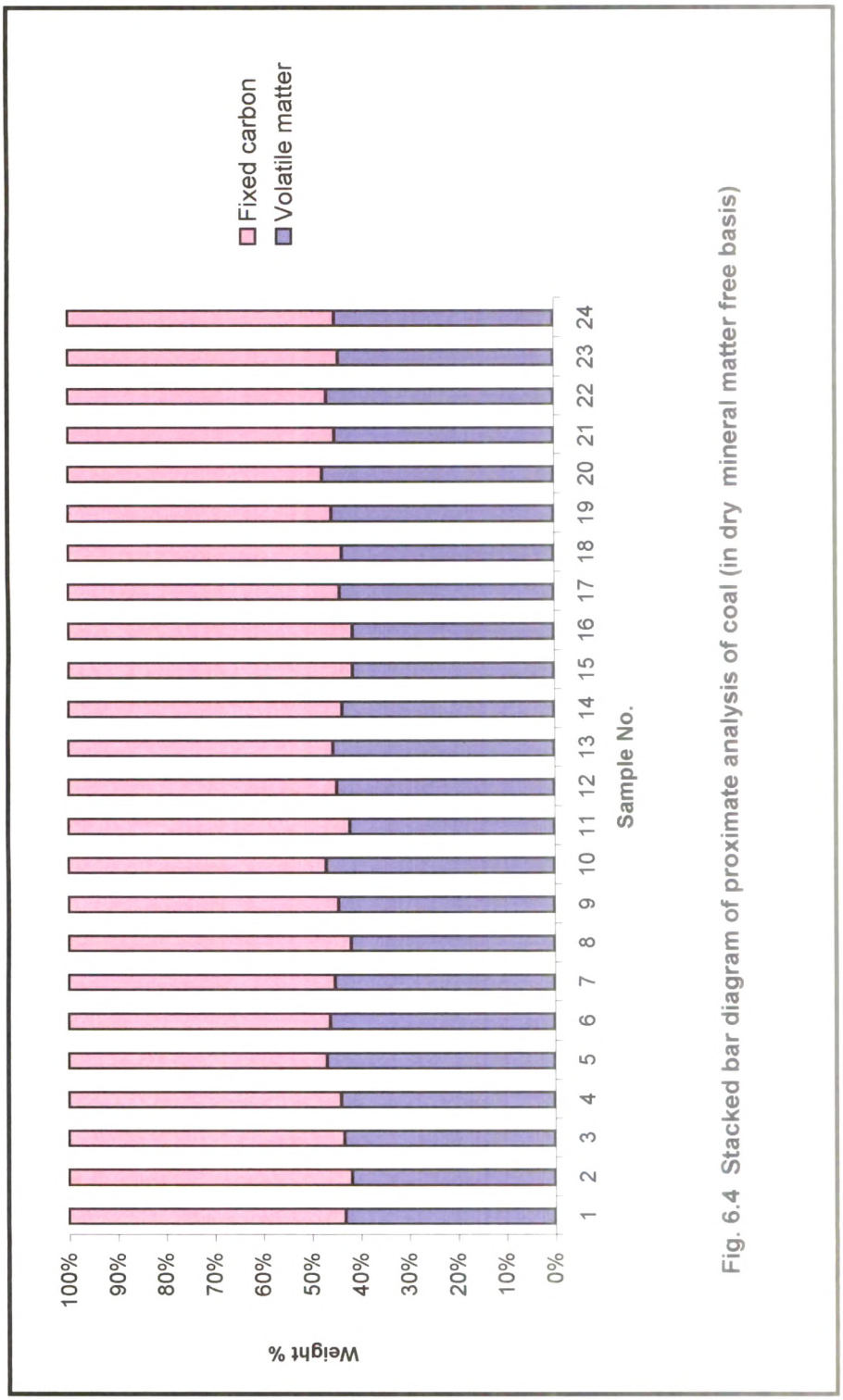


Fig. 6.4 Stacked bar diagram of proximate analysis of coal (in dry mineral matter free basis)

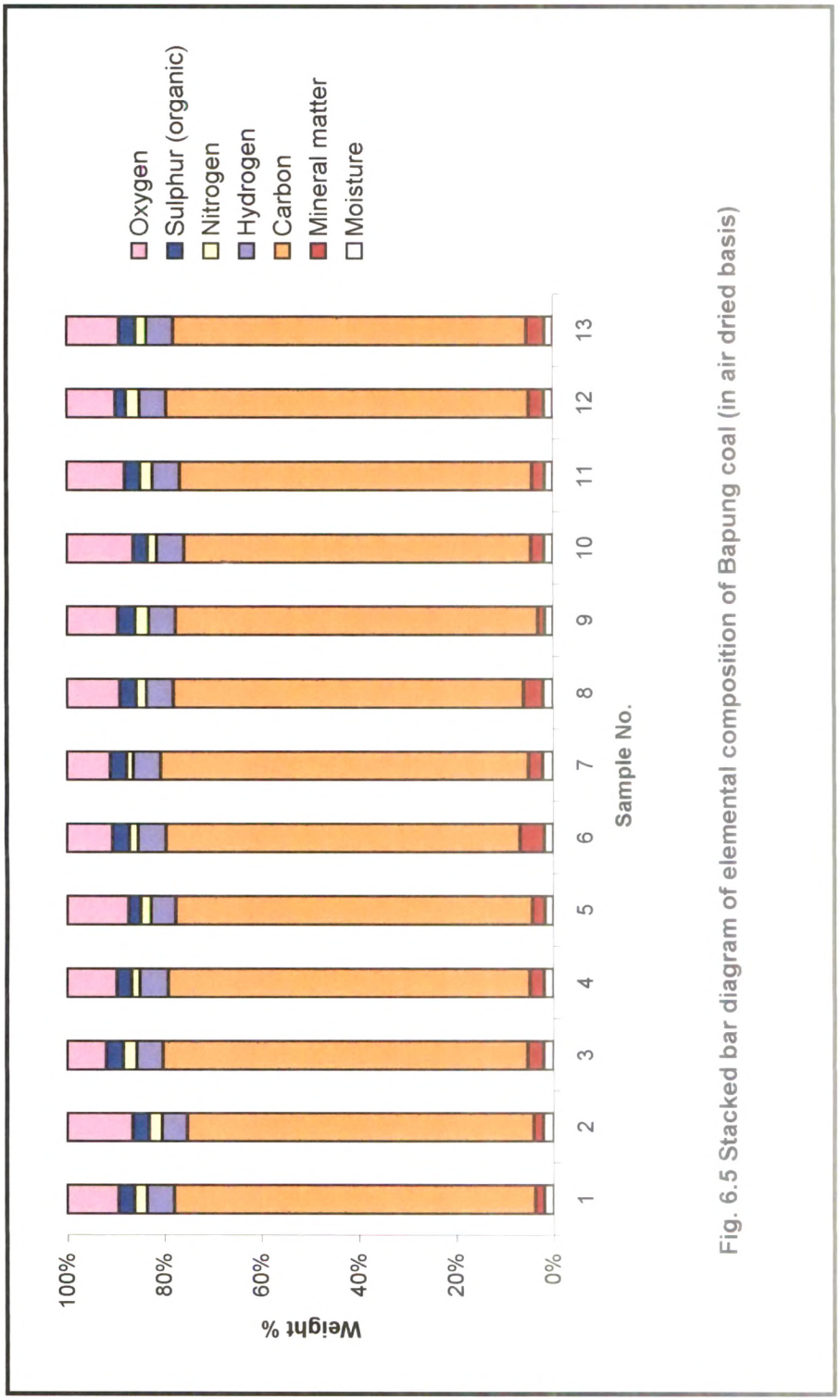


Fig. 6.5 Stacked bar diagram of elemental composition of Bapung coal (in air dried basis)

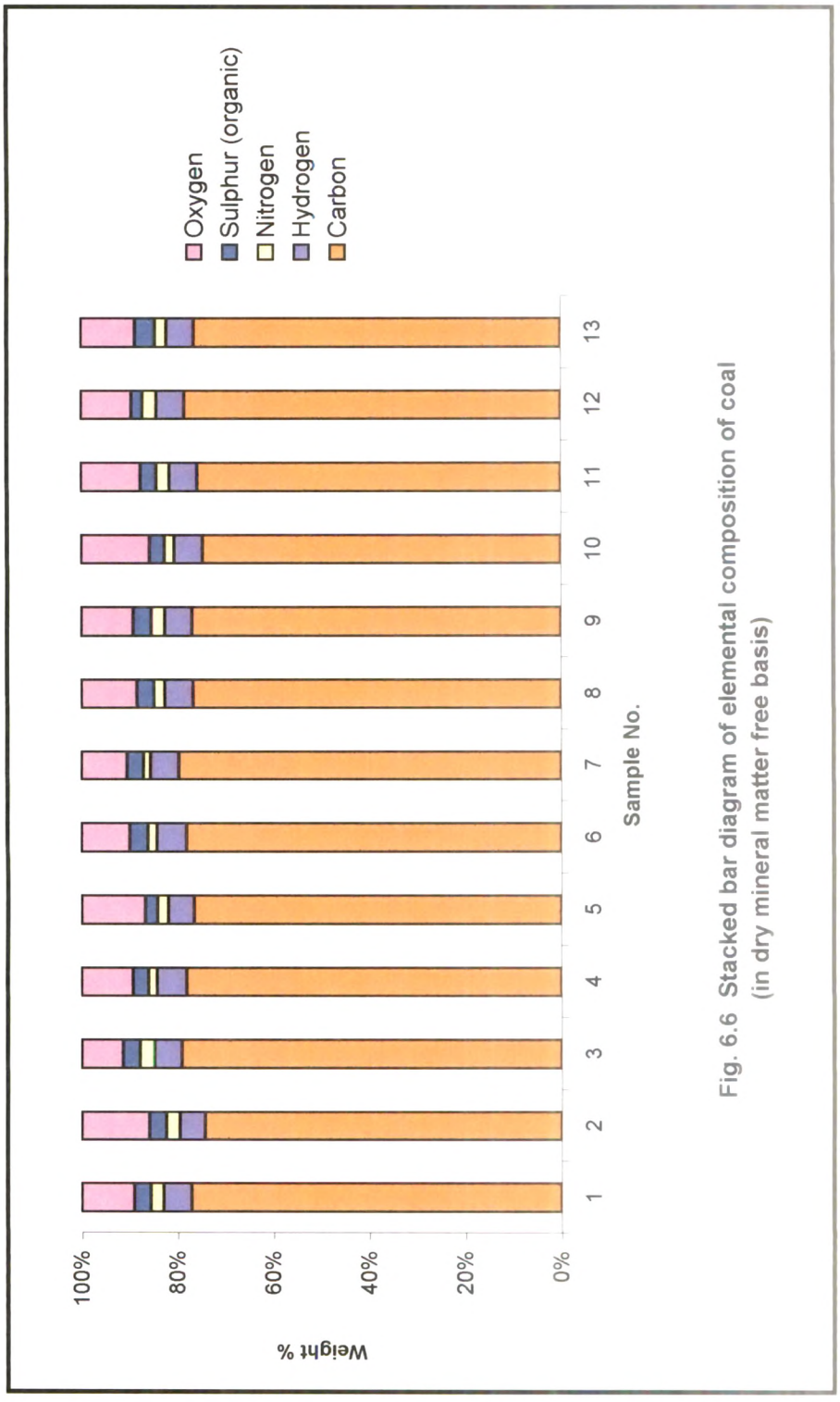
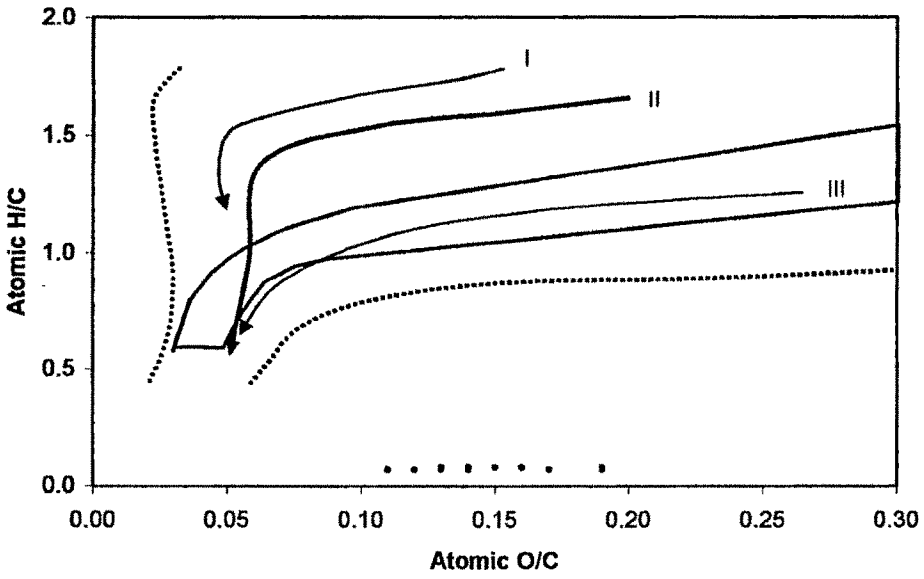


Fig. 6.6 Stacked bar diagram of elemental composition of coal (in dry mineral matter free basis)



Main path of humic coals (1984)

Boundaries of the field of kerogen

Evolution path of the principal types of kerogen

Fig. 6.7 Plots of Bapung coal in Van Krevelen diagram (after Tissot and Welte, 1984)

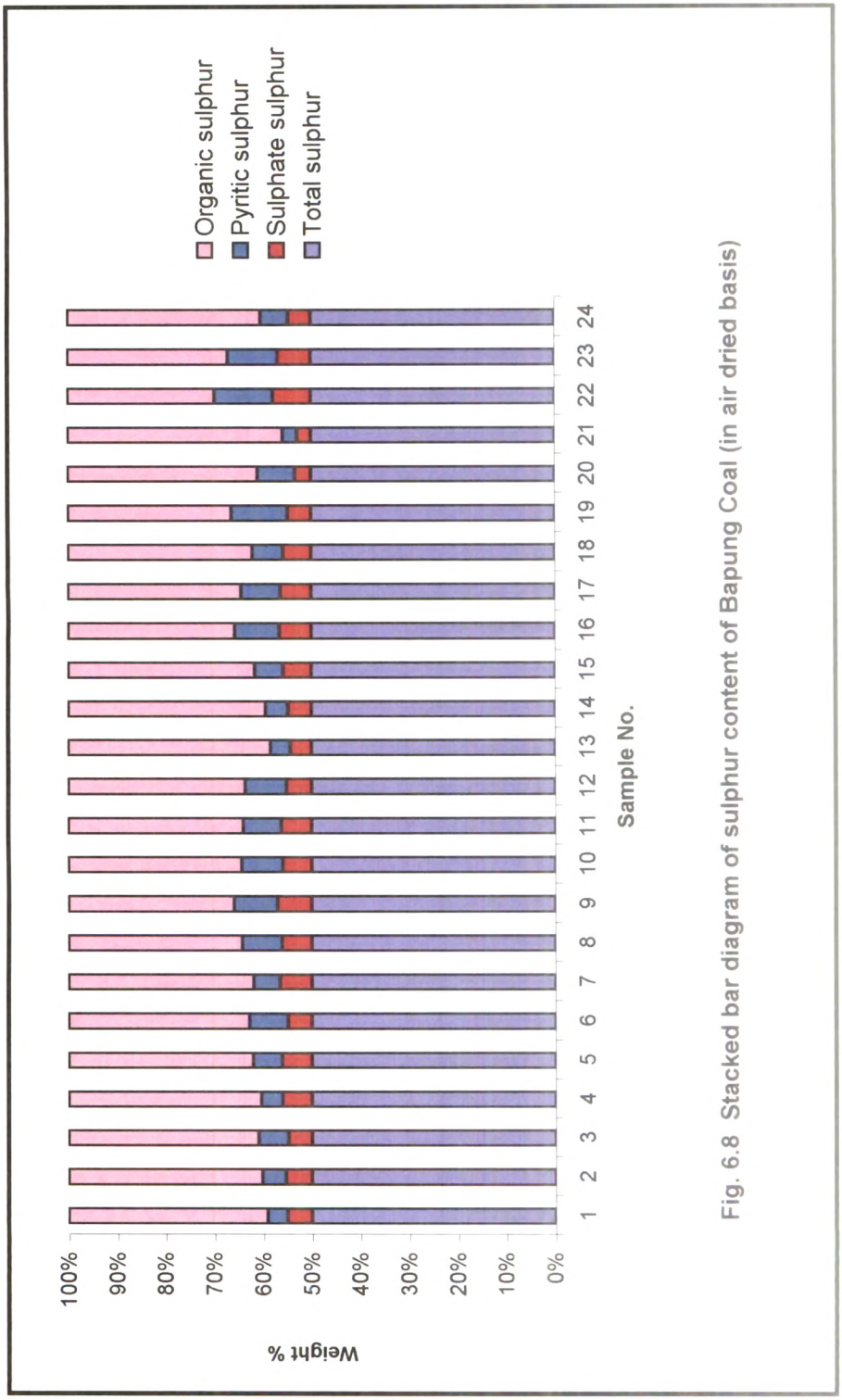


Fig. 6.8 Stacked bar diagram of sulphur content of Bapung Coal (in air dried basis)

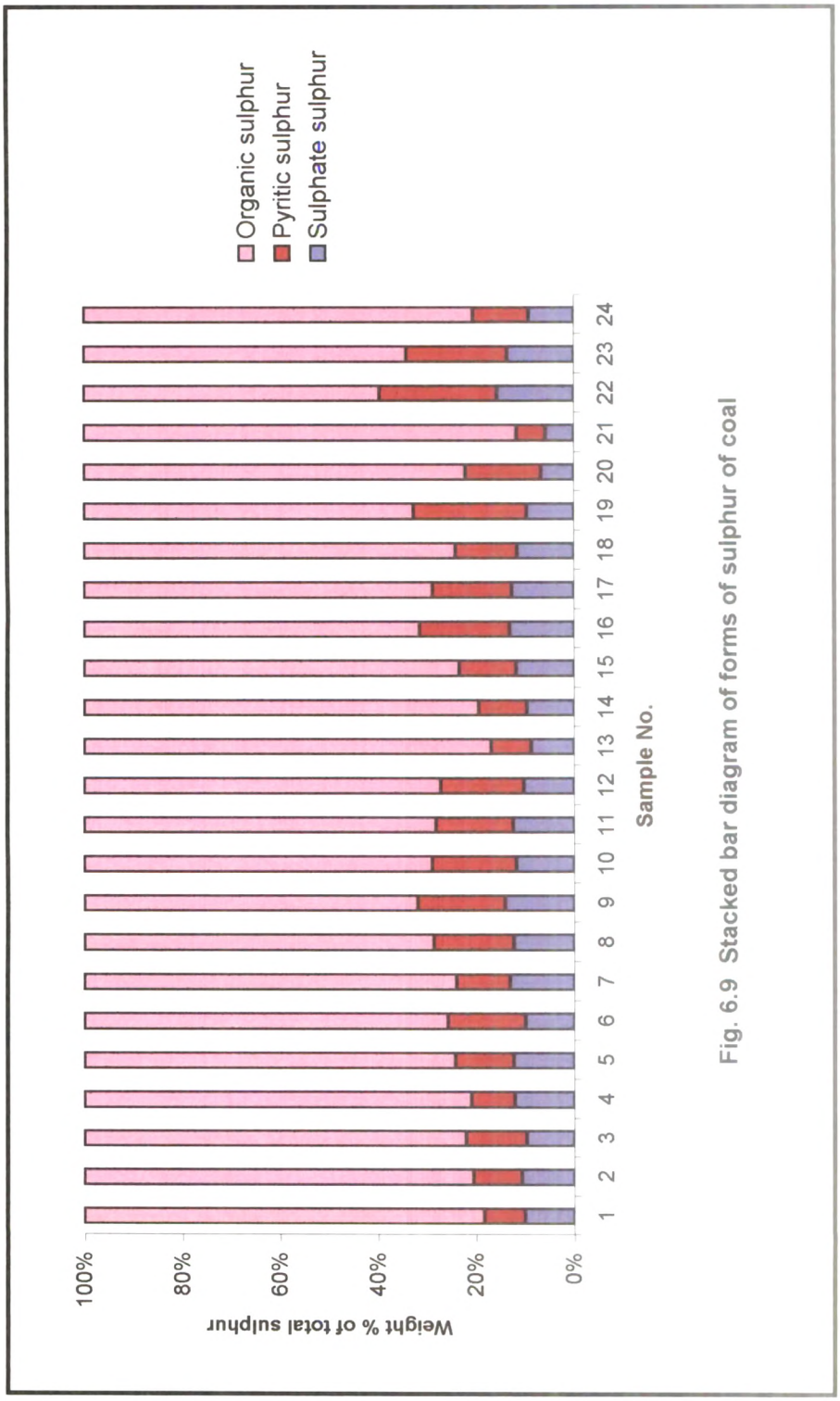


Fig. 6.9 Stacked bar diagram of forms of sulphur of coal

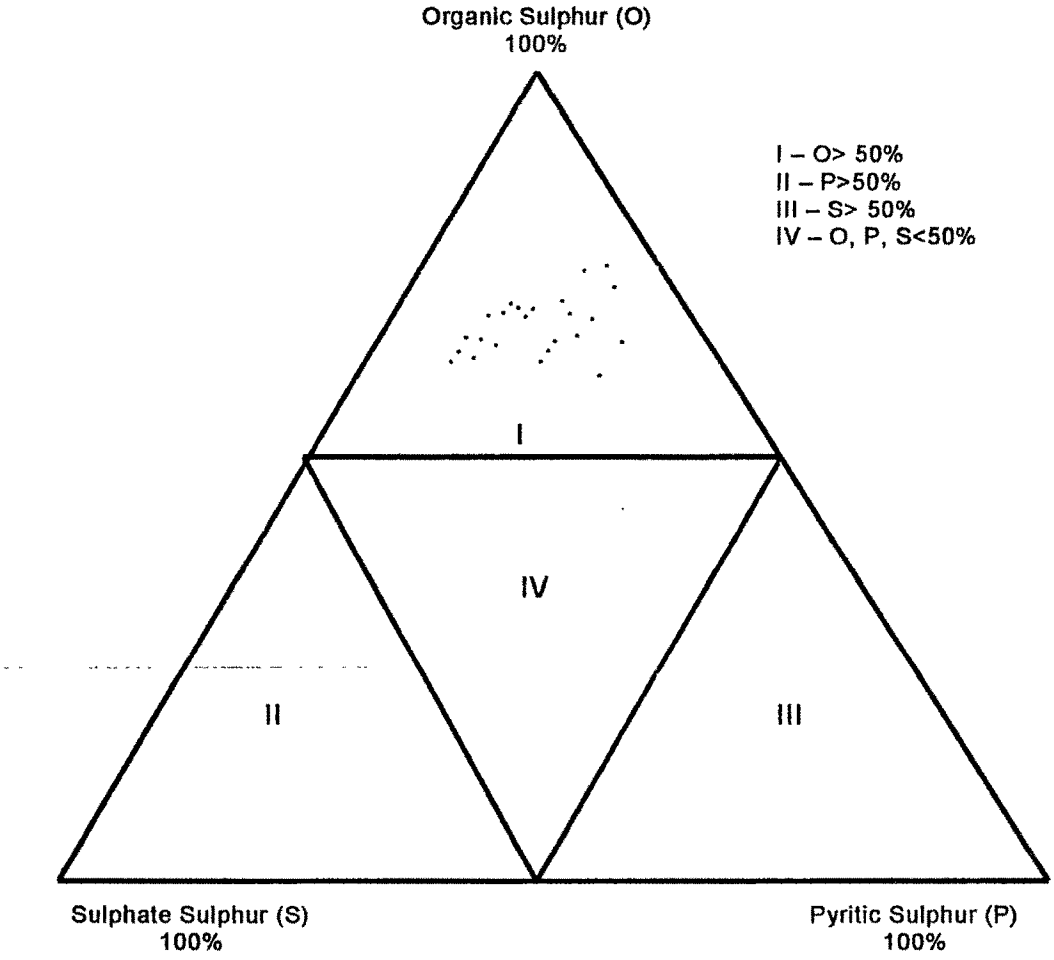


Fig. 6.10 Triangular plots of forms of sulphur

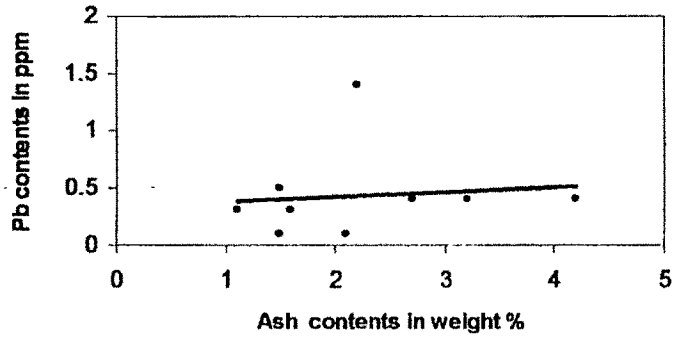


Fig. 6.11 Plots of lead contents versus ash contents of Bapung coal

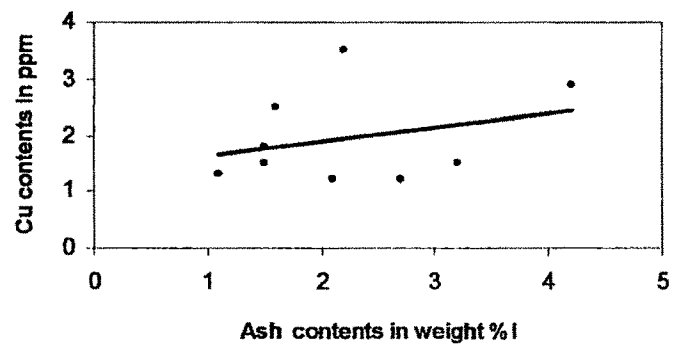


Fig. 6.12 Plots of copper contents versus ash contents of coal

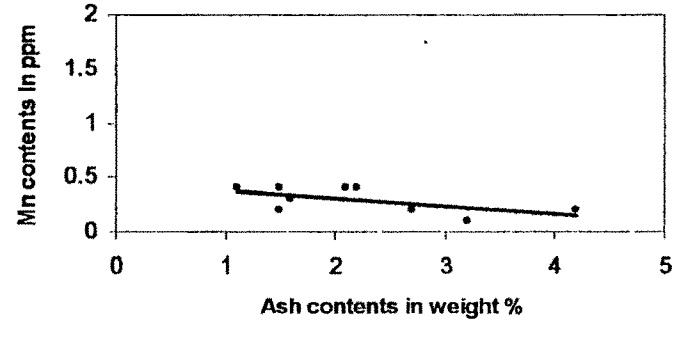


Fig. 6.13 Plots of manganese contents versus ash contents of coal

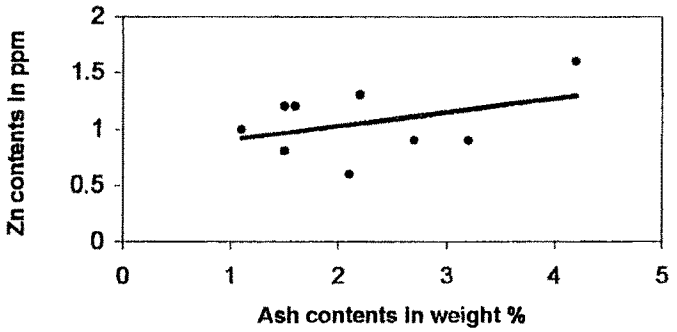


Fig. 6.14 Plots of Zinc contents versus ash contents of coal

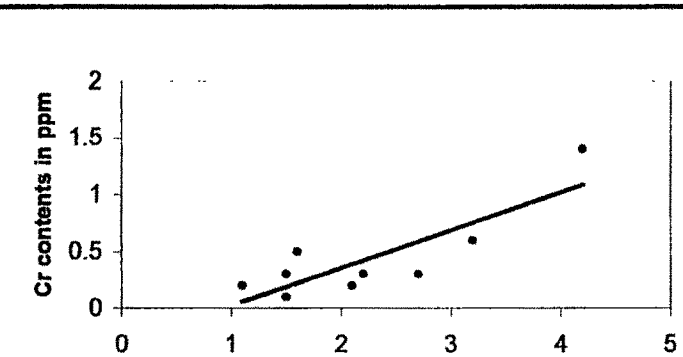


Fig. 6.15 Plots of chromium contents versus ash contents of coal