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TECHNICAL MEMORANDUM NO. 14 OF 1969.

ASPECTS OF THE EXPLOSIBILITY OF COAL MACERALS

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RESEARCH FOR THE COAL MINING
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INTRODUCTION

In continuing the investigations into the causes of the lesser susceptibility of South African coal dusts to explosion, attention has been given to the relationship between the petrographic composition of coals and their explosibility.

South African coals are in general deficient in vitrinite and exinite and have a relatively high mineral matter content. These two properties are suggested as reasons for sustained flame propagation not being satisfied and could explain the weak explosibility of many of our coals.

The results of explosibility tests on the specific gravity separations of coal samples indicate a strong tendency of higher explosibility in the lighter fractions, i.e. with a higher exinite and vitrinite content. Attention has also been given to the effect of the reduction in the mineral matter content of the more reactive samples.

COAL DUST EXPLOSIBILITY

It is reasonably certain that the mechanism of flame propagation in a dust cloud is predominently, or entirely, a thermal process. The criterion for continued flame propagation is that each unit mass of burning dust should provide sufficient energy which, transferred ahead of the flame, will ignite a further unit mass of dust.

When a coal dust particle is heated two separate but not independent processes can be distinguished. Pyrolysis of the coal occurs with the progressive evolution of both combustible and incombustible volatile matter, which leaves a solid residue progressively richer in carbon. The amount of and composition of the volatile matter will not necessarily correspond to that obtained in standard tests but will vary with the rate of heating and the final temperature reached.

/The composition ....

The composition of the residue will depend on the same factors with one extreme being that of the original coal and the other that of carbon contaminated with inorganic impurities. In the latter process a part or all of the combustible volatile matter driven off may ignite and burn. The solid residue which remains is unlikely to ignite and burn to any large extent in the first instance. The processes of devolatilization and combustion may proceed sequentially or simultaneously, depending on the relative rates of heat and mass transfer and the chemical reactions involved.

THE PETROGRAPHIC COMPOSITION OF COAL*

Coal, just as inorganic rock, consists of petrological components called macerals. Coal differs mainly from inorganic rock in that its composition is not constant but varies according to the degree of coalification or rank of the coal.

Coalification is the chemical change of the original fossil plant material resulting in a general increase in carbon content. This metamorphism is brought about inter alia by temperature which depends on the geothermal gradient in the coal-bearing strata.

It has been found that the woody tissue of the original plant material is capable of coalification, without loss of morphological structure, to the principal coal macerals, viz., vitrinite, exinite, and inertinite.

The volatile matter released by macerals differ in quantity as well as in nature. This is shown in the pyrograms in Figure 1**. Compared with vitrinite, exinite shows a greater number of non-dramatic peaks appearing before benzene (peak No. 17) in the pyrogram.

/The pyrogram ....

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*The petrographic work mentioned in this report was undertaken by the Coal Petrography Section of the Fuel Research Institute.

**From J.Komovocéle and J. Kubát, Anal.Chem. Vol. 40 p. 1119-1968. Pyrograms are obtained from pyrolysis gaschromatography, i.e. the analysis of gases volatilized from a solid sample by heating in the inert carrier gas stream and fed directly into the separating column of a gas chromatograph.

The pyrogram for inertinite is poor in all characteristic pyrolysis products except for toluene (peak No. 27) which, it is stated, is due to the residual solvent used for the isolation of the maceral.

South African coal seams consist of predominently dull coal with bands of bright coal present in places. Coals from Natal are generally brighter than those from the Transvaal. These coals, in contrast to those from Europe and the U.S.A., can be characterized by relatively low amounts of the active constituents vitrinite and exinite and high amounts of inertinite.

The ratio of the former to the latter is in most cases about 1:1 or less. Coals from the Northern Transvaal are an exception, and contain high proportions of vitrinite and exinite by South African standards. In this respect they are similar to European and American coals. Commercial exploitation of the Northern Transvaal coalfields has not yet started.

The mineral matter content of South African coals is high. The ash content varies between about 12 and 35 per cent, depending on the coalfield and the seam. The mineral matter is intimately associated with the coal and it is seldom if ever possible to effect a complete separation of the two. Separation of the coal according to specific gravity, does, however, yield fractions in which the vitrinite and to a lesser extent the exinite are enriched. The yield at a specific gravity of 1.28 or 1.30 is seldom more than about 10 per cent.

THE PETROGRAPHIC COMPOSITION AND THE EXPLOSIBILITY OF COAL

In order to determine the possible relationship between the explosibility of a coal and its petrographic composition, four coals were subjected to specific gravity separation. The petrographic composition and the explosibility of each specific gravity fraction was determined. The results are given in Table 1.

Three of the coals examined each yield one explosive fraction which constitutes only 4.6 per cent of the raw coal. It is of interest to note that the petrographic composition of the ten explosive lower specific gravity fractions isolated from the four coals is similar to that of the Pittsburgh raw coal.

/The maximum ....

The maximum rate of pressure rise (lb/sq inch/sec) which is one of the most important explosibility parameters, is plotted in Figure 2 as a function of vitrinite plus exinite content of the various specific gravity fractions. The experimental points fall within a well-defined band on the graph, from which it can be concluded that coals with a combined vitrinite plus exinite content of less than about 50 per cent are not explosive. This finding is in agr3ement with the fact that the majority of South African coals are only very weakly explosive and have a vitrinite plus exinite content of 50 per cent or less. The choice of 50 per cent as an explosibility limit is based on the data in Figure 2 only and it would probably be displaced to a lower value in the case of a coal with an abnormally low ash content.

THE RÓLE OF THE MINERAL MATTER IN COAL IN ITS EXPLOSIBILITY CHARACTERISTICS

The mineral matter present in coal can influence the ignition and combustion of coal dust in one of the following ways:

1. As a component that alters the permeable structure of the coal and obstructs the process of devolatilization.
2. As an agent which acts as a catalytic poison, quenching the combustion reaction.
3. As a radiation shield.
4. As a heat sink or thermal load.
5. As an inert dilutent.

Mode 1 is considered to be of importance. South African coals have a high intrinsic ash content and it is conceivable that the mineral matter can have a damping effect on the rate of volatile matter formation.

Mode 2 is of lesser importance. However, the combustion of coal dust suspensions can be chemically inhibited by mineral constituents of the coal. The mineral matter contains, inter alia, silicates, sulphates, and oxides of calcium, aluminium iron and magnesium, as well as carbonates and other salts of the alkaline earth metals, including chlorides. Chlorides are present in concentrations of up to one per cent in British coals and somewhat less in American coals, occurring almost wholly as a mixture of potassium and

/sodium chlorides ....

sodium chlorides. These salts are well-known inhibitors of the combustion of coal dust and gaseous fuels. A pulverized salt mixture is approximately three times more efficient than ground limestone for preventing coal dust combustion in a large duct. It has been suggested that flame inhibition is due to radical-chain breakage that occurs mainly in the gas phase.

Modes 3 and 4 are supplementary to each other but of still lesser importance than Mode 2. Mineral matter particles in homogeneous mixtures with coal dust suspensions will only have a small effect as a heat ballast. Also, calculations have shown that massive proportions of mineral matter would be required to effect marked attenuation of the radiation from a coal dust flame front.

The exact influence of coal ash when in the form of discrete particles, as an inert dilutent (Mode 5) remains unknown. However, Essenhigh*** reached the conclusion that stone dust acts purely as a dilutent. Approximately 40 per cent of inert stone dust is required to effect changes in flame propagation through coal dust and still larger proportions to completely suppress combustion.

Concomitant with the enrichment of the active petrographic constituents in the lower specific gravity fractions is a decrease in the ash content of the coal. As discussed above, coal ash can influence the explosibility of coal dust in several ways. Experiments were carried out to study the effect of increasing the ash contents of the different specific gravity fractions by adding inert material. Finely ground carbonaceous shale was used for this purpose rather than coal ash. Many of the minerals present in coal are altered or destroyed when the coal is ashed. In one series of experiments the inert mineral matter content of Pittsburgh coal was increased by the addition of minus 200-mesh (B.S.S.) shale and the explosibility of the resultant mixtures determined. Results are given in Table 2. The total inert content of this coal had to be increased to between 30 and 40 per cent before an appreciable suppresion of its explosibility was noted. When the total inert content was increased to 60 per cent the

/explosibility ....

***R.H. Essenhigh. Colliery Engineering, 1961, p. 534.

explosibility was nil.

In further experiments the various specific gravity fractions of the Waterberg coal were chemically de-ashed (ash content $< 1\%$) according to the Radmacher method with hydrofluoric acid, and the de-ashed coal tested. Thereafter the ash content of each fraction was restored to its original value by the addition of finely ground shale and each fraction once more tested. The results of these experiments are given in Table 3. Removal of the mineral matter by chemical means led to a marked increase in the explosibility of the three lower specific gravity fractions and also rendered the 1.40 specific gravity sink fraction explosive. Restoration of the ash content to its original value by the addition of shale tended to suppress explosibility, but not to such an extent as the intrinsic mineral matter did. The sink fraction (44.1% ash content) was originally non-explosive, but after removal of its intrinsic ash and the addition of shale this fraction became marginally explosive. These findings are considered adequate proof that intrinsic mineral matter has a greater damping effect on explosibility than added mineral matter, on a weight for weight basis.

CONCLUSION

The weak explosibility of South African coals is attributed to the fact that they are generally both deficient in the active petrographic constituents, vitrinite and exinite, and have a relatively high ash content. The former characteristic is probably the more important of the two.

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4th March, 1969.
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TABLE 1.

THE PETROGRAPHIC COMPOSITION AND EXPLOSIBILITY PROPERTIES OF VARIOUS SPECIFIC GRAVITY COAL FRACTIONS.

Coal	Specific Gravity Fraction	Yield Frac-tional %	Proximate Analysis (air-dry basis)			Maceral Analysis					Explosibility Properties				
			% H_2O	% Ash	% Vol. Mat.	Vitrinite %	Exinite %	Inertinite %	Visible Minerals %	Vitrinite plus Exinite %	Minimum Ignition Temp. °C	Minimum Expl. conc. oz/ft³	Minimum Ign. Energy m. Joule	Maximum Pressure lb/sq.in.	Maximum Rate lb/sq.in./sec.
Waterberg	1.30 float	13.8		3.9		96.4	2.6	0.3	0.7	99.0	620	0.12	83	75	2500
	1.30-1.35	19.4		9.8		87.3	4.7	4.0	4.0	92.0	625	0.16	213	71	1667
	1.35-1.40	17.0		16.3		79.8	4.9	8.0	7.3	84.7	625	0.16	337	65	1250
	1.40 sink	49.0		44.1		47.1	2.7	12.1	38.1	49.8	640	>2.0	>25000	-	-
	Raw coal	-		26.0		70.0	4.0	5.3	20.7	74.0	630	0.20	2590	54	1000
Union	1.30 float	2.0		3.5		85.2	5.5	8.8	0.5	90.7	620	0.08	93	93	2500
	1.30-1.35	26.8	3.2	6.0	35.4	84.7	4.5	10.5	0.3	89.2	630	0.12	297	80	1667
	1.35-1.40	22.8	3.1	8.9	33.0	65.5	4.9	28.6	1.0	70.4	625	0.16	22180	60	833
	1.40 sink	48.4		22.0		42.8	5.1	45.3	6.8	47.9	640	>2.0	>25000	-	-
	Raw coal	-	3.2	14.3	31.2	56.9	5.0	32.2	5.9	61.9	625	0.20	>25000	44	650
Bellevue	1.30 float	0.9		-		82.6	6.4	10.6	0.4	89.0	620	0.08	497	84	1500
	1.30-1.35	15.9	4.6	7.7	35.3	74.6	4.8	18.8	1.8	79.4	625	0.12	7094	81	1500
	1.35-1.40	20.1		10.2		71.5	1.8	24.0	2.7	73.3	630	0.12	22180	70	625
	1.40 sink	63.1		19.5		50.4	3.6	37.1	8.9	54.0	635	>2.0	>25000	-	-
	Raw coal	-	4.6	16.1	31.6	56.3	3.4	29.8	10.5	58.6	630	0.56	>25000	46	389
Springbok	1.30 float	4.6	2.8	4.8	34.2	80.3	5.1	14.2	0.4	85.4	625	0.12	1172	73	1092
	1.30-1.35	20.4	3.0	7.5	29.7	50.5	3.9	44.8	0.8	54.4	635	>2.0	>25000	-	-
	1.35-1.40	19.8		9.5		32.2	3.8	62.5	1.5	36.0	635	>2.0	>25000	-	-
	1.40 sink	55.2		18.0		23.8	2.3	64.0	9.9	26.1	645	>2.0	>25000	-	-
	Raw coal	-	2.5	13.5	28.0	42.1	2.7	48.4	6.8	44.8	635	>2.0	>25000	-	-
Pittsburgh	Raw coal	-	1.5	4.3	37.0	82.6	5.3	10.0	2.1	87.8	610	0.055	60	83	2500

TABLE 2

	Total ash content, %	Maximum pressure, lb/sq.in.	Maximum rate, lb/sq.in./sec.
Pittsburgh coal	5	82	2300
	10	81	2300
	20	72	1800
	30	65	1390
	40	35	850
	50	15	250
	60	-	-

TABLE 3

Waterberg coal	Original specific gravity fractions			De-ashed fractions. Ash content, < 1%		Ash content restored	
	Ash, %	Max. pres., lb/sq.in.	Max. rate, lb/sq.in./sec.	Max. pres., lb/sq.in.	Max. rate, lb/sq.in./sec.	Max. pres., lb/sq.in.	Max. rate, lb/sq.in./sec.
1.30 float	3.9	75	2500	77	2500	78	2500
1.30-1.35	9.8	71	1667	74	2100	71	1950
1.35-1.40	16.3	65	1250	73	1850	70	1500
1.40 sink	44.1	-	-	65	1450	25	400
Raw coal	26.0	54	1000	71	1700	61	1450

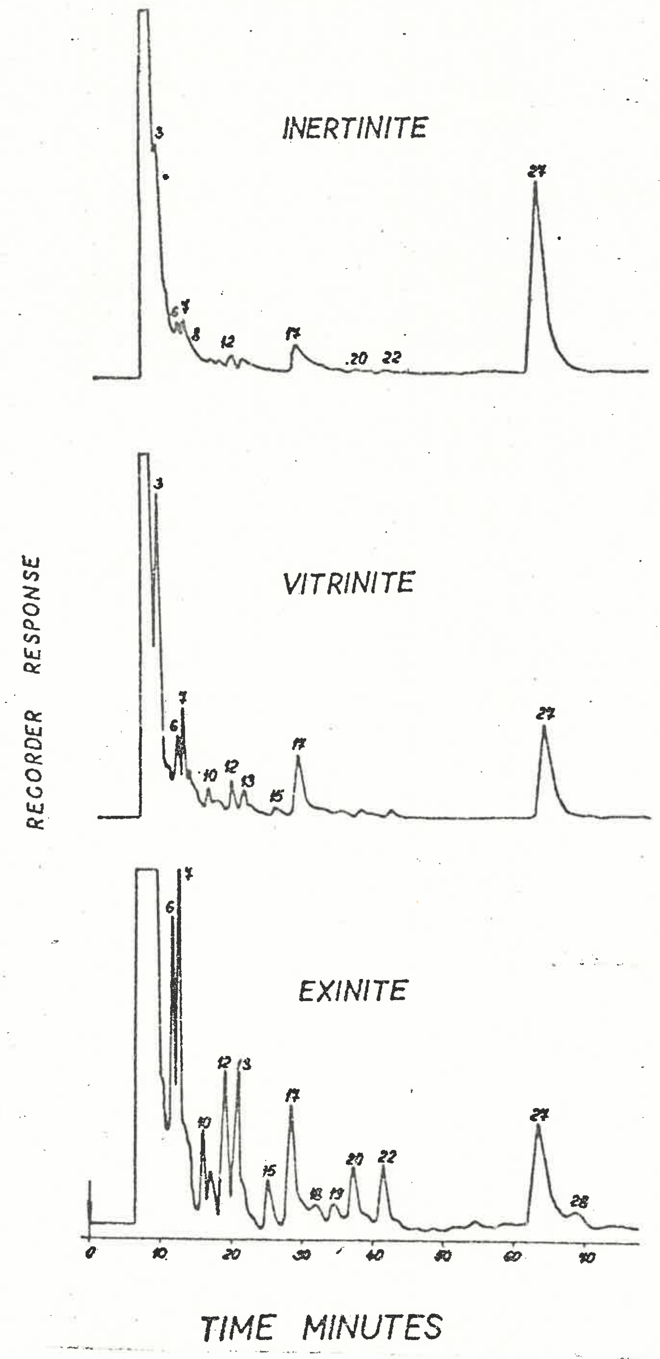
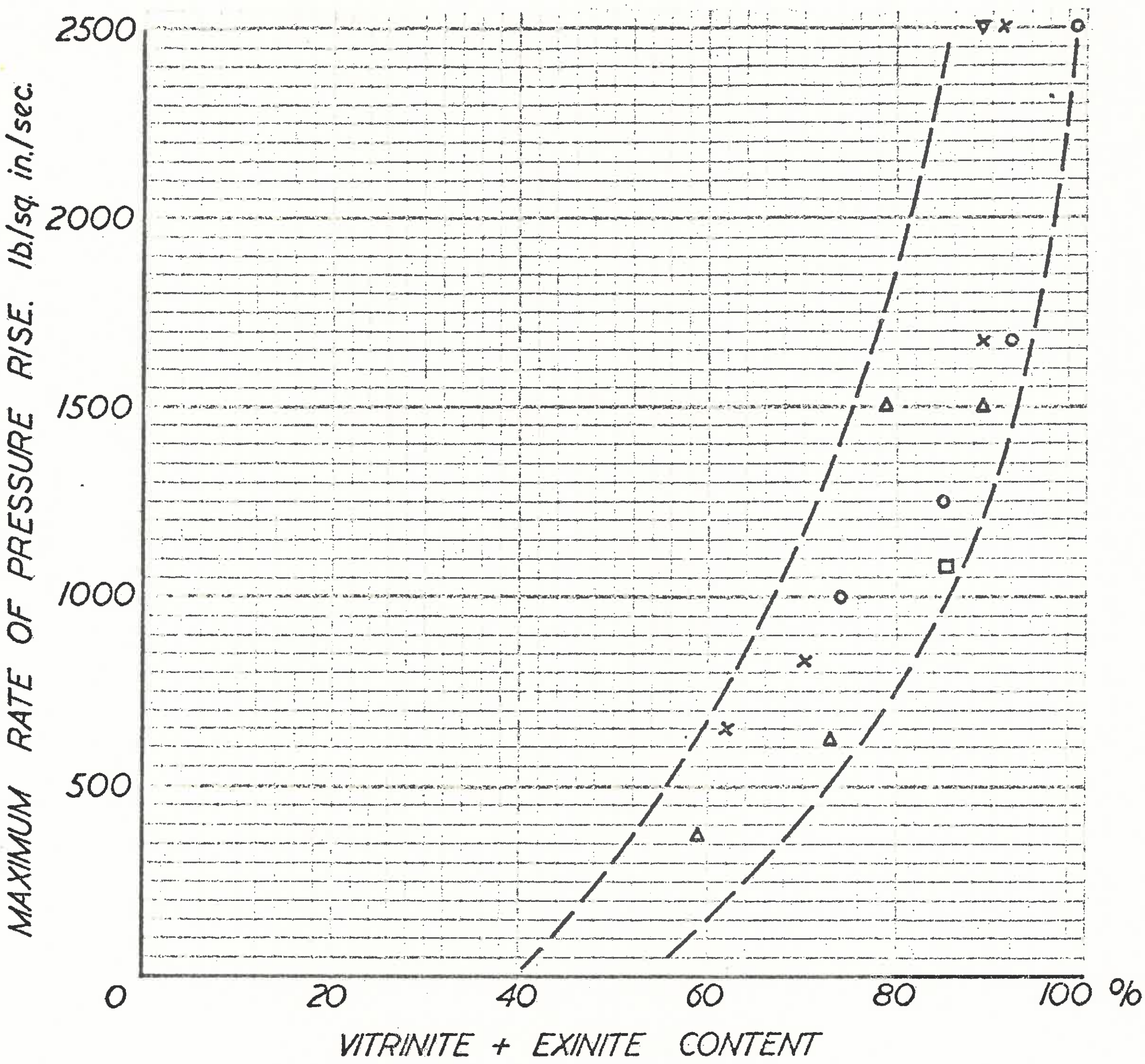


FIGURE 1

Pyrograms of the macerals from semi-bituminous coal.

FIG. 2.

MAXIMUM RATE OF PRESSURE RISE PLOTTED AS A FUNCTION OF VITRINITE PLUS EXINITE CONTENT FOR VARIOUS SPECIFIC GRAVITY COAL FRACTIONS.



Key:
- o Waterberg
- x Union
- Δ Bellevue
- □ Springbok
- ∇ Pittsburgh