SAIMM

J. S. Afr. Inst. Min. Metall., vol. 93, no. 8.
Aug. 1993. pp. 203–206.

The explosibility of South African coals as determined in a 40-litre explosion vessel

by T.P. Knoetze*, I.I.M. Kessler*, and M.P. Brandt*

SYNOPSIS
It has generally been accepted that the volatile matter in a coal is the factor that determines whether or not a specific coal dust is an explosion risk. This paper presents the results of an attempt to relate the explosibility index (K_{ex}) of South African coals, as determined in a 40-litre explosion vessel, to the volatile matter content of the coal and the calorific value of the volatiles. A good relationship between the calorific value of the volatiles and the explosibility index was established, which makes it possible to calculate the violence of an explosion, as expressed by K_{ex}, for South African coals. The K_{ex} value is but one of a number of parameters that influence the explosion hazard in a specific colliery and cannot be used as the sole predictor of the propagation of an explosion underground. Other parameters include the ignitability of the coal, temperature, humidity, dispersibility of the dust, methane concentration, amount of incombustibles present, and ventilation.

SAMEVATTING
Dit is 'n algemeen aanvaarde feit dat vlugstofinhoud die faktor is wat bepaal of 'n spesifieke steenkoolstof 'n ontploffingsrisiko inhou of nie. Hierdie dokument bevat die resultate van 'n poging om die ontplofbaarheidsindeks (K_{ex}) van Suid Afrikaanse steenkool (soos in die 40-literhouer bepaal) met die vlugstofinhoud daarvan en die verbrandingswaarde van vlugstowwe in verband te bring. Daar is gevind dat 'n goeie verband tussen die verbrandingswaarde van die vlugstowwe en die K_{ex} bestaan. Dit maak dit moontlik om die impak van 'n ontploffing, soos deur K_{ex} uitgedruk, vir Suid-Afrikaanse steenkool te bereken. Die K_{ex}-waarde is maar een van 'n hele aantal parameters wat die ontploffingsrisiko in 'n spesifieke steenkoolmyn beïnvloed en dit kan nie as die enigste voorspeller van die voortplanting van 'n ondergrondse ontploffing gebruik word nie. Voorbeelde van ander parameters is die ontsteekbaarheid van die steenkool, temperatuur, vogtigheid, verspreibaarheid van die stof, metaankonsentrasie, hoeveelheid onverbrandbare stowwe aanwesig en ventilasie.

INTRODUCTION

It has generally been accepted that the content of volatile matter in a coal is the factor that determines whether or not a specific coal dust is an explosion risk[1–4]. The explosion behaviour of coal dusts can be described most simply in terms of the combustion of liberated volatiles[5]. It is therefore not surprising that correlations between the explosibility and the volatile matter in particular coals have been reported in the literature[6–10].

In the existing South African regulations, the total amount of incombustibles required to stop the propagation of an explosion in an underground colliery is determined by the dry ash-free volatile matter in the coal dust[11]. This assumption, namely that the content of volatile matter in the coal is directly related to the explosion hazard presented by the coal, is made in the regulations of several other countries as well[12].

The assessment of measures required to provide protection against explosion hazards involving combustible mixtures of dust and air requires prior determination of the violence of an explosion of such mixtures through the measurement of explosion indices[13]. The experimentally determined explosibility index (K_{ex}) of South African coals can be used as a first approximation of the explosion severity and hazard presented by the coal. This paper presents the results of an attempt to relate the explosibility index of South African coals, as determined in a 40-litre explosion vessel, to the volatile matter content of the coal and the calorific value of the volatiles. A good relationship between the calorific value of the volatiles and the explosibility index is established. This makes it possible to calculate the violence of an explosion as expressed by K_{ex} for South African coals.

* G.P. Badenhorst Research Facility, Division of Energy Technology, CSIR, P.O. Box 395, Pretoria 0001.

THE EXPLOSIBILITY INDEX

The practice of expressing the explosibility of coal dust in terms of K_{ex} was developed in Germany during the 1960s. This index has been used in South Africa for a number of years, and is favoured because of its ability to measure explosibility directly.

The propagation of mine explosions involving coal dust depends on a conducive environment with respect to the following main factors, which are taken into account by the K_{ex} index[14].

- Sufficient heat must be present to ignite unreacted coal particles.
- The coal dust must be dispersed to form a dust cloud with sufficient coal and oxygen present to support combustion.
- The size distribution of the particles in the dust cloud must be in the explosive range.

The K_{ex} of a coal is determined in a 40-litre explosion vessel at fixed experimental conditions. Any changes in these parameters will change the value of K_{ex}. Dust with a grain size of 20 μm median and 125 μm top size is used, representing the mean size distribution of dusts encountered underground. The coal dust must contain less than 5 per cent mineral matter (15 per cent for South African coals) and is prepared in a hammer mill. The samples of coal used must be washed to eliminate the influence of ash on the explosibility of the coal dust. The coal dust is blown into the explosion vessel with compressed air, and the resulting dust cloud is exposed to the heat flux delivered by an 8,7 kJ igniter. The liberated volatiles deflagrate, and the resultant gas pressure is recorded against time. K_{ex} values higher than 90 bar/s can be determined without any problems. Values lower than 90 bar/s become difficult to determine experimentally owing to the lower repeatability of such measurements.

The value of K_{ex} is calculated from the resultant curve of pressure versus time. The square root of the product of the maximum rate of pressure rise and the average rate of pressure rise is determined. The definition of K_{ex} is expressed graphically in Figure 1.

A coal dust with a K_{ex} value of 70 bar/s or less is considered to be non-explosive. Dusts with values between 70 and 95 bar/s must be evaluated in an explosion gallery. Coal dusts with values exceeding 90 bar/s will propagate an explosion in an underground coal mine. These values are empirical borderlines determined in Germany from correlations between the explosion vessel and the gallery used[15]. The fact that many South African coals appeared to have K_{ex} values between 70 and 95 bar/s was one of the main reasons for the construction of an explosion gallery in South Africa.

EXPERIMENTAL

Relationship between K_{ex} and Volatile Matter in Coal

The relationship between K_{ex} and volatile matter was investigated for forty-six South African coals. The coal samples were selected to represent all the different coals found in this country. The results of this investigation are presented in Table I. Most of the K_{ex} values are well in excess of 90 bar/s. The relationship between the volatile matter in the coal and the explosibility index determined in the laboratory is given in Figure 2. The coefficient of correlation of straight-line fit through the data points is 0,4283. The equation of the line is given by

$$K_{ex} = 1,99\,(\text{volatiles}) + 102,03. \qquad [1]$$

Figure 2 indicates that there is not a good relationship between the K_{ex} and the volatile matter content of South African coals. A possible explanation for this observation may be that there is no direct relationship between volatiles and rank (% ROV) for South African coals, as is the case for European coals. The difference between South African and European coals is highlighted by Figures 3 and 4. Figure 3 gives the relationship between volatile matter content and rank for European coals[16], and Figure 4 the same for South African coals[17]. That there is no direct relationship between rank (% ROV) and volatile matter content for South African coals is illustrated clearly by these figures.

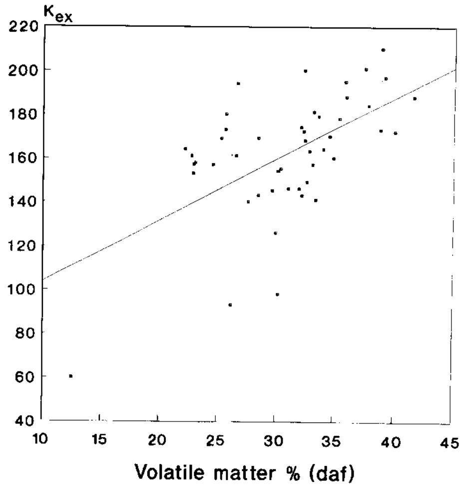

Figure 2—Plot of volatile metter against K_{ex}

Relationship between K_{ex} and Volatile Energy

It is known that K_{ex} gives an indication of the energy of an explosion. Since the explosion behaviour of coal dusts can be described most simply in terms of the combustion of liberated volatile matter, it was logical to investigate the relationship between the explosibility of a coal and the energy released by the combustion of the volatiles in the coal.

The calorific value (CV) of the volatile portion of the coal was calculated from the experimentally determined CV of the coal and the percentage of volatile matter in the coal. This is obtained by subtracting the amount of energy

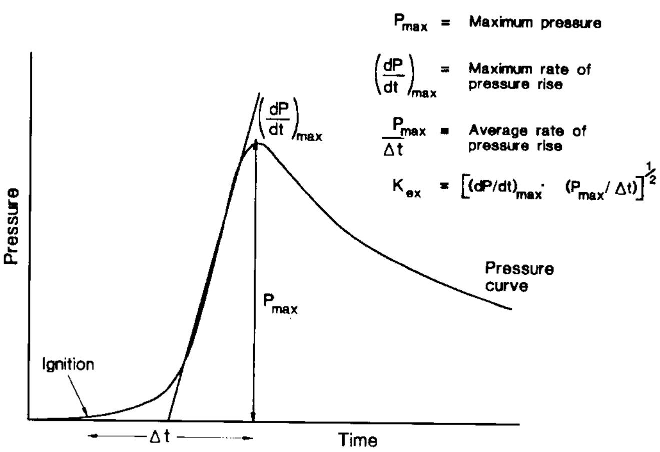

Figure 1—Graphical representation of K_{ex}

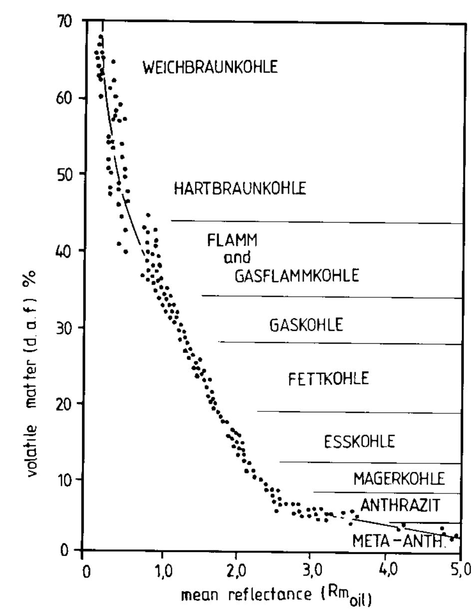

Figure 3—The relationship between volatile matter and reflectance in German coals (after Bartenstein and R. Teichmüller, 1974)

Table I

Experimental results for selected coal samples

Sample	Volatile matter			K_{ex} bar/s	Sample	Volatile matter			K_{ex} bar/s
	Content, %	DAF*, %	CV†, MJ/kg			Content, %	DAF*, %	CV†, MJ/kg	
SP2	21,80	26,17	6,83	93	COMG	20,20	22,12	10,28	164
BE	25,50	30,14	7,62	98	BAS2	28,50	32,39	10,18	168
BAP	24,50	29,91	8,27	126	NVM2	22,10	25,26	10,75	169
GH4	2.3,40	27,56	7,93	140	VRD	24,00	28,40	10,56	169
KR4	28,30	33,33	9,14	141	GR	30,20	34,51	10,91	170
BO	24,90	28,42	7,13	143	USL	34,50	39,98	11,01	172
NDC5	26,60	32,13	8, 17	143	GHS2	29,00	32,26	11,12	172
BAB2	26,20	29,60	9,47	145	NDCO	32,90	38,80	10,48	173
NDC8	26,80	31,87	8,31	146	COLD	23,10	25,61	10,49	173
NDNN	25,80	30,94	8,11	146	GHH4	28,60	32,03	10,89	174
NDNE	27,90	32,56	8,74	149	AT2	31,50	35,31	11,47	178
COT	20,20	22,82	9,90	153	VDS	29,50	33,56	10,64	179
BA2	26,40	30,07	9,66	154	WEM	22,60	25,65	10,32	180
ZI	26,20	30,29	9,82	155	BAL	29,80	33,11	11,15	181
DE2	28,20	33,06	8,77	157	ER	32,40	37,76	11,28	184
COB	21,40	24,51	10,38	157	GOB4	34,10	41,53	11,76	188
ENDB	20,70	22,85	9,77	157	WO2A	31,60	35,87	10,57	188
COUD	21,10	23,01	10,44	158	HLG	23,30	26,60	10,28	194
KHC	29,60	34,86	9,66	160	KL	32,20	35,78	11,84	195
TS	18,80	22,68	10,08	161	MA5	34,30	39,09	11,02	197
VRA	22,70	26,52	10,37	161	DUT	28,50	32,24	11,55	200
PAT	29,0	32,77	8,68	163	BAW5	32,80	37,44	12,33	201
AR2	29,0	34,00	9,53	164	OP2	34,30	38,84	11,29	210

* DAF =
† CV = Calorific value

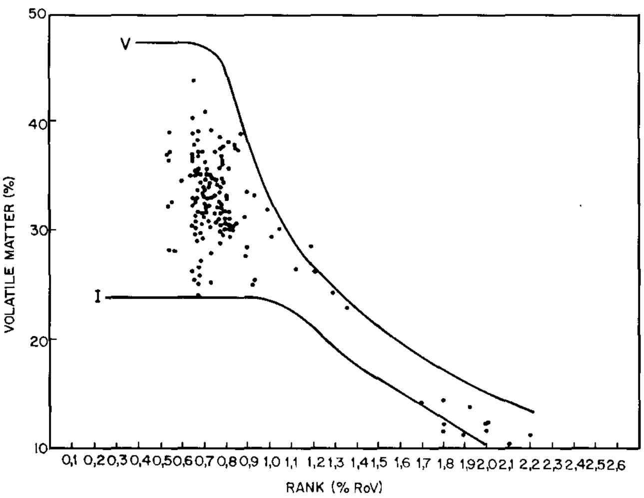

Figure 4—The relationship between volatile matter and reflectance in South African coals (after Barnard)

released by the combustion of the fixed carbon part of the coal from the CV of the coal. The assumption is made that the combustion of the fixed carbon would release the same energy as an equivalent amount of graphite. It is further assumed that the amount of volatiles reported by a conventional proximate analysis can be attributed to only the organic part of the coal, and that the contribution of the inorganic part is negligible. The formula used in the calculation of the energy released by the volatile portion of the coal is as follows:

$$CV \text{ of total volatile material} = (100\ CV \text{ of coal} - 32{,}8\ FC)/100, \quad [2]$$

where CV = Calorific value
32,8 = Calorific value of graphite[17], MJ/kg
FC = Fixed carbon, %.

The relationship between K_{ex} and the calorific value of the volatile matter portion of the 46 coals investigated is shown in Figure 5. The data from the 46 tests were subjected to a statistical analysis. It was attempted to explain K_{ex} in terms of the volatile matter content of the coal, the dry ash-free volatile matter content of the coal, and the calorific value of the volatile matter portion of the coal. It was found that the CV of the volatiles is the most significant explanatory variable for K_{ex}. The estimating equation for the K_{ex} of these samples with an ash content of less than 15 per cent in terms of the CV of the volatiles is

$$K_{ex} = 15{,}81\ (\text{CV of volatiles}) - 6{,}35. \quad [3]$$

This equation is valid for K_{ex} values between 90 and 210 bar/s, and can be used only with extreme caution outside this range of K_{ex} values.

The standard error of estimate is a measure of the reliability of the estimating equation, indicating the variability of the observed points around the regression line. It is thus an indication of the extent to which observed values differ from predicted values on the regression line. In this case, the standard error of estimate is 11,92.

The coefficient of determination is a measure of the proportion of variation in the dependent variable that can be explained by the regression line, i.e. by the dependent variable's relationship with the independent variable. Here, the coefficient of determination is 0,7532, which means that 75,32 per cent of the variation in K_{ex} can be explained by the regression line. The square root of the coefficient of

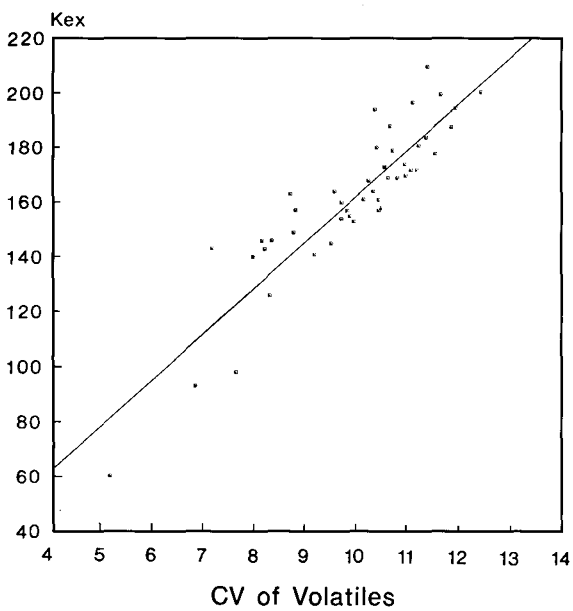

Figure 5—Plot of the CV of the volatile matter portion of a coal against K_{ex}

determination gives the coefficient of correlation, which is 0,8679 in this case.

From this discussion, it is clear that there is a very good empirical relationship between K_{ex} and the CV of the volatile matter portion of the coal. The explosibility of a coal expressed in terms of K_{ex} is thus mainly constituted of the energy released by the rapid combustion of the volatile portion of the coal. The K_{ex} for South African coals is therefore based on the energy of the volatiles, and not on the amount of volatiles. The K_{ex} for any coal sample with an ash content of less than 15 per cent can be calculated from the equation.

$$K_{ex} = 0{,}1581\ (100\ CV \text{ of coal} - 32{,}8\ FC) + 6{,}35. \qquad [4]$$

CONCLUSIONS

The investigation indicated that, for South African coals, the amount of volatile matter does not directly express the explosibility as measured in the 40-litre explosion vessel. The explosibility measured in the vessel is directly proportional to the amount of energy released during the combustion of the volatile matter in the coal.

The explosibility of South African coals as measured by the K_{ex} index in the explosion vessel is thus volatile-based. It is, however, based on the energy of the volatiles and not on the amount of volatiles. This also confirms the assumption that the reaction taking place in the explosion vessel is predominantly the combustion of liberated volatiles. It is recommended that the K_{ex} be calculated in future from the formula presented in this paper. Since the K_{ex} values for most South African coals are higher than 90 bar/s, no further testing to determine the explosibility should be necessary. This will lead to considerable savings in money and manpower.

The K_{ex} value of a coal gives an indication of the violence of an explosion should the coal explode, and can be used only as a first approximation for the explosion hazard of the coal. It must, however, be remembered that the value of K_{ex} is dependent on the experimental conditions of the test. For the specified experimental conditions, the values can be used comparatively. Although a good correlation was established between the intrinsic explosibility, K_{ex}, and the energy of the volatile portion of the coal under the specified experimental conditions, it is difficult to project these findings to the practical mining situation owing to in-mine variation of the parameters influencing the explosibility. The K_{ex} value is but one of a number of parameters that influence the explosion hazard in a specific colliery. These include factors such as the ignitability, temperature, humidity, dispersibility of the dust, methane concentration, amount of incombustibles present, and ventilation. The earlier assumption that K_{ex} can be used as the sole predictor of the propagation of an explosion underground is not correct.

ACKNOWLEDGEMENTS

The authors are grateful to I. Mthombeni, who performed part of the sample preparation and experimental work for this investigation. The contributions of the Government Mining Engineer's Steering Committee for the GP Badenhorst Research Facility and of the Division of Energy Technology of the CSIR, and the financial support of the Energy Branch of the Department of Mineral and Energy Affairs, are gratefully acknowledged.

REFERENCES

1. CYBULSKI, W. *Coal dust explosions and their suppression*. Warsaw, 1975.
2. TORRENT, J.G., ARMADA, I.S., and PEDREIRA, R.A. A correlation between composition and explosibility index for coal dust. *Fuel*, vol. 67. 1988. p. 1629.
3. NAGY, J. Explosibility of carbonaceous dusts. *Report of Investigation* 6597, US Bureau of Mines, 1965.
4. LYSENKOV, P.A. Predicting the explosive properties of coal dust. Zapiski Leningrad. *Gorn. Inst. Im. G.V. Plekhanova*, vol. 55, no. 1. 1968. p. 72.
5. CASHDOLLAR, K.L., HERTZBERG, M., and ZLOCKHOWER, I.A. Effect of volatility on dust flammability limits for coals, gilsonite and polyethylene. *Proceedings 22nd Symposium on Combustion*, Seattle, 1988. p. 1757.
6. REEH, D. Explosionsgefährlichkeit van Kohlenstäuben. *VGB Kraftwerkstechnik*, vol. 59, no. 4. 1979. p. 326.
7. JOUBERT, F.E., and DESTERKE, S.M.G. Interim report on explosibility of 16 coal samples from 16 AAC Collieries. *FRI Report* no. 46 of 1980, 1980.
8. ISIHAMA, W., ENOMOTO, H., and UMEZU, M. Experimental study of explosion characteristics of carbonaceous dust clouds. *Archiwum Termodynamiki i spalania*, vol. 7, no. 3. 1976. p. 349.
9. WOSKOBOENKO, F. Explosibility of Victorian brown coal dust. *Fuel*, vol. 67. 1988. p. 1062.
10. RICHMOND, J.K. Effect of rock dust on explosibility of coal dust. *Report of Investigation* RI 8077, US Bureau of Mines, 1975.
11. *Minerals Act*. Act No. 50 of 1991, Lex Patria Publishers, Johannesburg.
12. SAPKO, M.J., GRENINGER, N.B., and WATSON, R.W. Review Paper. Prevention and suppression of coal mine explosions. *Proceedings 23rd International Conference on Safety in Mines Research Institutes*. Washington DC, Sep. 1989. p. 791.
13. INTERNATIONAL ORGANIZATION FOR STANDARDIZATION. *Explosion protection systems–Part 1: Determination of explosion indices of combustible dusts in air*. ISO 6184/1, 1st ed., 1985.
14. HELWIG, N. Die Explosionseigenschaften von Kohlenstaub verschiedener Flöze. *Glückauf – Forschungshefte*, vol. 27, no. 6. 1966. p. 283.
15. REEH, D. Untersuchungen über die Explosionsgefährlichkeit von Kohlenstäuben. Paper presented at a Conference.
16. STACH, E., MACKOWSKY, M.T., TEICHMÜLLER, M., TAYLOR, G.H., CHANDRA, D., and TEICHMÜLLER, R. *Stach's textbook of coal petrology*. Berlin, Gebrüder Borntraeger, 1982.
17. VAN VUUREN, M.C.J. (formerly of Division of Energy Technology, CSIR). Personal communication, 1991.

INFACON BURSARY AWARD

Applications are invited for the award of a bursary to undertake post-graduate level research on ferro-alloys and alloy steels. The background to and the conditions of the award are as follows:

1. The bursary was established by FAPA, MINTEK and the SAIMM, who were the organizers of the 6th International Ferro-Alloys Congress (INFACON), which was held jointly with the International Chromium Steels and Alloys Congress (INCSAC).
2. The objective of the award is to promote post-graduate research on applied and fundamental aspects of ferro-alloy production, or the production of stainless and alloy steels in Southern Africa.
3. The research must be undertaken on a non-confidential basis, so that the results are publishable in the *Journal* of the SAIMM or any suitable internationally recognised journal, and specifically intended to form the basis of contributions to future INFACON Congresses. Topics for research may, in addition to production and uses of alloy steels, include related aspects such as environmental issues, raw materials and economics.
4. The research is to be conducted at or under the supervision of any university or technikon in South Africa, and may be at a post-doctoral level or lead to higher degrees or qualifications on a post-graduate level.
5. The award is primarily intended to provide financial support in the form of a bursary to the applicant, but, at the discretion of the Awards Committee, may include amounts for operating expenses (such as local travel, library and computer costs and consumables) and for special equipment.
6. The award may be used to supplement other grants, provided that the non-confidentiality of the work is not prejudiced.
7. The academic status and research capability of the candidates will be a primary consideration for the selection of bursars. However, the suitability of the topic of research and the status and capabilities of the department will also be important considerations.
8. Applications should be submitted to:

   INFACON Bursary Committee
   South African Institute of Mining and Metallurgy
   P O Box 61127
   Marshalltown
   2107

   and should include the applicant's CV, a detailed description of the research topic and a supporting motivation from the Head of Department concerned indicating the supervisor and facilities available for the research. Applications should preferably reach the Committee before the end of February, 1994.
9. The award of the bursary will be at the sole discretion of the INFACON Bursary Committee of the SAIMM, whose decision regarding the award will be final.