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The Jones–Trickett ratio—a worthwhile management tool

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SYNOPSIS

This paper describes some of the work of Jones and Trickett (1954), and demonstrates the usefulness of their findings by applying them to three fire incidents in South Africa. It is shown that the Jones–Trickett ratio can be used to indicate the type of explosion that has occurred in a mine and the level of activity or passivity of a fire behind seals. A knowledge of these factors is extremely important to a mine manager, whose prime duty during the crisis conditions resulting from a mine fire is to protect the men involved in the hazardous duty of fire-fighting.

SAMEVATTING

Hierdie referaat beskryf van die werk van Jones en Trickett (1954) en toon die nut van hul bevindings deur hulle op drie brandvoorvalle in Suid-Afrika toe te pas. Daar word getoon dat die Jones-Trickett-verhouding gebruik kan word om aan te dui watter tipe ontploffing in 'n myn plaasgevind het en wat die aktiwiteits- en passiwiteitspeil van 'n brand agter seëls is. Kennis van hierdie faktore is uiters belangrik vir 'n mynbestuurder wie se vernaamste plig tydens die krisistoestande wat op 'n mynbrand volg, is om die manne wat by die gevaarlike taak van brandbestryding betrokke is, te beskerm.

Introduction

The Jones–Trickett ratio resulted from numerous examinations of the gases formed as byproducts of colliery explosions. Jones and Trickett suggested that analyses of the gases in a sealed area may indicate whether methane or coal dust had been involved in an explosion[1].

They treated the combustion of methane and of coal theoretically, in each case deriving a relationship between the amount of oxygen used in the reaction and the amounts of carbon dioxide, carbon monoxide, and hydrogen produced. All these quantities can be determined when a sample of gas is analysed. The relationship for methane is different from that for coal because of the difference in chemical composition; hence, observation of the relationship makes it theoretically possible for the products of a methane explosion to be distinguished from those of a coal-dust explosion.

The present paper includes gas analyses from an incident that verifies the suitability of the Jones–Trickett ratio in confirming a methane explosion. Analyses of the gases within a sealed area after a heating are included to show that this ratio can indicate whether a heating is in an active or a passive state. This alone makes the ratio an exceptional tool for use by management during the crisis conditions of an underground coal-mine fire.

Combustion Products

Although Jones and Trickett dealt with the combustion of methane and of coal, and applied their findings to colliery incidents, only the combustion of methane is considered here.

The combustion of methane gives carbon monoxide, carbon dioxide, hydrogen, and water as the only products. The overall reaction can be represented by the stoichiometric equation

$$a \cdot CH_4 + b \cdot O_2 \rightarrow c \cdot CO_2 + d \cdot CO + e \cdot H_2 + f \cdot H_2O. \quad (1)$$

As the numbers of atoms of carbon, hydrogen, and oxygen must be the same on both sides of the equation,

for carbon atoms, $a = c + d$, ... (2)

for hydrogen atoms, $4a = 2e + 2f$, and .... (3)

for oxygen atoms, $2b = 2c + d + f$. .... (4)

However, because it is not possible to measure the amounts of methane burnt and water formed in a colliery explosion, a and f have to be eliminated from these three equations. This gives the equation

$2b = 4c + 3d - e$ in which

$$\frac{c + \frac{3}{4}d - \frac{1}{4}e}{b} = 0{,}5. \quad (5)$$

Although the values of a, b, c, d, e, and f will vary from one combustion to another, equation (5) will be true whatever the values.

In equation (5) b, c, d, and e refer to the numbers of molecules of each kind that are consumed or produced in the reaction. These numbers of molecules are proportional to the volumes of gas concerned, since equal volumes of different gases contain equal numbers of molecules provided that the temperature and pressure are the same. Thus equation (5) becomes

$$(CO_2 \text{ produced} + \tfrac{3}{4}\, CO \text{ produced} - \tfrac{1}{4}\, H_2 \text{ produced})/O_2 \text{ used} = 0{,}5,$$

where the gases are given by volume. This can be abbreviated to

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$(CO_2 + ¾\ CO - ¼\ H_2)/O_2$ used = 0,5. ...... (6)

Equation (6) is also valid if CO_2, CO, and H_2 refer to the percentage composition of the gas mixture after combustion. In that case, the O_2 used represents the millilitres of oxygen consumed per 100 ml of the final mixture. For combustion in air, this value can be calculated from the nitrogen content of the products, and is referred to as the oxyen deficiency:

Oxygen deficiency = 0,2647 $N_2 - O_2$.

Any dilution of the product gases with air or methane will not affect the value of equation (6) since the values for CO_2, CO, H_2, and O_2 used are reduced in the same proportion.

Thus, the basic Jones–Trickett ratio can be given as

$(CO_2 + ¾\ CO - ¼\ H_2)/(0,2647\ N_2 - O_2)$
= 0,5. .... (7)

The reaction of methane with steam to give carbon monoxide and hydrogen does not introduce any new molecular species to the system and is therefore covered by the above equations.

If steam is present before the reaction commences, the value of f in equations (1) and (7) may be negative, but this will not affect the validity of the equations. Similarly, any interaction between steam and the reaction products, such as the water–gas reactions

$C + H_2O \rightarrow CO + H_2$
$CO + H_2O \rightarrow CO_2 + H_2$,

is also covered.

For the combustion of methane to give carbon monoxide, carbon dioxide, hydrogen, and water as the only products, equation (6) applies. If there are other products of combustion,

$(CO_2 + ¾\ CO - ¼\ H_2)/O_2$ used $\leq$ 0,5, ... (8)

and the amount by which the ratio is less than 0,5 will be a measure of the amounts of carbon, ethylene, and ethane that have been formed.

Comparison of Experimental Results

In an attempt to validate their ratios, Jones and Trickett examined several experimental results obtained by other investigators.

Table I gives the results obtained at the Newcastle Coal Survey Laboratory (U.K.), where mixtures of methane and air were exploded at pressures slightly below atmospheric and the product gases analysed. The amounts of carbon monoxide and hydrogen in the product gases were found to be approximately equal, and there was thus very little difference between the results obtained with the Jones–Trickett formula and the original simplified formula.

Again, a sample of flue gases taken from a boiler at Haig Pit (U.K.) that had been fired with methane alone was found to contain approximately equal amounts of carbon monoxide and hydrogen, so that the two formulae give similar results (Table II). The amount of air admitted to the furnace had been insufficient for complete combustion, and a considerable amount of carbon had been deposited.

The findings of various other investigators are listed in Table III.

In their detailed study of the literature on methane-air explosions, Jones and Trickett[1] reported on the work of Bone and Townsend (1927) and of Vanpee and Samain (1952).

Bone and Townsend (1927) carried out a considerable amount of work on the explosion of mixtures of methane and oxygen at pressures varying from 1 to 13 atmospheres. Table IV gives two typical results.

The results of Vanpee and Samain (1952) relate both to the slow oxidation and to the explosion of mixtures of methane and oxygen. The values are of considerable interest in view of the wide range covered by the analyses of the final products. Tables V and VI give some of their results, chosen because they cover both slow oxidation and explosion and because of the presence of ethylene and ethane in the products.

Jones and Trickett concluded from their investigation of the combustion of methane that, for all the above experiments, the expression $(CO_2 + ¾\ CO - ¼\ H_2)/(O_2$ used) is approximately equal to 0,5. The precise values obtained are generally slightly below that value.

For mixtures of methane and air, the quantities of carbon monoxide and hydrogen formed are often of the same order, and in such cases the ratio $(CO_2 + ½\ CO)/(O_2$ used) is also approximately equal to 0,5.

For mixtures of methane and oxygen, in which the quantities of carbon monoxide and hydrogen differ considerably, the values of $(CO_2 + ½\ CO)/(O_2$ used) depart appreciably from 0,5, and this simple formula cannot be used.

The agreement between the theoretical conclusions and the experimental figures is particularly striking in view of the fact that some of the analyses were carried out many years ago and the work was not performed specifically for the investigation undertaken by Jones and Trickett.

Applications of the Jones–Trickett Ratio to Incidents in South Africa

During 1986, a study[5] was made by the author of three incidents in South African coal mines.

Coal Mine in the Witbank Area

The first incident was a fire initiated by a methane explosion in the goaf of a rib-pillar retreating section in the Witbank area. Fig. 1 illustrates the sequence of events that occurred. During the fire, samples of gas were collected at the two points indicated, Wall 1 and Wall 4.

Fig. 2 depicts the values of the Jones–Trickett ratio that were calculated from the product gases sampled at AA on Wall 1 against time, and Fig. 3 is a detailed illustration of the initial period.

In Fig. 2, which shows the Jones–Trickett ratio for the whole period of the incident, fluctuations occurred in days 1 and 2 (26th and 27th October, 1982) as the seals were being erected and while equilibrium was being attained behind the fire seals. As Fig. 3 shows, the ratio is constant at 0,5, which validates the Jones–Trickett ratio for a methane explosion.

The graphical representation of the values of product gases recorded at sample point BB on wall 4 (Fig. 4) again

TABLE I
EXPERIMENTS IN THE NEWCASTLE COAL SURVEY LABORATORY[1] (1951)

Original methane %	Analysis of residual gas, % of original gas						O_2 corresponding to N_2	O_2 used	$\frac{CO_2 + ½ CO}{O_2 \text{ used}}$	$\frac{CO_2 + ¾ CO - ¼ H_2}{O_2 \text{ used}}$
	CO_2	CO	H_2	CH_4	O_2	N_2				
6	5,8	0,1	Nil	0,1	6,9	75,7	20,0	13,1	0,45	0,45
	5,9	0,1	Nil	Nil	6,7	75,7	20,0	13,3	0,45	0,45
9	8,5	0,2	0,1	0,3	0,6	73,2	19,4	18,8	0,46	0,46
	8,4	Nil	Nil	0,6	1,6	72,7	19,3	17,7	0,47	0,47
11	7,5	2,3	1,0	1,2	Nil	70,9	18,8	18,8	0,46	0,48
	7,2	2,7	1,2	1,1	Nil	71,1	18,8	18,8	0,46	0,47
12	6,4	4,5	2,8	1,1	Nil	70,2	18,6	18,6	0,47	0,49
	6,4	4,4	2,0	1,2	Nil	70,8	18,8	18,8	0,46	0,49
13	5,6	6,4	4,6	1,0	Nil	70,0	18,5	18,5	0,48	0,50
14	5,0	6,4	5,8	2,6	Nil	69,4	18,4	18,4	0,45	0,46
	5,1	6,1	6,1	2,8	Nil	69,9	18,5	18,5	0,44	0,44
	4,9	6,7	6,0	2,4	Nil	69,0	18,3	18,3	0,45	0,46
							Mean		0,46	0,47

TABLE II
FLUE GASES AT HAIG PIT[2]

Composition of flue gases, %						O_2 corresponding to N_2	O_2 used	$\frac{CO_2 + ½ CO}{O_2 \text{ used}}$	$\frac{CO_2 + ¾ CO - ¼ H_2}{O_2 \text{ used}}$
CO_2	CO	H_2	CH_4	O_2	N_2				
5,77	5,67	4,93	5,58	1,96	76,09	20,15	18,19	0,47	0,48

TABLE III
EXPERIMENTS BY OTHER INVESTIGATORS

Original methane %	Composition of products, %						O_2 corresponding to N_2	O_2 used	$\frac{CO_2 + ½ CO}{O_2 \text{ used}}$	$\frac{CO_2 + ¾ CO - ¼ H_2}{O_2 \text{ used}}$	Author
	CO_2	CO	H_2	CH_4	O_2	N_2					
14,8	5,0	8,7	10,7	2,1	–	73,5	19,5	19,5	0,48	0,48	Burgess and Wheeler[2] (1914)
7,9	9,2	0,2	–	–	3,8	86,8	23,0	19,2	0,48	0,49	Wheeler[3] (1918)
10,0	10,9	1,1	0,7	–	–	87,3	23,1	23,1	0,50	0,50	
12,1	8,1	5,9	4,0	0,1	0,1	81,9	21,7	21,6	0,51	0,53	
13,9	5,5	9,0	9,4	1,0	–	75,2	19,9	19,9	0,50	0,50	
14,7	4,1	9,9	11,1	0,6	–	74,3	19,7	19,7	0,46	0,45	
12,8	5,5	8,7	7,3	0,5	–	78,0	20,7	20,7	0,48	0,49	Payman and Wheeler[4] (1921)
12,5	6,0	7,8	6,7	0,4	–	79,0	20,9	20,9	0,47	0,49	
10,0	8,7	1,0	0,8	0,3	–	70,5	18,7	18,7	0,49	0,50	Coward and Hartwell[1] (unpublished)
								Mean	0,49	0,49	

TABLE IV
EXPERIMENTS BY BONE AND TOWNSEND (1927)

Composition of products, %				P1	P2/P1	O_2 used	$\frac{CO_2 + ½ CO}{O_2 \text{ used}}$	$\frac{CO_2 + ¾ CO - ¼ H_2}{O_2 \text{ used}}$
CO_2	CO	H_2	CH_4					
6,8	41,3	50,8	1,1	651,6 mm	1,031	48,5	0,57	0,52
7,45	38,5	54,5	–	12,61 atm	1,12	44,6	0,60	0,51

TABLE V

EXPERIMENTS BY VANPEE AND SAMAIN (1952)

Composition: $2\ CH_4 + O_2$
Experimental conditions: Slow oxidation
Initial pressure 66 cm Hg
Temperature 58°C

Original vol. %		Volume of products, % of original										
CH_4	O_2	CO_2	CO	H_2	CH_2	C_2H_4	C_2H_6	H_2O	O_2	O_2 used	$\frac{CO_2 - ½\ CO}{O_2\ used}$	$\frac{CO_2 - ¾\ CO - ¼\ H_2}{O_2\ used}$
53,61	26,86	0,30	4,87	1,52	46,52	?	0,76	11,83	18,63	8,23	0,33	0,43
53,48	26,80	0,61	5,11	1,72	45,37	0,04	0,85	13,73	17,19	9,61	0,33	0,42
53,36	26,74	0,66	6,73	2,12	43,32	0,13	0,92	14,26	16,00	10,74	0,38	0,48
53,63	26,84	0,95	8,22	2,62	41,25	0,25	1,15	18,78	12,81	14,03	0,36	0,46
53,63	26,84	1,03	8,95	2,64	40,74	0,27	0,97	20,19	11,66	15,18	0,36	0,47
53,88	29,97	1,28	9,35	2,69	40,01	0,16	1,20	23,77	9,55	17,42	0,34	0,43
52,94	27,16	1,45	12,15	2,57	36,15	0,08	1,07	29,89	3,69	23,47	0,32	0,42
										Mean	0,35	0,44

TABLE VI

EXPERIMENTS BY VANPEE AND SAMAIN (1952)

Composition: $CH_4 + O_2$
Experimental conditions: Initial pressure 59 to 60 cm Hg
Temperature 510°C
No ethylene was detected

Original vol. %		Volume of products, % of original									
CH_2	O_2	CO_2	CO	H_2	CH_2	C_2H_2	H_2O	O_2	O_2 used	$\frac{CO_2 - ½\ CO}{O_2\ used}$	$\frac{CO_2 - ¾\ CO - ¼\ H_2}{O_2\ used}$
							Slow oxidation				
38,16	38,13	0,28	3,46	0,34	32,65	0,04	4,27	33,09	5,04	0,40	0,55
39,69	39,73	0,49	4,40	0,12	33,88	0,15	12,15	31,07	8,66	0,31	0,41
40,07	40,03	0,49	4,86	0,57	33,45	0,10	13,33	30,39	9,64	0,30	0,41
40,33	40,34	0,91	6,84	0,70	30,95	0,14	16,30	27,65	12,69	0,34	0,46
39,11	39,08	4,05	12,65	1,33	21,37	0,15	33,36	12,12	26,96	0,38	0,49
									Mean	0,35	0,46
							Explosion				
39,85	39,85	5,62	27,87	38,75	4,85	0,37	32,16	4,38	35,47	0,55	0,48
40,42	40,42	5,94	29,24	40,97	4,87	0,03	30,32	4,99	35,43	0,58	0,50

validates the ratio in that the value of 0,5 is indicative of a methane ignition, which was the source of the fire recorded in the incident.

Coal Mine in the Vaal Triangle

The incident resulted from a heating in a production section; reheating occurred after the initial sealing as the result of a holing in a pillar that had been cut through by a coal-cutter jib prior to the incident. Fig. 5 indicates the values of the Jones–Trickett ratio as calculated from the product gases versus time.

Because of the nature of the incident, the Jones–Trickett ratio did not have the value that one would expect after an explosion of methane, which would be 0,5. However, as the graph shows, the Jones–Trickett ratio does decrease as the fire behind the seals decreases in intensity. Further, the moment of reheating of the fire area is very noticeable. The Jones–Trickett ratio can thus be used as an indication of whether a fire is in an active or a passive state.

Old Fire Area, Vaal Triangle

This incident was not an open fire but occurred in an old fire area that had become re-heated as a result of the cracking of coal pillars and fire seals, which allowed the ingress of oxygen.

The graph of the Jones–Trickett ratio (Fig. 6), which was calculated over the four-month period of the re-heating, shows that, at about 79/02/20, the fire was decreasing in intensity and was going out; at about 79/03/25, the fire had re-ignited and, at 79/03/25, the fire had again become passive with a final activity at about 79/04/20.

Conclusions

The finding of Jones and Trickett that the expression

$(CO_2 + ¾\ CO - ¼\ H_2)/O_2$ used,

$\frac{CO_2 + \frac{3}{4} CO - \frac{1}{4} H_2 - \frac{1}{4} C_2H_4 - \frac{1}{2} C_2H_6}{O_2 \text{ used}}$
0,46
0,44
0,51
0,49
0,49
0,46
0,44
0,47

$\frac{CO_2 + \frac{3}{4} CO - \frac{1}{4} H_2 + \frac{1}{4} C_2H_6}{O_2 \text{ used}}$
0,56
0,42
0,42
0,47
0,49
0,47
0,48
0,50

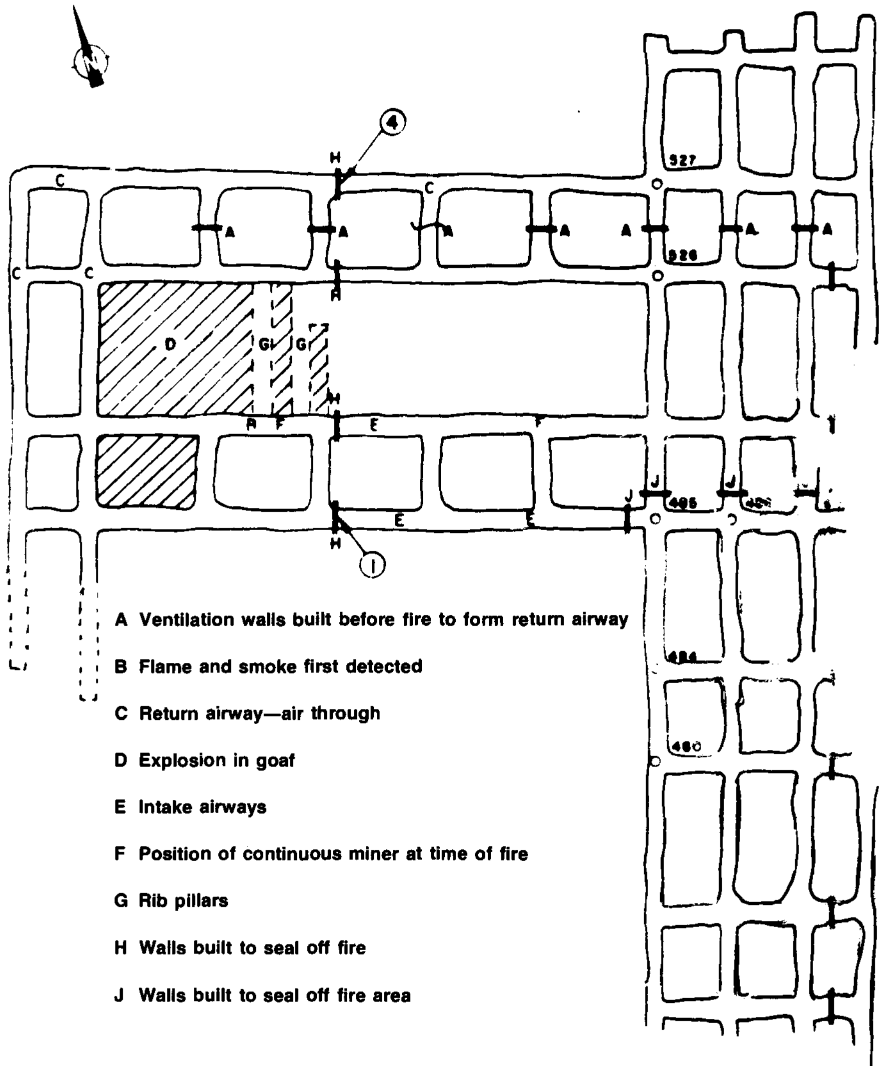

Fig. 1—Fire in a rib-pillar retreating section in a Witbank mine

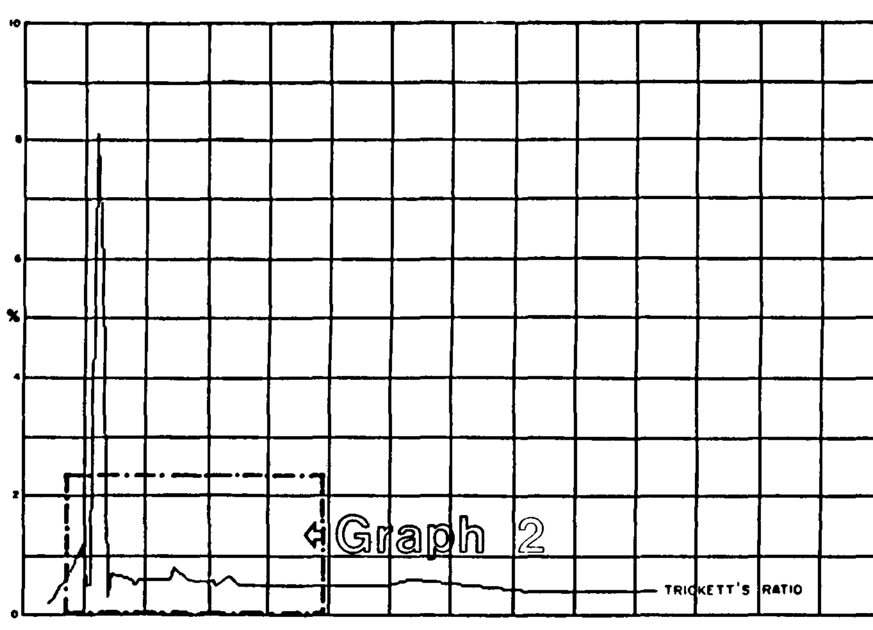

Fig. 2—Jones-Trickett ratio calculated from the product gases, Witbank area (Graph 2 appears in Fig. 3)

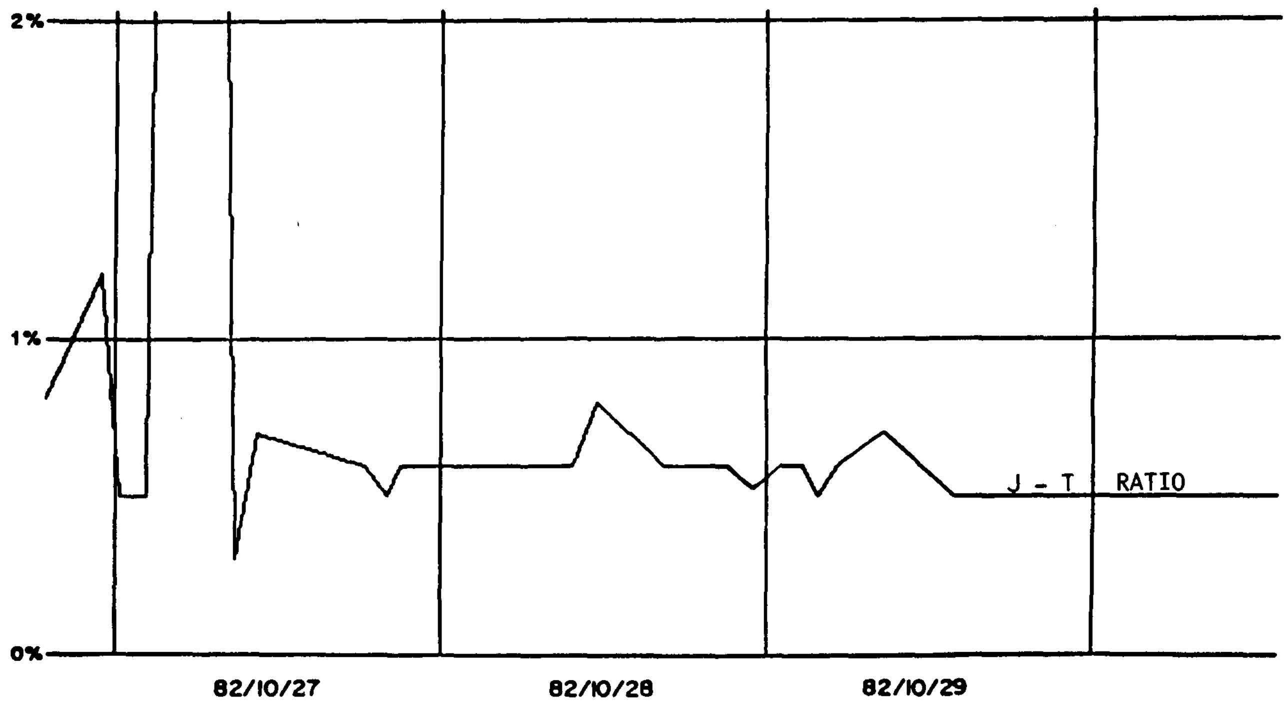

Fig. 3—Detail from Fig. 2

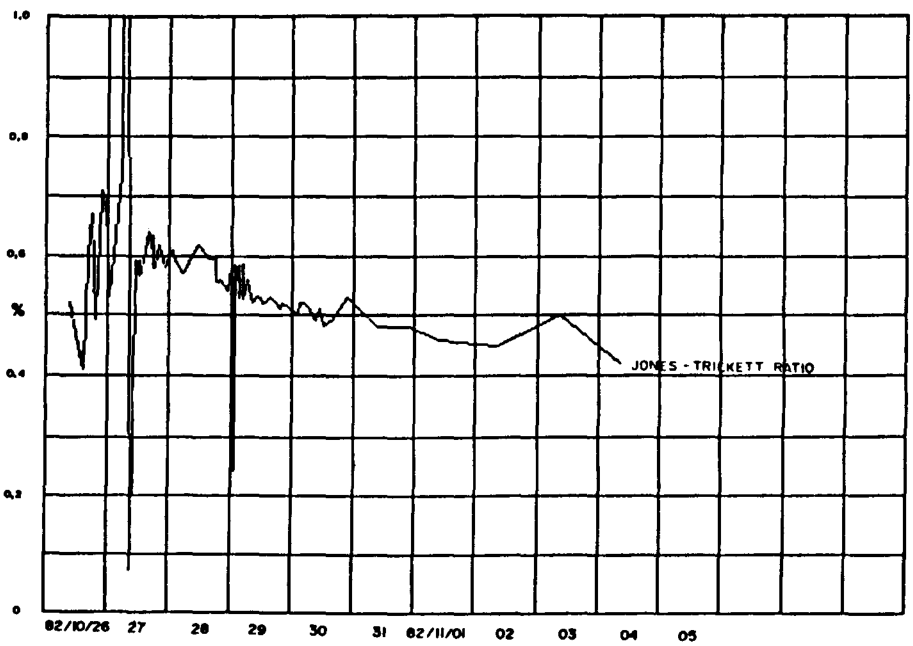

Fig. 4—Jones-Trickett ratio for the product gases recorded at BB on Wall 4

when applied either to the product of a methane explosion carried out in the laboratory or to the products of a methane explosion at a mine, gives a value of approximately 0,5 was confirmed in the South African investigation. Additional work by Jones and Trickett applied to experimental coal-dust explosions gave the value of approximately 0,85 for the same expression.

Jones and Trickett concluded that the formula could be used to differentiate between a methane and a coal-dust explosion. It must be stressed that, in practice in a coal mine, it is rare to obtain an ideal explosion of either of these types, for some coal dust will generally be raised and participate in a methane explosion and a coal-dust explosion is normally initiated by an ignition of methane.

It must be mentioned that the methane explosion investigated at Witbank occurred in an isolated section of the mine. In an explosion occurring over a large area of a mine, the gaseous products of reaction would be subjected to a considerable amount of dilution by the ventilating current.

The Jones–Trickett ratio is a valuable tool that should be used more frequently by mine managers in determining

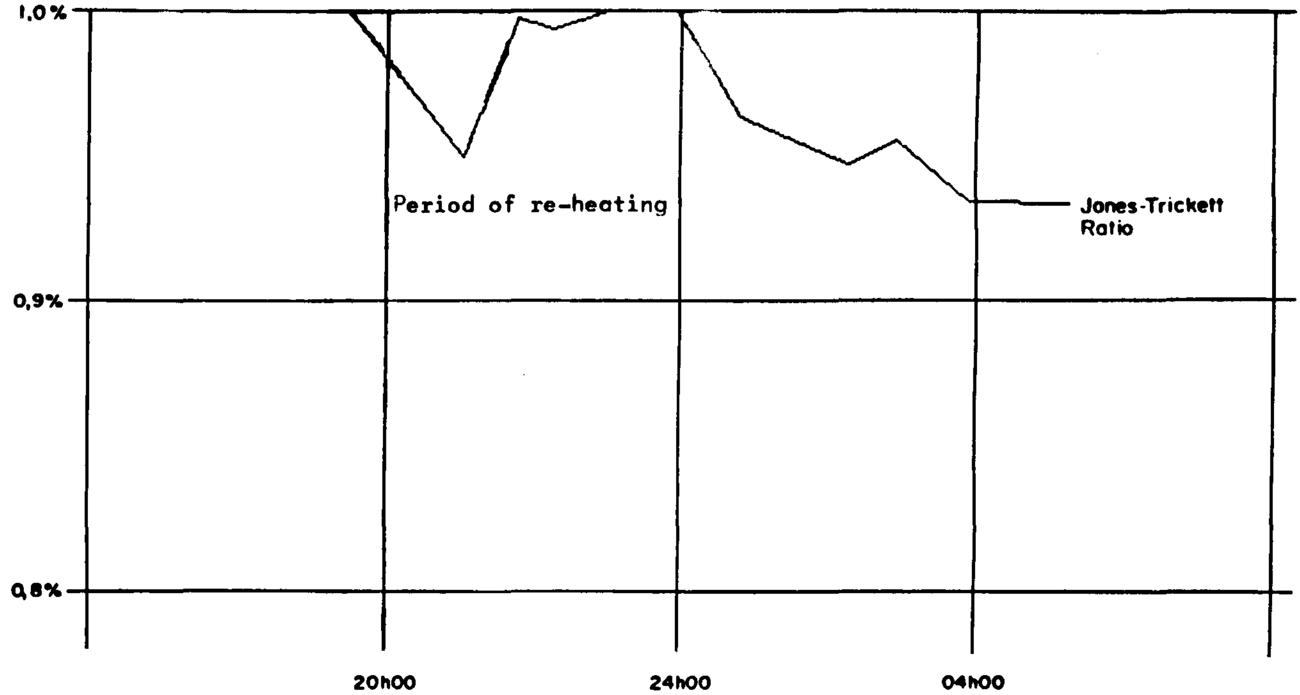

Fig. 5—Jones-Trickett ratio for the product gases, Vaal Triangle

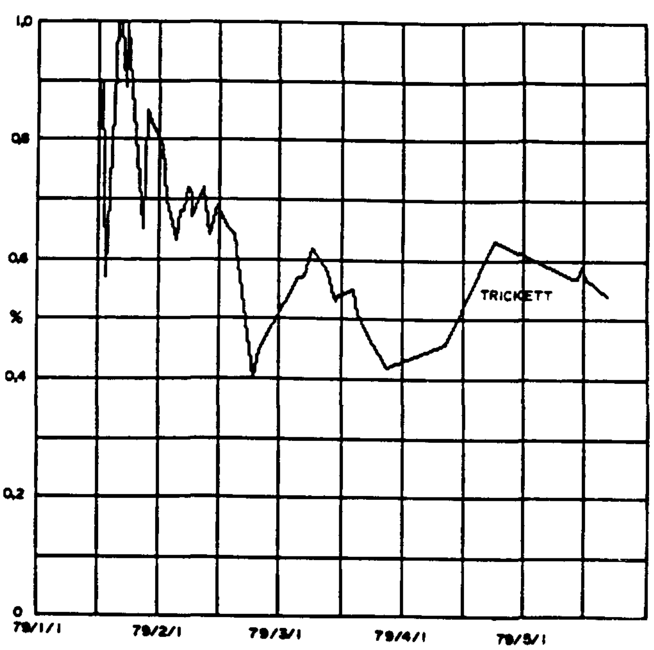

Fig. 6—Jones-Trickett ratio for the product gases, Vaal Triangle

the type of any explosion that has occurred within the workings of a coal mine. Additionally, it can be used as an indication of the level of activity or passivity of the fire behind fire seals. Such knowledge is extremely important to a mine manager whose prime duty during the crisis conditions resulting from a mine fire is to protect the workmen involved in the hazardous duty of fire fighting.

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