FUEL RESEARCH INSTITUTE OF SOUTH AFRICA.

TECHNICAL MEMORANDUM NO. 26 OF 1965.

FLAME PROPAGATION IN PULVERISED COAL-AIR MIXTURES.

BY:

T. C. ERASMUS.

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INTRODUCTION:

Flame propagation in pulverised-coal-air mixtures may be studied by placing an ignition source in a pulverised-coal-air stream. The fuel-air mixture is ignited at the source and the flame propagates laterally into the stream to form a conical flame. It thus follows that the apex angle of the flame will be a function of both the propagation velocity and the axial velocity of the fuel-air mixture. The relation is complicated due to bending of the flow lines by thermal expansion in the vicinity of the flame front. H. Hattori[*] proposed the following relation:

$$\sin \theta = \frac{V_f}{\sqrt{V_o^2 + V_f^2(1 - \rho_2/\rho_1)}} \quad \ldots\ldots\ldots \quad (1)$$

where θ = half the apex angle

V_f = flame propagation velocity

V_o = velocity of unburned fuel-air mixture of the flame front.

ρ = density

subscripts 1 and 2 refer to conditions before and after the flame front, respectively.

OBJECT OF EXPERIMENTS.

Having thus established a relation between the apex angle of the flame and the characteristics of the system it is possible to investigate the effects of, for example, (a) fuel-to-air ratio and (b) the ash content of the fuel on flame propagation.

EXPERIMENTAL .../

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[*] Hattori, H., 6th International Symposium on Combustion p. 590.

EXPERIMENTAL REQUIREMENTS.

Examination of equation (1) will indicate necessary experimental conditions to be fulfilled.

A major source of experimental error lies in the determination of the apex angle. The error would be relatively less when the angle is wide and this desirable condition can be achieved by reducing the value of V_o in equation (1), or, as a consequence, by reducing the axial velocity of the fuel-air mixture. Reduction of the axial velocity is, however, limited by the instability of the flame at low axial velocities and hence one should aim at the smallest value still giving reasonably stable conditions.

Due to the bending of the flow lines the flame is not a true cone but presents a convex flame front to the oncoming fuel-air mixture. Only in the vicinity of the ignition source, where the flow lines are assumed straight, does V_o equal the axial velocity. For any other position along the flame front V_o is indeterminable. The apex angle must thus result from tangents drawn to the portion of the flame front bordering the ignition source.

For the expected small values of θ it may be shown that the density ratio in equation (1) has an insignificant effect on the propagation velocity. Thus for relatively low fuel-to-air ratios, the chemical composition changes, due to combustion, may be neglected and the density ratio may be replaced by the corresponding temperature ratio. The latter can be readily determined experimentally.

Bearing the foregoing in mind, equation (1) can be rewritten as:

$$\text{Sin } \theta = \frac{V_f}{\sqrt{V_1^2 + V_f^2 (1 - T_1/T_2)}} \quad \ldots\ldots\ldots \quad (2)$$

where V_1 = axial velocity of unburned fuel-air mixture

T = absolute temperature

In ...../

In summary it may be said that the following conditions must be observed:

(i) the axial velocity of the fuel-air mixture must be a minimum;

(ii) the apex angle must be determined from the flame front near the ignition source;

(iii) the fuel-to-air ratio must be small.

TEMPERATURE RATIO.

The temperature of the unburned fuel-air mixture is readily determinable by means of a mercury thermometer. The temperature of the combustion products poses a problem in that the thermocouple, upon insertion into the flame, becomes covered with a carbon char. Since, however, the temperature ratio has little effect on the propagation velocity the temperature T_2 may be assumed equal to that of the ignition source. The temperature of the ignition source can be determined using a fuel-to-air ratio equal to zero. This simplification will introduce a negligable error.

APPARATUS.

The apparatus consists of a screw-feeder force-feeding the pulverised coal from a hopper to a cyclone mixer where it is mixed with air and then discharged through the annulus of a concentric burner. Gas is supplied through the central tube of the burner and ignited to form the ignition source. The flow rates of the ignition gas and the air are measured with rotameters. The annular space of the burner contains a number of fine wire screens to render the velocity profile, of the fuel-air mixture, uniform. The apparatus is vibrated to promote a steady flow of the pulverised coal.

PROCEDURE.

The gas flow rate was set to a predetermined value[*] and the pilot flame ignited. Compressed air at

a fixed .../

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[*] H. Hattori found the apex angle of the flame to be independent of the ignition gas flow rate provided a critical flow rate is exceeded. This was tested and found to be correct. A gas flow rate well in excess of the critical rate was employed in this study.

a fixed rate[**] and pulverised coal at a constant rate were supplied to the cyclone mixer and the resulting flame was photographed. The coal feed rate was determined by weighing the coal supplied to the mixer over a period of one minute. For each fuel studied various coal feed rates were employed. The apex angle of the flame was determined from projected film images.

RESULTS.

The experimental observations are given in Appendix I. The various fuels used can be characterised as follows:

Fuel No.	F.R.I. Sample No.	Ash %	Vol. Mat. %	Fixed Carbon %
1	64/1231 E	9.6	23.0	66.4
2	64/1163 A	11.6	26.0	60.2
3	64/1163 B	14.3	25.3	58.2
4	64/1174 D	16.5	27.5	53.0
5	64/1154 C	19.1	22.6	56.5
6	64/1182 A	22.3	22.0	54.1
7	64/1183 A	27.8	24.4	43.1

For this study only -250 # size fractions of the coals were used. The computed results are represented in Figures I - VIII. Figures I - VII indicate the effect of the fuel - to - air ratio on the propagation velocity for various types of fuel. The effect of the ash content, under a constant fuel - to - air ratio, on the flame propagation velocity is illustrated in Figure VIII.

DISCUSSION .../

[**] Hattori points out that the pilot flame becomes unstable for axial velocities below 0.8 m/sec. A mean axial velocity of 1.09 m/sec was selected for this study.

DISCUSSION.

The effect of the fuel-to-air ratio on the flame propagation velocity was investigated using various fuels ranging in ash content from 9 to 27 per cent. The fuels were chosen so that their volatile matter contents were within a narrow margin. In addition, the mean axial velocity of the fuel-air mixture was maintained at 1.09 m/sec. It may thus be assumed that the volatile matter content and axial velocity do not enter into the variation of the flame propagation velocity. The only remaining controlled variables to affect the propagation velocity are thus the fuel-to-air ratio and the ash content of the fuel.

As may be seen from figures 1, 2, 3, 4 and 6, the flame propagation velocity increases with increase in the fuel-to-air ratio. This tendency is in agreement with findings published by H. Hattori. The flame propagation velocities in figures 5 and 7 exhibit a maximum value at a coal feed rate of about 2 grams per minute. Hattori observed a similar phenomenon for coal having a low carbon content. The peak velocities, however, were obtained at much higher fuel-to-air ratios. It is thought that the maxima in figures 5 and 7 are due to experimental error rather than being a property of the fuel.

The scatter of the experimental propagation velocities appears to indicate that the coal feed rate is not constant. This was verified by weighing. The mean feed rate, i.e. the mean of the weight of coal supplied to the mixer by the worm feed over a period of 1 minute varied as much as 20 per cent during consecutive determinations. This feed rate variation corresponds to 0.5 cm./sec. variation in the flame propagation velocity. The error introduced in determining the apex angle is of the order of $\frac{1}{4}$ degree which corresponds to a flame propagation velocity variation of about 0.2 cm./sec. Bearing in mind that the errors may be addative, it is quite possible that the maxima in figures 5 and 7 were due to the inadequacies of the experimental equipment.

From .../

From the plot of the flame propagation velocity, at constant coal feed rate, versus the ash content of the coal it is observed that the ash content appears to have no effect on the flame propagation velocity. This was anticipated from the fact that char covered the thermocouple upon insertion. This appears to indicate that carbon in the fuel does not enter into the early stages of combustion and only for this stage the propagation speed is measured. Flame propagation depends mainly on the liberation and combustion of the volatile matter.

FUTURE INVESTIGATIONS.

The effect of the following factors on the propagation velocity is to be studied in the future:

(1) The effect of particle size.
(2) The effect of volatile matter.

(SIGNED) T. C. ERASMUS.
SENIOR TECHNICAL OFFICER.

PRETORIA.
5th July 1965.

APPENDIX I

$$V_o = 1.09 \text{ m/sec.}$$

$$\frac{T_1}{T_2} = 0.32$$

Fuel No. 1.

% ash = 9.6 % Volatile Matter = 23.0

	Run I	Run II	Run III
	Mass coal/min = 0.5 gm/min	Mass coal/min = 1.3 gm/min	Mass coal/min = 2.2 gm/min
2θ	16°	$16\frac{1}{2}^{\circ}$	$18\frac{1}{2}^{\circ}$
	$16\frac{1}{4}^{\circ}$	17°	19°
	$15\frac{1}{2}^{\circ}$	$17\frac{1}{2}^{\circ}$	$18\frac{1}{4}^{\circ}$
Mean	15.9°	17°	18.6°

Fuel No. 2.

% ash = 11.6 % volatile matter = 26.0

	Run I	Run II	Run III
	Mass coal/min = 0.6 gm/min	Mass coal/min = 1.9 gm/min	Mass coal/min = 1.4 gm/min
2θ	15°	17°	$16\frac{1}{2}^{\circ}$
	$15\frac{1}{2}^{\circ}$	$17\frac{1}{4}^{\circ}$	$16\frac{1}{4}^{\circ}$
	16°	17°	$17\frac{1}{4}^{\circ}$
	$15\frac{1}{4}^{\circ}$	-	-
Mean	15.4°	17.0°	16.7°

Fuel No. 3 ..../

Fuel No. 3

% ash = 14.3 % Volatile Matter = 25.3

	Run I	Run II	Run III
	Mass coal/min = 1.2 gm/min	Mass coal/min = 1.9 gm/min	Mass coal/min = 3.1 gm/min
2θ	$17\frac{1}{4}^{\circ}$	$16\frac{3}{4}^{\circ}$	$17\frac{1}{2}^{\circ}$
	16°	$17\frac{1}{2}^{\circ}$	$18\frac{1}{4}^{\circ}$
	16°	$17\frac{1}{2}^{\circ}$	$18\frac{1}{2}^{\circ}$
Mean	16.4°	17.2°	18.1°

Fuel No. 4

% ash = 16.5 % volatile matter = 27.5

	Run I	Run II	Run III
	Mass coal/min = 0.7 gm/min	Mass coal/min = 1.6 gm/min	Mass coal/min = 3.1 gm/min
2θ	$16\frac{1}{4}^{\circ}$	$17\frac{1}{4}^{\circ}$	$17\frac{1}{2}^{\circ}$
	$16\frac{3}{4}^{\circ}$	$17\frac{1}{2}^{\circ}$	$17\frac{3}{4}^{\circ}$
	$15\frac{1}{2}^{\circ}$	18°	$17\frac{3}{4}^{\circ}$
Mean	16.2°	17.6°	17.7°

Fuel No. 5.

% ash = 19.1 % volatile matter = 22.6

	Run I	Run II	Run III
	Mass coal/min = 0.8 gm/min	Mass coal/min = 2.9 gm/min	Mass coal/min = 1.6 gm/min
2θ	15°	18°	$18\frac{1}{4}^{\circ}$
	15°	$17\frac{1}{2}^{\circ}$	$17\frac{3}{4}^{\circ}$
	16°	$17\frac{3}{4}^{\circ}$	$18\frac{1}{2}^{\circ}$
Mean	15.3°	17.7°	18.2°

Table No. 6 .../

Fuel No. 6.

% ash = 22.3 % volatile matter = 22.0

	Run I	Run II	Run III
	Mass coal/min = 0.6 gm/min	Mass coal/min = 1.7 gm/min	Mass coal/min = 3.8 gm/min
2θ	$15\frac{1}{4}^\circ$ $14\frac{1}{4}^\circ$ $15\frac{1}{4}^\circ$	$17\frac{1}{4}^\circ$ $16\frac{3}{4}^\circ$ 16°	$18\frac{1}{4}^\circ$ $18\frac{1}{2}^\circ$ 18°
Mean	14.9°	16.7°	18.2°

Fuel No. 7

% ash = 27.8 % volatile matter = 24.4

	Run I	Run II	Run III
	Mass coal/min = 0.8 gm/min	Mass coal/min = 2.9 gm/min	Mass coal/min = 1.9 gm/min
2θ	$15\frac{1}{2}^\circ$ 16° $16\frac{1}{2}^\circ$	$16\frac{1}{2}^\circ$ 17° 16°	$18\frac{1}{2}^\circ$ $17\frac{1}{2}^\circ$ 17°
Mean	16°	$16\frac{1}{2}^\circ$	17.7°

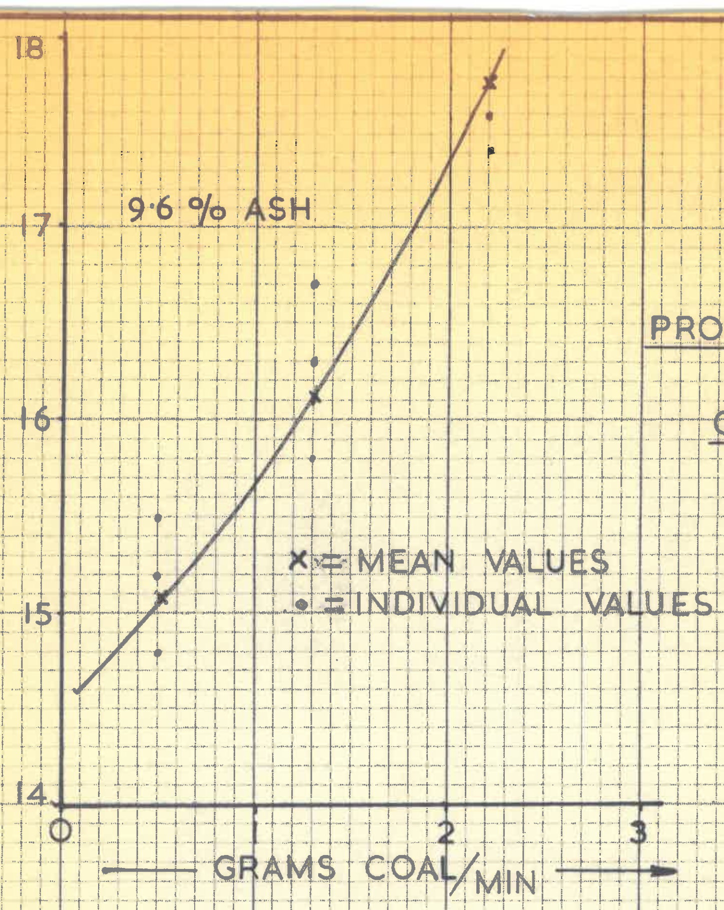


FIG. 1

PROPAGATION VELOCITY
VS.
COAL FEED RATE

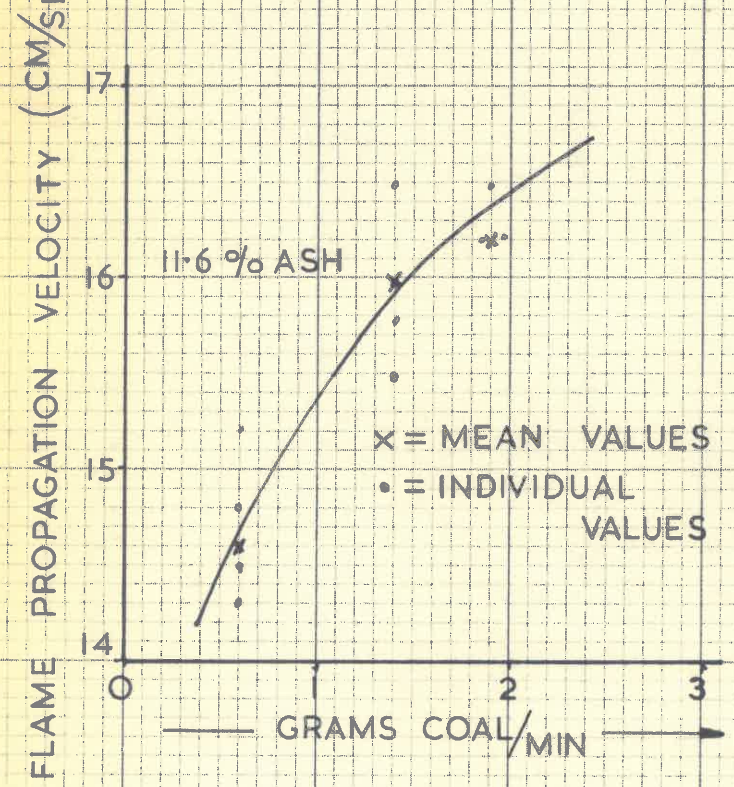


FIG. 2

PROPAGATION VELOCITY
VS.
COAL FEED RATE

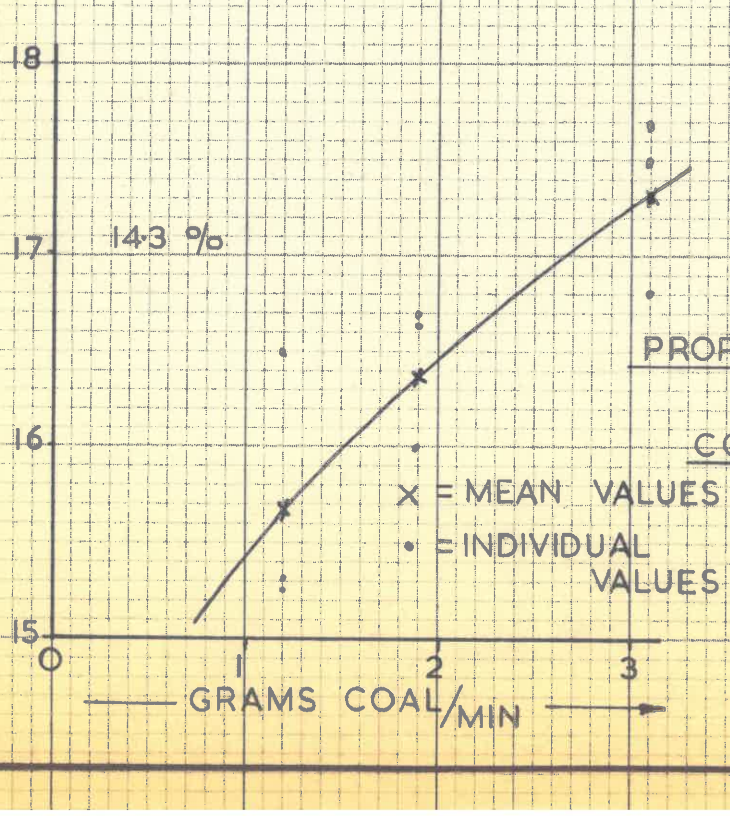


FIG. 3

PROPAGATION VELOCITY
VS.
COAL FEED RATE

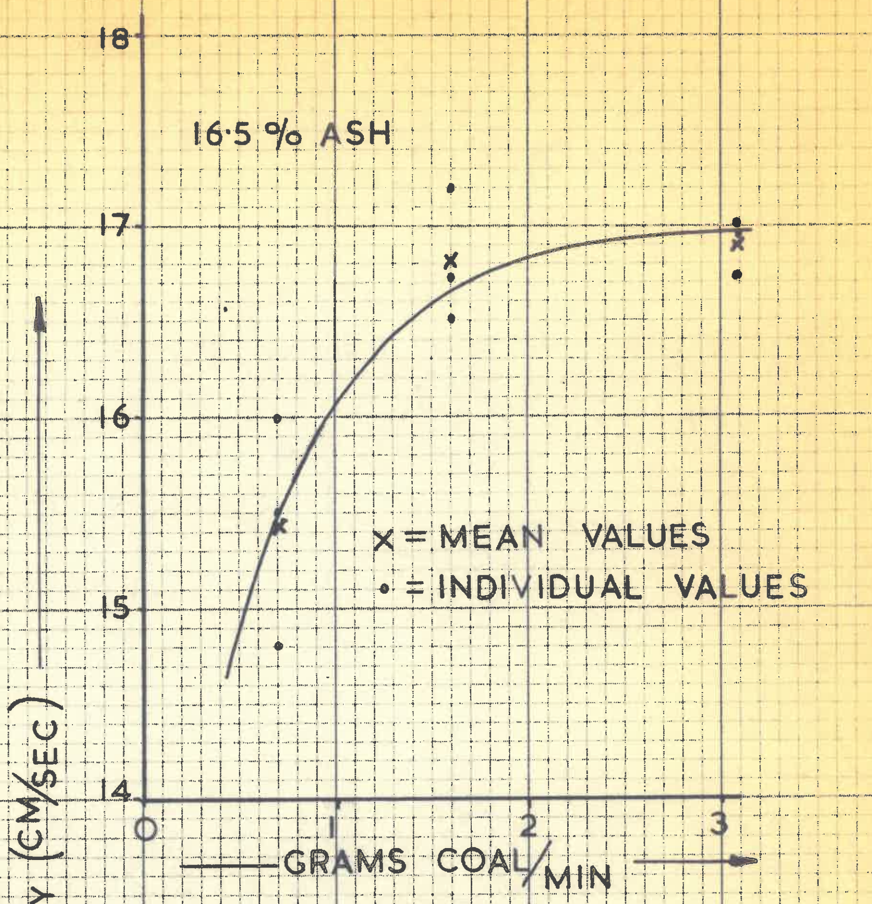


FIG. 4

PROPAGATION VELOCITY
VS.
COAL FEED RATE

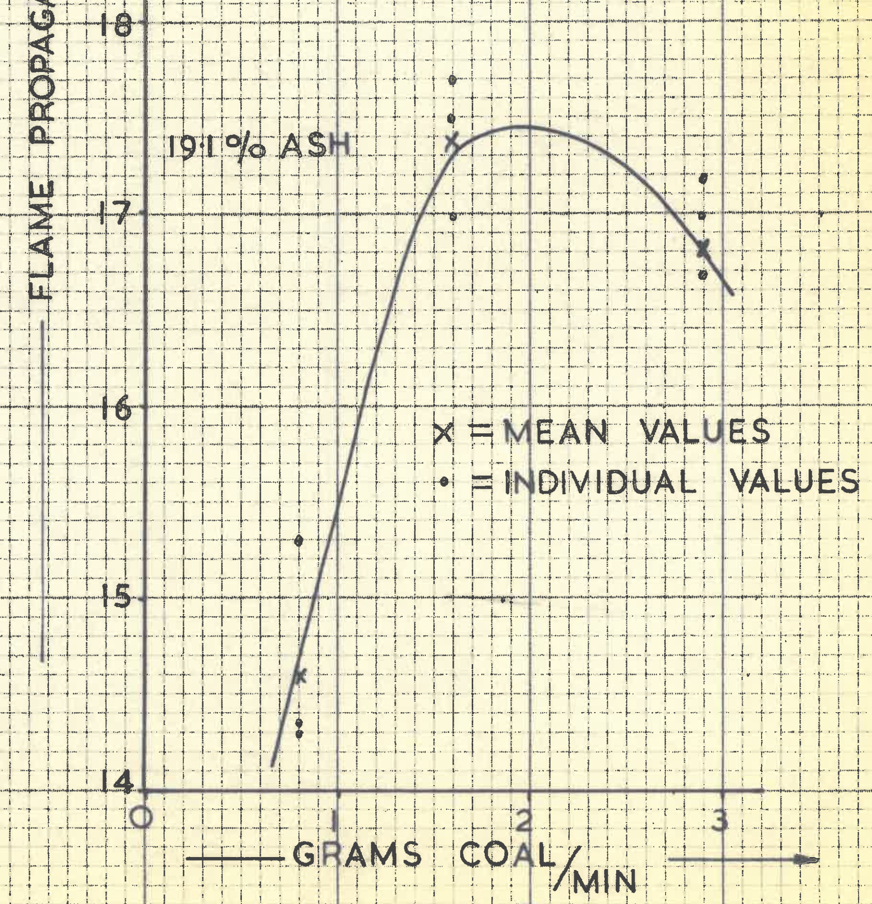


FIG. 5

PROPAGATION VELOCITY
VS.
COAL FEED RATE

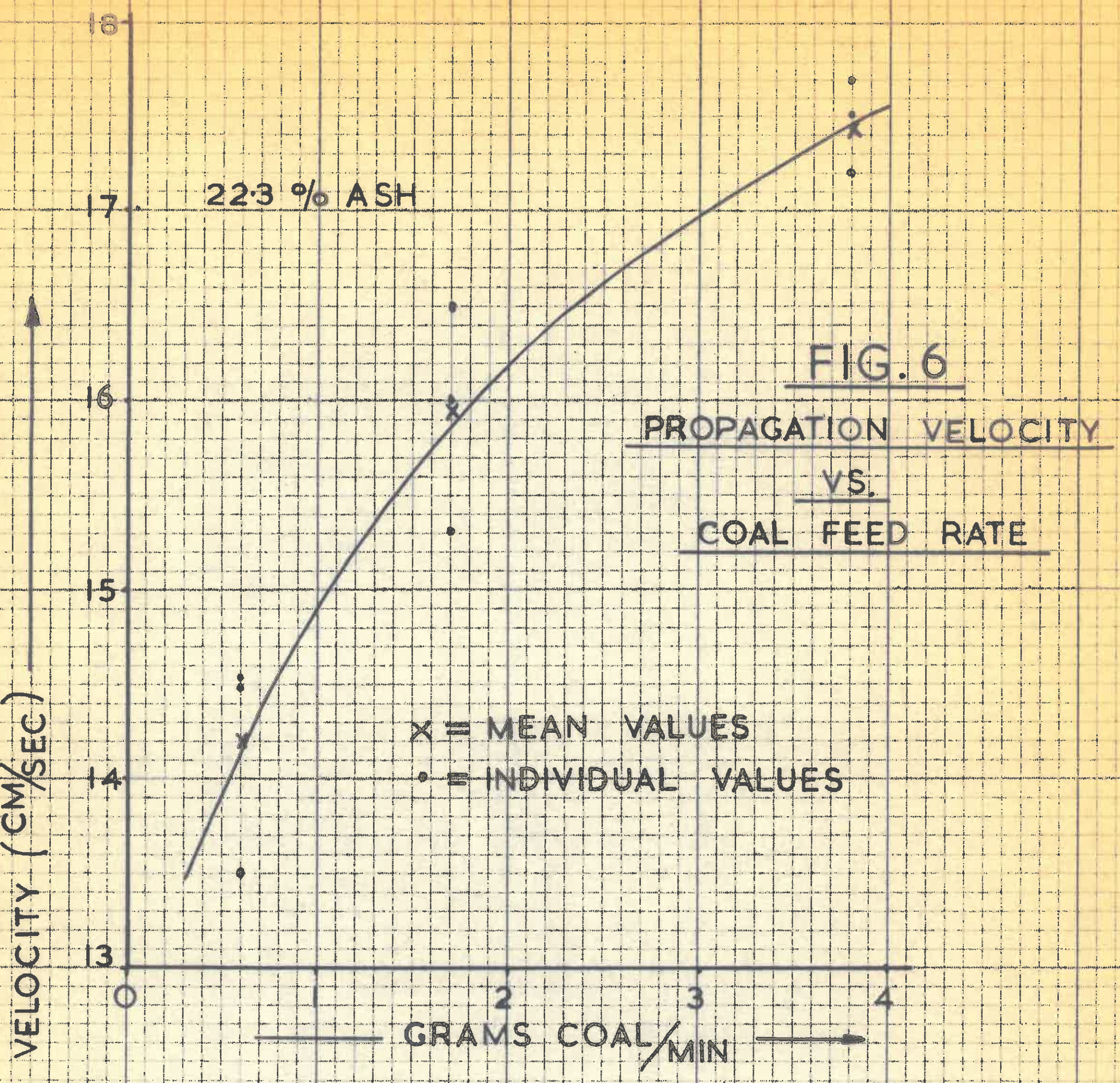


FIG. 6

PROPAGATION VELOCITY
VS.
COAL FEED RATE

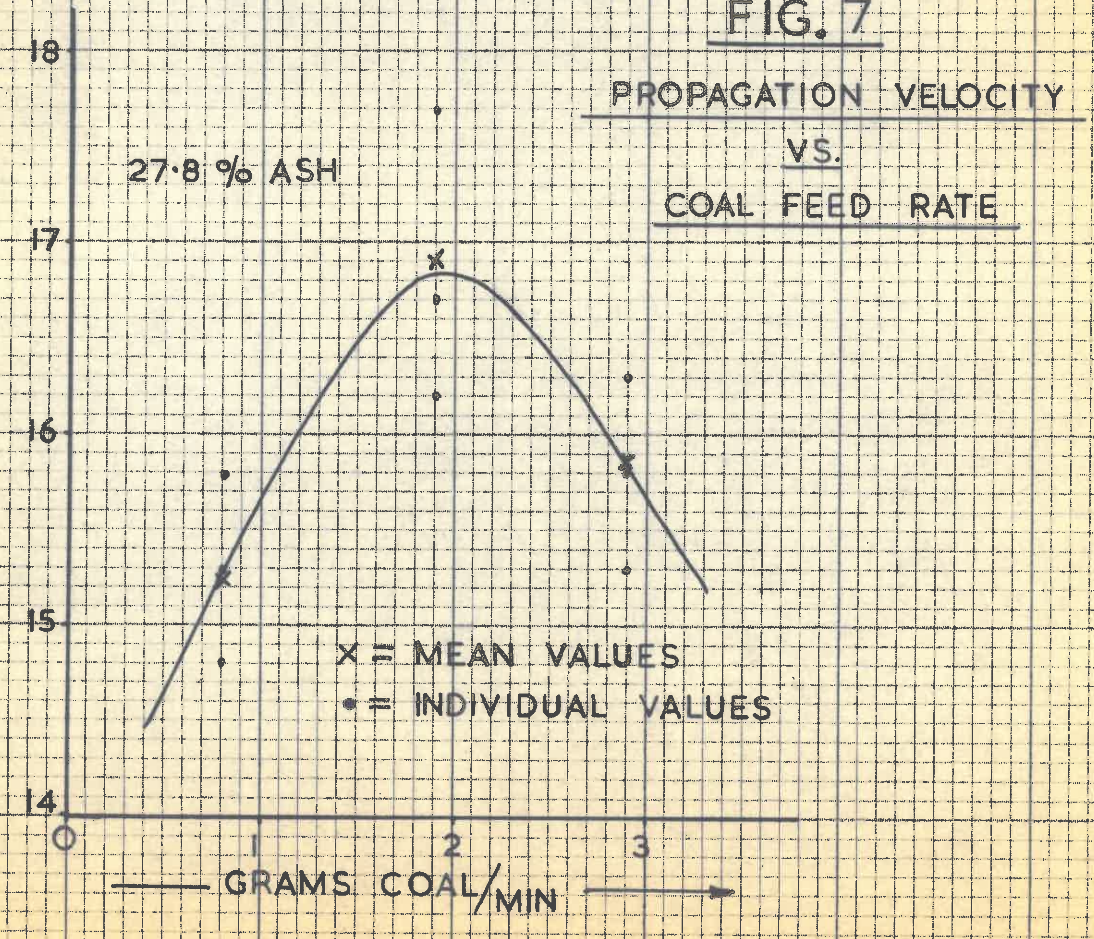
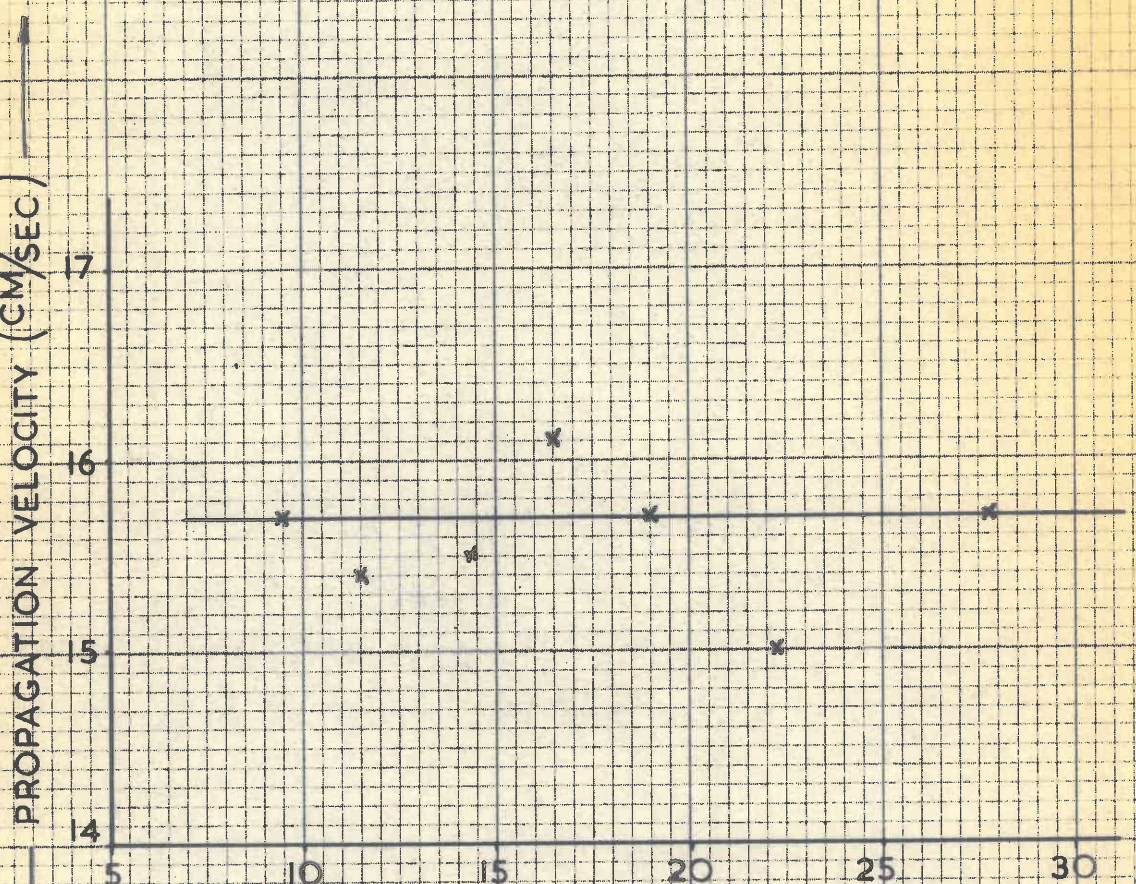


FIG. 7

PROPAGATION VELOCITY
VS.
COAL FEED RATE

FIG. 8



THE EFFECT OF ASH CONTENT OF THE PULVERIZED COAL ON THE PROPAGATION VELOCITY (COAL FEED RATE = 1 $GM/_{MIN}$)