EDUCAÇÃO e TECNOLOGIA

Revista do Instituto Politécnico da Guarda

"EDUCAÇÃO E TECNOLOGIA"
Propriedade: INSTITUTO POLITÉCNICO DA GUARDA

Director: **João Bento Raimundo**

Redacção: **Rua Comandante Salvador do Nascimento**
Telfs. 211634/213062 . Fax 211690
6300 - GUARDA

Composição, Execução Gráfica e Impressão: **Secção de Reprografia do IPG**

Depósito legal nº 17. 981/87

Nº VIII/Julho de 1991

Capa: *Novo Edifício dos Serviços Centrais do IPG*

UM SÍMBOLO DA EVOLUÇÃO

"(...) uma criatura só não presta quando deixou de ser inquieta."

Miguel Torga

"Educação e Tecnologia" é bem o símbolo da evolução registada no Instituto Politécnico da Guarda nestes últimos seis anos.

Esta Revista firmou-se e afirmou-se editorialmente, reuniu colaborações, projectou um espaço de diálogo cultural, pedagógico e científico, definiu horizontes precisos, concretos.

Hoje, *"Educação e Tecnologia"* é bem uma das múltiplas vertentes da Instituição de Ensino Superior onde é editada com a periodicidade estipulada desde a sua criação. Não cristaliza fórmulas e conteúdos, antes pelo contrário assimila e cria outras ideias e projectos, utiliza progressivamente novos meios e tecnologias colocados à sua disposição, do ponto de vista gráfico e técnico.

"Educação e Tecnologia" assume, naturalmente, um papel informativo mas dimensiona, igualmente, o seu, cada vez maior, impacto difusor de temáticas e ideias, rejuvenescendo em cada edição.

O presente número antecede a entrada em funcionamento do novo edifício dos Serviços Centrais do Instituto Politécnico e igualmente do Pólo de Seia do IPG. Se em termos de colaborações e participações a nossa Revista consolidou uma equipa, em termos de estruturas físicas encontra assim, doravante, uma nova e promissora realidade.

João Bento Raimundo
Presidente da C. I. do
Instituto Politécnico da Guarda

THE MEASUREMENT AND INTERPRETATION OF THE STARCH DUST-AIR EXPLOSION PARAMETERS IN A CLOSED SPHERICAL VESSEL

Luis Teixeira de Lemos* e Robert Bouriannes**

1. Introduction

Most combustible dusts,when dispersed and mixed with air, if ignited, can explode with severe effects. This hazard exists in all the industrial processes where pulverized dusts are handled or manufactured. Agricultural dusts represent the major risk (over than 50% of the accidents in the United States and Canada (Field (1982)) and more than 60% in Germany (Bartknecht (1985)).

In order to get a better knowledge of dust combustion characteristics, several experiments have been conducted in isochoric condition.

A special attention is focussed in the flame temperature measurement: a monochromatic emission-absorption pyrometer was specially designed for the dust flame temperature measurement.

2. Experimental Setup and Studied Mixtures

The isochoric combustion of starch-air mixtures is studied.

* Prof. Coordenador da ESTG

** Prof. Catedrático da Universidade de Poitiers

The experimental setup (see Fig.1), described in detail elsewhere (Lemos et al. (1989 a)), consists of a 20 litre spherical chamber with central electric ignition.

The starch-air suspension (chemical starch particles $(C_6H_{10}O_5)_n$ of about 20 μm in diameter) is generated by elutriation over a fluidized bed.

For this mixture, the stoichiometric composition corresponds approximately to a concentration of 230 $g.m^{-3}$.

The explosion pressure, the maximal rate of pressure rise, (presented elsewhere (Lemos et al. (1989a)), and the combustion temperature were determined in the range of equivalence ratios between 0.6 and 3.0.

2.1. Pressure measurements

The pressure measurements were made with a piezo-electric pressure transducer (Kistler) connected to a charge amplifier. This system allows the direct measurement of the rate of the explosion pressure evolution.

2.2. Temperature measurements

The temperature measurements were performed with a monochromatic emission-absorption pyrometer (described in detail elsewhere (Lemos et al. (1989b)), in which the electronically modulated source signal is easily separated from the flame's signal.

This pyrometer was designed for measuring solid particles temperature and its wavelength of work is 940 nm.

2.2.1. Optical method.

The pyrometry by generalized emission-absorption is a variation of the reversal technique (Moutet et al. 1974). This method permits the temperature measurement of flames when the radiation emitted varies rapidly with time

A detector must collect three monochromatic signals separately:

—R emitted by the reference source at the brightness temperature T_R

—B emitted by the flame alone

—RB emitted by the reference source through the flame

The ratio Γ determined by experience, may be written as:

$$\Gamma = \frac{B}{B+R-RB} \tag{1}$$

In the case of a spherical flame, develloping from the central ignition point, and according to the monochromatic radiation intensity equation (see Lemos et al. 1990), it may be written:

$$R = C.\,L_o \tag{2}$$

$$B = C.\,\frac{kab}{keb}.\,\tau_f(1-\tau_b).\,L^o_B \tag{3}$$

$$RB = C.\,[\tau_f.\,\tau_b^2.\,L_o + \frac{kab}{keb}.\,\tau_f.\,(1-\tau_b).\,L^o_B] \tag{4}$$

Where

C is an equipment factor

Kab, Keb are respectively the absorption and the extinction coefficient of the burnt products

τ_f, τ_b are the transmittances respectively of the unburnt and of the burnt mixture

$L^o{}_B$ is the black body monochromatic radiation intensity at T_B

L_o is the incident monochromatic radiation intensity

The ratio Γ becomes then:

$$\Gamma = \frac{kab}{keb}.\,\frac{\tau f\,(1-\tau\,b)\,L^o_B}{(1-\tau^2{}_f.\tau_b)\,L_o} \tag{5}$$

For the limiting case, which corresponds to the end of the combustion, the flame touches the wall, r=ro and τ_f=1.We may write:

$$R = C.\,L_o \tag{6}$$

$$B = C.\frac{kab}{keb}.(1-\tau_b^*).L_B^o \quad (7)$$

$$RB = C.[\tau_b^*.L_o + \frac{kab}{keb}.(1-\tau_b^*).L_B^o] \quad (8)$$

$$\Gamma = \frac{kab}{keb}.\frac{L_B^o}{L_o} \quad (9)$$

and

$$\varepsilon = \alpha = 1 - \tau_b = \frac{B+R-RB}{R} \quad (10)$$

Wien's law leads to the value of the burnt products temperature T_B:

$$\frac{1}{T_B} = \frac{1}{T_R} - \frac{\lambda}{C_2}.Ln.\frac{kab}{keb}.\Gamma \quad (11)$$

2.2.2. Pyrometer's principle.

The determination of the signals B and RB involves the simultaneous measurement of the emission of the burnt gases B and also of the emission of the reference through the burnt gases RB. The optical assembly between the emitting reference source and the detector must have two distinct optical ways.

The conception of the pyrometer MT4 and PIREA of the O.N.E.R.A. (Moutet et al. 1974), (Charpenel 1979) is based in this principle.

Neverthless the optical system may have only one optical way if the two signals are obtained one after the other, by modulation of the emitting reference signal. This modulation is often mechanical (rotating disc) and the optical assembly becomes simplified.

In order to treat easily the signal and to avoid rotating parts in the pyrometer, the electronic modulation of the signal R was chosen. Thus, in this case, the reference source is a pulsed infra-red diode.

2.2.3. Optical assembly

The optical system is shown in Fig 2, and consists essentially of three borosilicate lenses of 22.4 mm in diameter. This lens material was chosen because it has a transmittance of 0.93 at the wavelength of work.

The L_1 lens (focal distance 20 mm) projects the image of the infrared source to a diaphragm. There, the L_2 lens (focal distance 200 mm) produces a parallel beam. This beam enters the spherical bomb through the borosilicate window h_1, traverses the chamber through its centerline and leaves it through the opposite window h_2. The L_3 lens (focal distance 200 mm) projects the source and the flame (whenever present) images upon the detector.

The emitting source is a light emitting diode modulated at a frequency of about 2 KHz. Its brightness temperature is adjustable. In the present work it was fixed at a value of 2000 K.

The emitting diode, the detector and the interference filter have their peak response for a wavelength of 940 nm. For this wavelength, the combustion products (at 2100 K) still radiate strongly.

The detector is a photodiode. Prior to making measurements it was calibrated with a carbon rod black body, set in the usual emitting diode's place. The aperture of its radiation cavity is aligned with the optical assembly axis center.

The brighteness temperature of the emitting diode is obtained at each experiment by using the detector's signal and based upon the calibration values previously found.

2.2.4. Electronic assembly

This assembly commands the modulation of the emitting diode and the separation, in the detector, of the continuos component due to the flame B, from the component R'=(RB-B) due to the pulsed emitting diode.

The ratio Γ comes then:

$$\Gamma = B/(R-R') \qquad (12)$$

This assembly includes (see Figs. 3 and 4):

—A modulation command working at 2 KHz (signal time 3 μs, total time 500 μs)

—A modulation system of the emitting diode

—A separating circuit (an high frequency pass filter and a low frequency pass filter) which allows the separation, in the received signal RB, of the continuos part B from the modulated signal R'

—A blocking and integrating system (also modulated as the the emitting diode) to integrate the signal R'.

A signal acquisition system allows the acquisition and the treatment of the three needed signals : R (before the experiment), B and R', which allows the flame monochromatic emissivity and the flame temperature determination.

3. Experimental Results

For starch-air mixtures the maximal values of the explosion pressure (see Fig.5) (13.4 bar) and of the maximal rate of pressure rise (see Fig.6) (92 bar.s-1) are obtained at an equivalence ratio of 3.0 while the maximal value of the combustion temperature (see Fig.7) (2170 K) corresponds to an equivalence ratio of 1.7.

This kind of situation has already been noted with fine pulverized-coal air mixtures (Horton et al. (1987)), (Smoot et al. (1977)), (Cashdollar (1979)), (Cashdollar et al. (1983)), (Cashdollar et al. (1985)).

The theoretical pressure and temperature values were given by the "QUATUOR" code (Heuze (1985)) in the adiabatic isochoric hypothesis and supposing that the starch burns completetely in a gaseous phase.

4. Results Discussion

Experimental pressure values are, for lean mixtures (equivalence ratios less than 1.6), slightly lower than the theoretical ones; for rich mixtures they are higher than the theoretical ones, calculated in the case of solid carbon formation, and dramatically different from those calculated without solid carbon.

Experimental temperature values are, for lean mixtures, much lower than the theoretical temperatures and for equivalence ratios greater than 1.6 they are very close to the calculated ones.

This situation may be explained by the fact that theoretical calculated temperatures are burnt gas final temperatures while experimental results correspond to mean final solids temperatures and not gas temperatures (gas radiation is negligible at the wavelength of work). For lean mixtures those solids must essentially be starch particles that pyrolyse ahead the flame front at a much lower temperature than the burnt gas temperature and for rich mixtures those solids must be very fine solid burnt particles, whose temperature would be very close to the burnt gas temperature.

Both results are consistent with the observation, after combustion and for equivalence ratios greater than 1.6, of a thick black cloud in suspension inside the chamber, probably containing solid carbon particles.

The measured emissivity (see Fig.8) also increases, in an almost linear way with the equivalence ratio, confirming that the solid burnt products are present in growing concentration for rich mixtures.

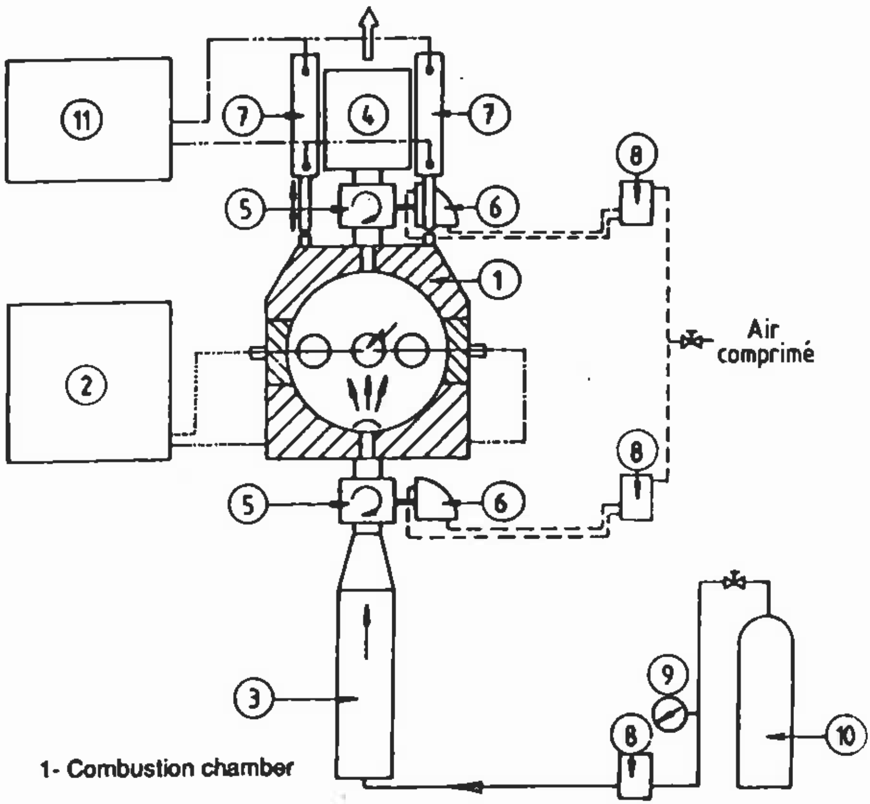
For those mixtures, the burnt gas composition changes, presenting an important concentration of typical pyrolysis products (see Table 1) such as: CO_2, H_2, CH_4 and other low density hydrocarbon gases.

All these results indicate that for rich mixtures, the combustion is not complete.

5. Conclusion

The infrared emitting-absorbing pyrometer described here is an useful tool for measuring particle temperatures in dust-air flames, giving good experimental results. It can be used either in trasient flames such as the explosion flames treated in the present case or in stationnary flames such as burner flames. Concerning the starch flames propagation mechanism, previous work has shown that starch particles pyrolyse almost completely prior to flame front arrival (Proust et al. (1988a)) ,(Proust et al. (1988b)).

Present results let us suppose that, for lean mixtures (equivalence ratios less than 1.6), starch dust particles completely pyrolyse before the flame front arrival, originating a classic gaseous premixed type flame without solid residue formation. On the other hand, for rich mixtures, the presence of the fine solid residue, of the pyrolysis gaseous products and the similarity of the experimental results with the calculated ones (in the hypothesis of solid carbon formation) indicate that although all the starch is pyrolysed, only a part of it completely burns in the gaseous phase. The rest continues its transformation behind the gaseous flame emitting strong radiation.



1- Combustion chamber

2- Spark generator

3- Fluidized bed

4- Dust recuperator system

5- Inlet and outlet valves

6- Pneumatic command system

7- Closing hydraulic system

8- Electrically actuated valve

9- Pressure gauge

10- Compressed air reservoir

11- Hydraulic station and command device

Figure 1. Experimental setup

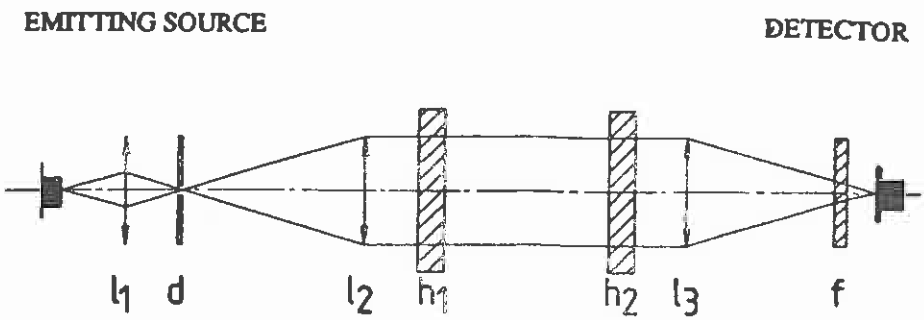


Figure 2. Optical assembly

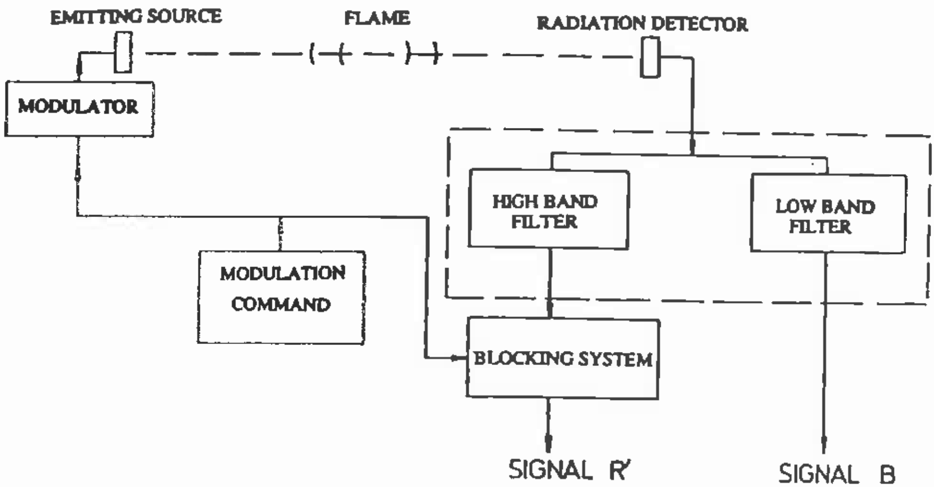


Figure 3. Electronic assembly

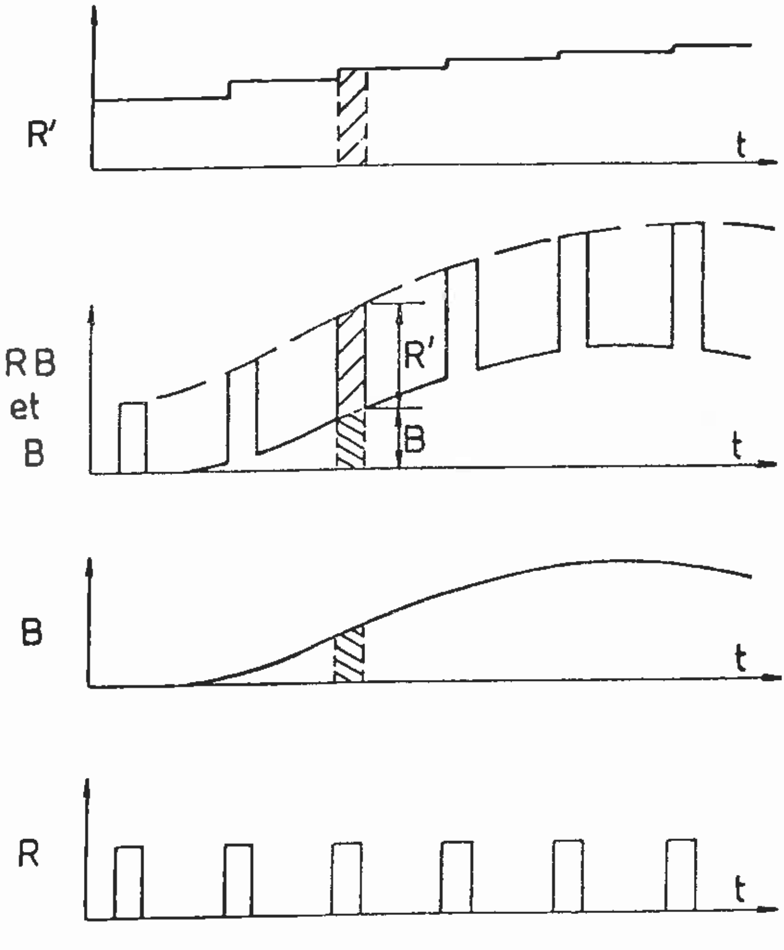


Figure 4. Signal's separation

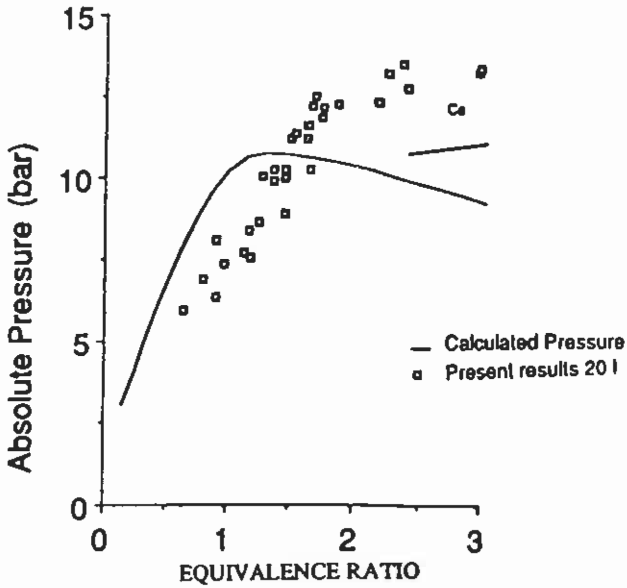


Figure 5. Starch-air combustion - Explosion pressures

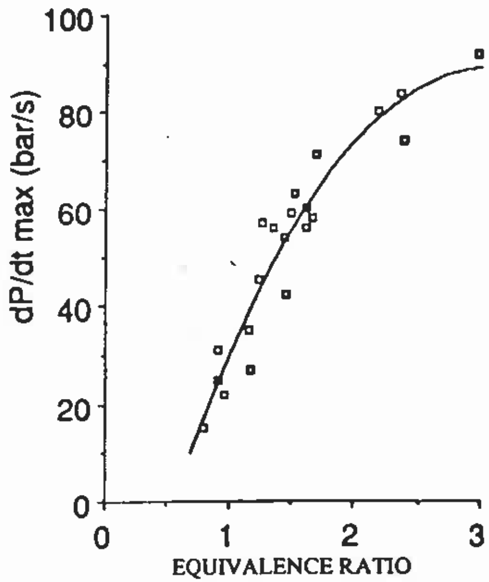


Figure 6. Starch-air combustion - Maximal rate of pressure rise

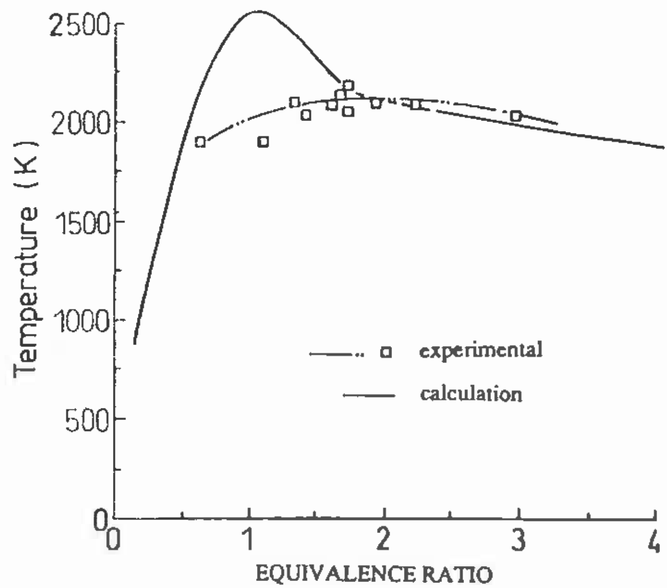


Figure 7. Starch-air combustion - Explosion temperatures

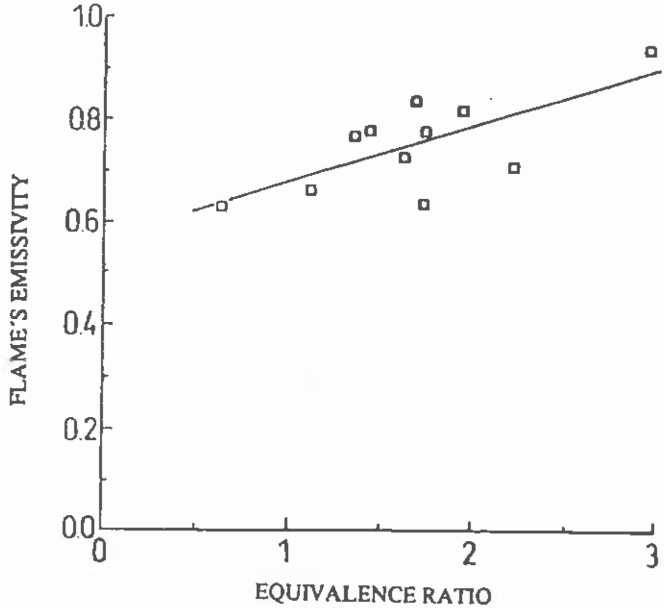


Figure 8. Starch-air combustion - Flame emissivity

Table 1 - Burnt composition (% per volume)

EQUIVALENCE RATIO	P exp (bar abs)	O_2	Ar	N_2	CO	CO_2	H_2	CH_4	C_nH_m
1.13	7.73	7.78	0.94	78	0.64	12.46	0.11	-	-
1.24	8.63	7.49	0.94	78	0.21	13.30	0.02	-	-
1.32	9.97	5.01	0.94	78	0.15	15.64	0.02	-	-
1.34	-	4.51	0.93	78	0.39	15.85	0.11	-	-
1.84	10.50	2.66	0.93	78	0.40	17.71	0.06	-	-
1.87*	12.22	0.57	0.88	73.3	5.55	17.10	2.05	0.34	-
2.97*	13.40	0.25	0.60	50.8	21.86	10.85	8.39	3.67	1.5

6. References

Bartknecht, W.(1985) " Gas, vapor and dust explosions - fundamentals, prevention, control", Int. Symp. on Grain Elevator Explosions,U.S.A.

Cashdollar, K.L.(1979) "Three-wavelength pyrometer for measuring flame temperatures", Appl. Optics, 18.

Cashdollar, K.L., Hertzberg M.(1983) "Infrared temperatures of coal dust explosions", Comb. and Flame, 51.

Cashdollar, K.L., Hertzberg M. (1985) "20 l explosibility test chamber for dusts and gases", Rev. Sci. Instrum., 4.

Charpenel,M. (1979) "Mesure instantanée par pyrométrie infrarouge des température des gaz de combustion. Application à la turbelence thermique", Rev. Physique Appliquée, 14.

Field, P. (1982) "Dust Explosions", Elsevier, Netherlands.

Heuzé, O.(1985) "Contribution au calcul des caracteristiques de detonation de substances explosives gaseuses ou condensées", Thèse de Docteur de l'Université de Poitiers, France.

Horton, M.D., Goodson F.P.and Smoot L.D.(1977) "Characteristics of flat, laminar, coal dust - flames" Comb. and Flame, 28.

Lemos, L., Bouriannes R.(1989 a) " Starch dust combustion characteristics in a closed spherical vessel", 12th ICDERS , U.S.A.

Lemos, L.(1989 b) "Contribution à l' étude de la combustion, en chambre spherique, des mélanges hétérogenes. Cas des mélanges amidon - air", Thèse de Docteur de l'Université de Poitiers, France.

Lemos, L., Bouriannes R.(1990) "Mesure, par pyrométrie optique, de la température de combustion d'un matériau pulvérulent en suspension dans l'air", Rev. Gen. de Thermique, nº 342-343.

Moutet, A. (1959) "Etudes de Pyrométrie Pratique",Eyrolles, France.

Moutet, A., Crabol J. and Nadaud, L. (1974) "Températures des gaz et des flammes" Techniques de l'Ingénieur, R 2750.

Proust, C. and Veyssière, B.(1988 a) "A new experimental apparatus for studying the propagation of dust - air flames" AIAA Prog. in Astron. and Aeron., 133.

Proust ,C. and Veyssière, B.(1988 b), "Fundamental properties of flames propagation in starch dust - air mixtures", Comb. Sci. and Tech., 62.

Smoot, L.D., Horton M.D. and Williams G.A.(1977) "Propagation of laminar pulverized coal - air flames",16th Symp. Int on Combustion.