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Numerical simulation of distribution of soot size in a laminar flame

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Abstract

The objective of this study is to determine the characteristics of soot (size and distribution) in a laminar flame of diffusion(ethylene_air).The non intrusive technique used is the incandescence induced by laser (LII) discovered by Melton[1].

The interaction laser-particle of soot is described by an ideal model of heat transfer and mass including the various modes of thermal losses (vaporization, conduction, radiation).The equations obtained describing the temporal evolution of the diameter and the temperature of the particle are solved numerically .The ideal model is validated by experimental measurements and confrontation with various powers of the exiting laser ,the result is satisfactory.

Key words: Incandescence Induced by Laser, Flame, Soot, Transfer of heat and mass.

1. Introduction

Laser-induced incandescence (LII) phenomenon is known since 1970 its principle is simple: under the effect of a radiation laser (typically an impulse of 10ns), the particles of soot present in a flame heats up very quickly (temperature can border 4000K),then cool by various thermal processes of transfer (vaporization, conduction and radiation) schematized in Fig.1, which the radiation of that transfer one names incandescence.

Thus the expressions of the energy balance on the level of the soot particle are gathered by Melton [1] in one only. It can be written in the form:

$$Q_{Int} = Q_{abs} - (Q_{sub} + Q_{con} + Q_{rad}) \qquad (1)$$

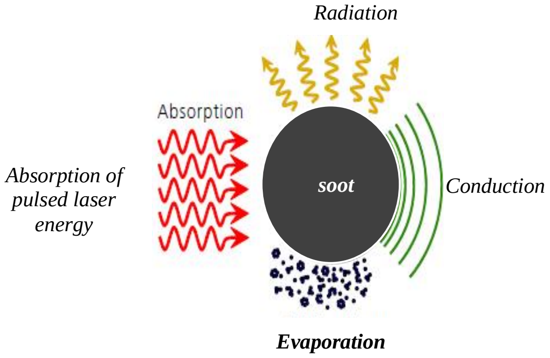


Fig.1. Modelling of LII

This equation coupled to that of conservation of the mass makes it possible to calculate, using a numerical routine, the soot temperature and diameter in all along LII process. An illustration of the evolution of the relative energy values during this process under conditions of atmospheric pressure is reproduced on Fig.2.

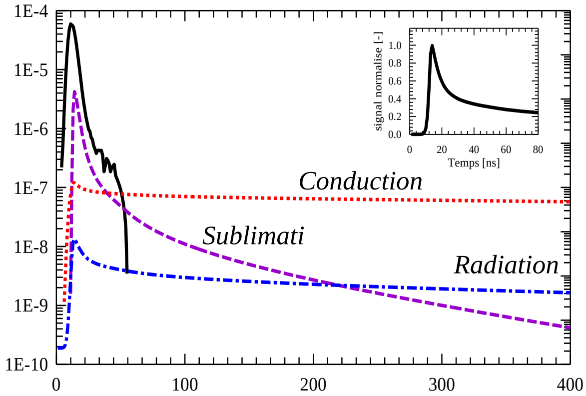


Fig.2. Evolution of the various energy terms in time (F=0.227J/cm^2, T_0=1900K, D_0=35nm)

One can observe that in the case of strong laser flows, sublimation is the energy process dominating during the first part of the cooling of the particle, the second phase roughly beginning 100 NS after (in condition of atmospheric pressure) is dominated by the conduction of heat transfer .

In addition, Melton [1] indicates the value of 3915 K as the temperature from which vaporization deviate dominantly. The thermal radiation is the least intense energy process during cooling of the particles. In the same figure, also the instantaneous evolution of signal LII is represented.

2. Intensity of the signal of induced incandescence

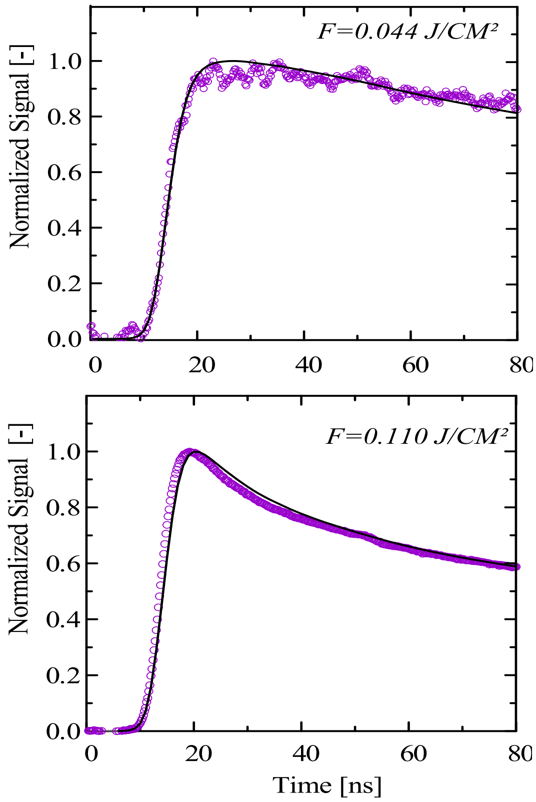
LII Signal resulting from a soot particle is collected with the wavelength λ which is expressed using the law of Planck corrected by a term of emissivity ε(λ):

$$S_{LII}(t) = C\frac{2\pi c^2 h}{\lambda_{\det}^5}\left(\exp(\frac{hc}{\lambda_{\det} k_B T(t)}) - 1\right)^{-1} \pi^2 D^3(t)\frac{E_m}{\lambda_{\det}}$$

Where C is a constant related to the device of detection, h, C, K_B are respectively the Planck's constant, the speed of the light and the Boltzmann constant, and T(t) is the soot temperature at the moment after the beginning of the laser impulse [4].Of the incandescence resulting ones from a volume of measurement containing N_p particles of soot is thus proportional to N_p D^3 (that is to say the volume fraction f_V) this is why the quantitative results on soot relate to in priority this size [3].

3. Results

The validation of the our ideal model is made with real measurements [2].In the latter, the temporal intensity of signal IIL was measured on a vast range of power of the going laser of F=0.044J/cm^2 until F=0.830 J/cm^2.The atmospheric flame is of diffusion type where the fuel C_2H_2 jet is surrounded by a flow of air. The soot particles were heated with impulses of a laser wavelength of excitation $\lambda_{éxc}$ = 532 nm. The initial diameter of the soot particle is D_0 = 35 nm and the temperature of gases is estimated at 1900 K . Fig.3 shows a comparison between the results of the ideal model and experimental measurements for various powers of the laser F .The model qualitatively shows a good agreement with measurements: a fast growth followed by a slow fall to low values of F, an increase and a faster decrease for the great values of the density F.



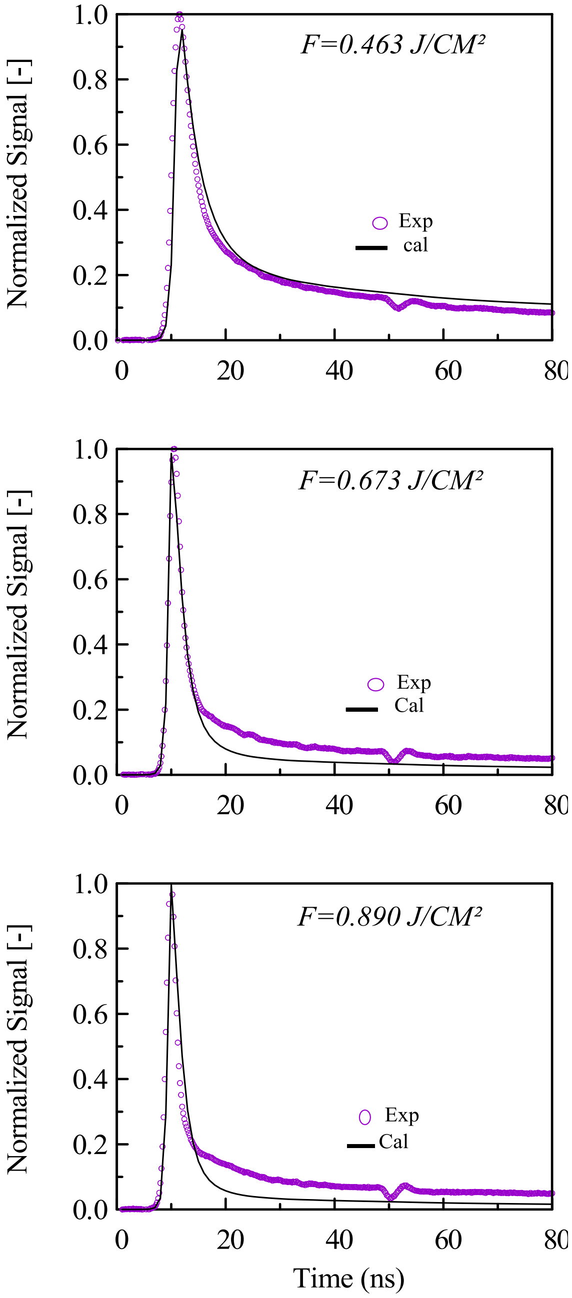


Fig.3. LII Model Validation

Then, this ideal model is extended to a whole of particles defined by a polydispers distribution of size of the lognormal type with a mean diameter D_m and a standard deviation σ_g.

The determination of the both (DM σ_g) in each fire point is obtained by the best fitting signal measured $SIIL_{mes}$ and a theoretical signal SIIL (t, DM σ_g) [5]. An example is presented in (Fig.4).

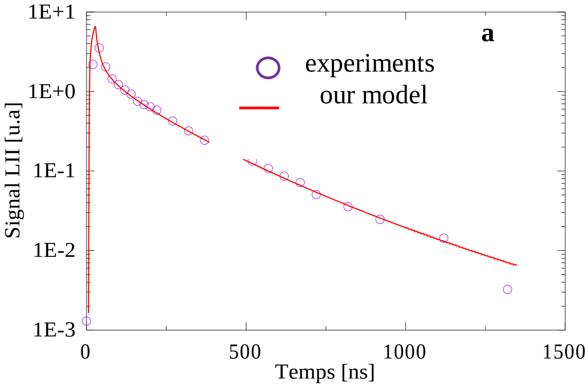


Fig.4.a- Temporal evolution of signal LII (HAB=30mm, r=3mm, D_m=28nm, σ_g=0.34)

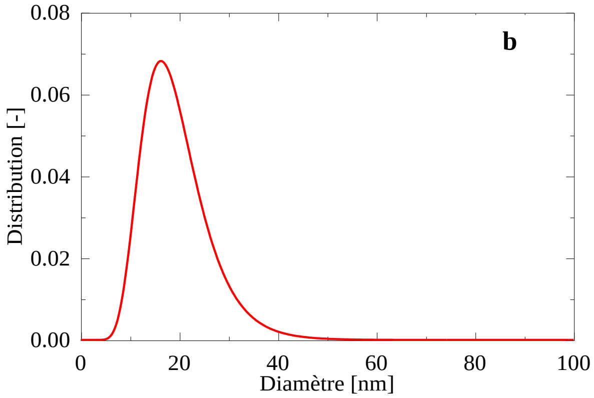


Fig.4.b-Granulometric distribution of soot (HAB=30mm, r=3mm, D_m=28nm, σ_g=0.34)

We also simulated with not detail flame studied to obtain qualitative results on the species generated during combustion. The mechanism of reaction GRIMECH 2 (49species, 279 reactions) was used in the commercial code Fluent 2D-Axisymmetric[6] .

The adopted geometry is shown in Fig. 4 with the conditions necessary limits.

The gas is inject at 300K with axial velocity profiles only governed by the volume flow:

$$0 \le r \le R_0 \qquad U(r) = \frac{2Q_f}{\pi R_0^2}\left(1 - r/R_0\right)$$

Where $Y_{C_2H_4} = 1 \quad et \quad Y_{i\neq C_2H_4} = 0$

And: $Y_{N_2} = 0.767$; $Y_{0_2} = 0.233$

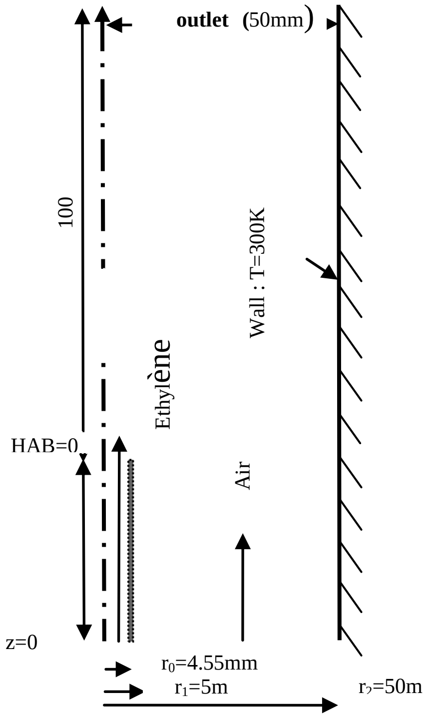


Fig.5.Geometric Configuration

In Fig.6 we present the radial evolution of mass fraction from some species for different height above burner (HAB).

It is noted that for the simulation of the diffusion flame in which the air and fuel are not premixed comprises a spreading zone reactions. In the pyrolysis zone (Hab = 10 mm) large hydrocarbons molecule of the fuel, brought to high temperature, decompose into fragments, some of which combine reactions carbonaceous rings or acetylene (C_2H_2) and carbon radicals play a key role. In the forming zone of the soot (Hab = 10 to 20 mm), these molecules are polymerized to form the soot particles precursor , liquid and almost transparent. With the collisionphenomena, these precursors grow in the growth zone (Hab =30 to40 mm) lose a part of their hydrogen and form aggregates of solid particles absorbing the light.

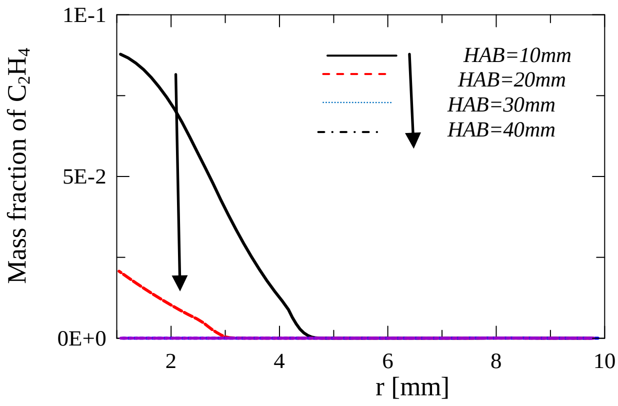


Fig.6. Radial evolution of mass fraction of C_2H_4

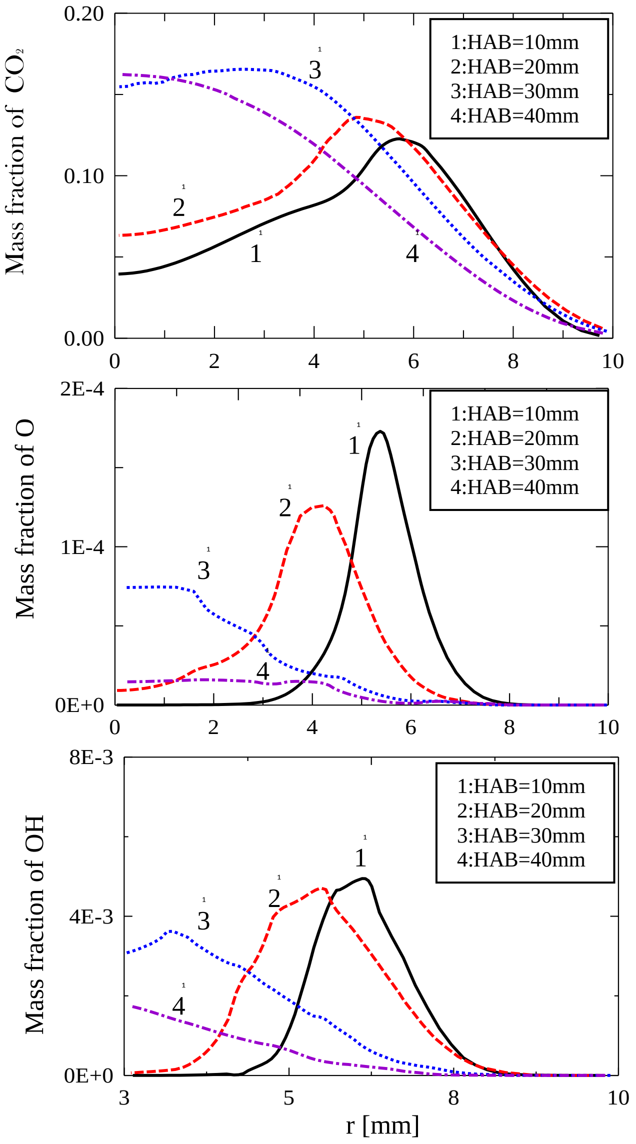


Fig.7. Radial evolution of mass fraction of CO_2, OH, and O

This work has been devoted to the application of the LII technique for determining the size of the soot particles in a laminar diffusion flame.

This non-intrusive technology based on an analysis of the radiation emitted by the particles heated with the laser flux to determine the size and concentration of the soot. Among the various modes of energy exchange in charge of the heating and cooling of the soot particles or the LII process a theoretical model able to predict the temporal evolution of the LII signal having been set up to estimate the mean particle diameter of soot was developed for conditions in free molecular regime and confirm with measures that confrontation is satisfactory. we proved that the LII signal is proportional relationship with the concentration of soot and the characteristic time of the decay is dependent on the men size of primary particles; plus a large particle is more it cools slowly. finally completed this work by a single flame numerical simulation considered.

References

[1] Melton L.A., Soot diagnostics based on laser heating, Appl. Opt. 23 (1984), 2201-2208.

[2] Michelsen H.A., Understanding and predicting the temporal response of laser-induced incandescence from carbonaceous particles, J. Chem. Phys.118 (2003), 7012-7045.

[3] Hadef R., Krüger V., Geigle K.P., Tsurikov M.S., Schneider-Kühnle Y., Aigner M., Measurements of soot size and concentration in the laminar premixed flame, Oil & Gas Science and Technology - Rev. IFP 61 (2006), 691-703.

[4] Michelsen H.A., Liu F., Kock F., Bladh H., Boiarciuc A., Charwath M., Dreier T., Hadef R., Hofmann M. , Reimann J., Will S., Bengtsson P.-E., Bockhorn H., Foucher F., Geigle K.P., Mounaïm-Rousselle C., Schulz C., Stirn R., Tribalet B., Modeling laser-induced incandescence of soot: a summary and comparison of LII models, Appl. Phys. B. 87 (2007), 712-745.

[5] H. Bladh, On the Use of Laser-Induced Incandescence for Soot Diagnostics From Theoretical Aspects to Applications in Engines, Doctoral, PhD Dissertation Division of Combustion Physics Department of Physic, Lund University, ISBN 978-91-628-7142-0 .

[6] F. Liu, K. J. Daun, D. R. Snelling, And G.J.Smallwood, Heat conduction from a spherical nano-particle: status of modeling heat conduction in laser-induced incandescence, Appl. Phys. B 83, 355 (2006)