Cédric VENET

Student Trainee at the Departement of Fire Protection Engineering
and Graduate student at the *Ecole Polytechnique Universitaire de Marseille (FRANCE)*

Research field : DUST EXPLOSION

Subject : Measurement of the fundamental laminar flame burning velocity in a dust-air mixture using a premixed burner.

Period :
June-August 2008

Supervisor : Professor Ali S Rangwala (assistant professor, WPI)
Professor Andrés Fuentes (lecturer, Polytech' Marseille)

THANKS

Professor Ali S. Rangwala and Professor Andrés Fuentes,
for the organization of this internship,
for their supervisation and their help in the research work.

The both school administrations,
for their collaboration.

Randy Harris, Scott Rockwell and Hey Ju Park,
for their precious help in my work.

Todd Hetrick, Joel Sipe and the others people met,
for their welcomming and their kindness.

MaNini,
who let me seize this opportunity, for her patience, her support.

My familly and Cécilia Florit,
for all their help in the preparation and the sequence of this trip.

CONTENTS

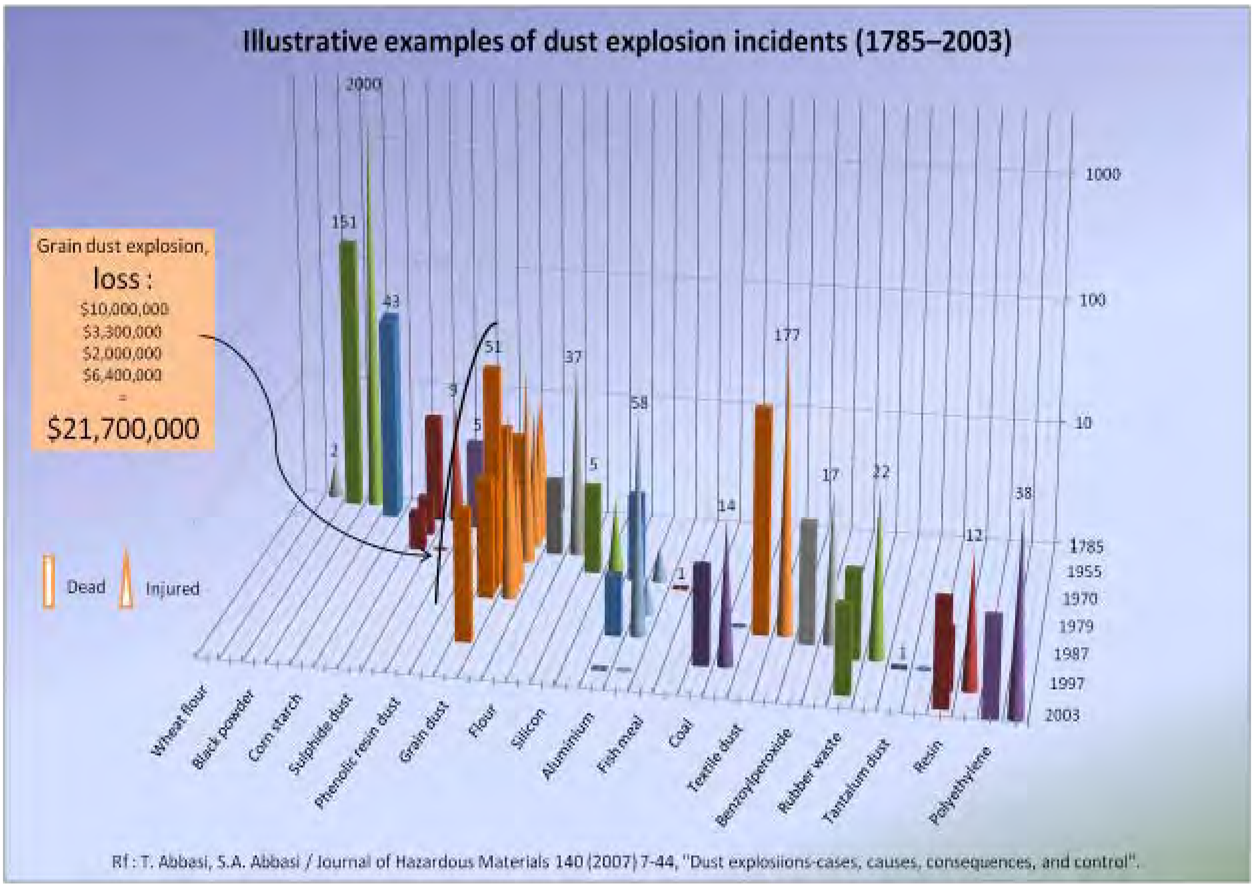
Introduction

Every year dust explosions cause extensive material damage, injury and loss of life. Initiation and propagation of industrial dust explosions are extremely complex phenomena from a fundamental scientific viewpoint.

This study is aimed at understanding the physics of deflagration mechanisms in a dust-air premixed mixture and will provide experimental data indispensable for mathematical model validation.

This sommary of my internship work will show the method used to determine the burning velocity (***total area air method*** and ***Laser Doppler Velocimetry***) and the experimental system built with its different parts (***anti-deflagration safety system***, ***nozzle burner design***, ***flame stabilizer system***, ***dust seeder system***).
It will review the problems met during the construction and the modifications made (nozzle burner shapes, deflagrator system, screw dust seeder system).

The next graph shows illustrative exemples of dust explosion incidents from 1785 to 2003. It produces the dommage caused (dead and injured) for different dust.



Definition :

Fundamental laminar flame burning velocity :

It's the movement velocity of the flame in an established flow with regard to an referential chosen.

In our case, the flow will be dust-air mixture flow at the end section of the burner and the referential will be the burner .

In this study, the method used to determinate the burning velocity is the **total area method** (rf: « determination of burning velocities: a critical review », G.E. Andrews and D. Bradley).

Total Area Method

S : burner section
Σ : flame surface
R : burner raduis
H : flame height

Vp : propagation velocity
Vs : spacial velocity
V : flowing out velocity
Vn : normal component of Vp
Vb : burning velocity, fundamental deflagration velocity

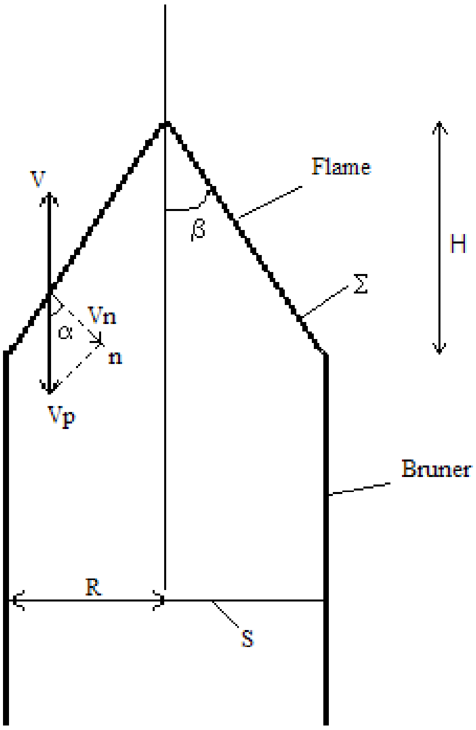
$$\left.\begin{array}{r} \vec{Vp} = \vec{Vs} - \vec{V} \\ \textit{stabilized flame} \Rightarrow \vec{Vs} = 0 \end{array}\right\} \vec{Vp} = -\vec{V}$$

$$\left.\begin{array}{r} Vn = Vp.\cos\alpha \\ Vp = V \end{array}\right\} Vb = Vp\frac{S}{\Sigma}$$ Average of Vn on Σ

$$\left.\begin{array}{r} S = \pi R^2 \\ \Sigma = \dfrac{\pi R^2}{\sin\beta} \end{array}\right\} \boxed{Vb = V.\sin\beta}$$

Measured by Laser Doppler Velocimetry

Measured by image processing with MATLAB $\rightarrow \tan\beta = \dfrac{R}{H}$

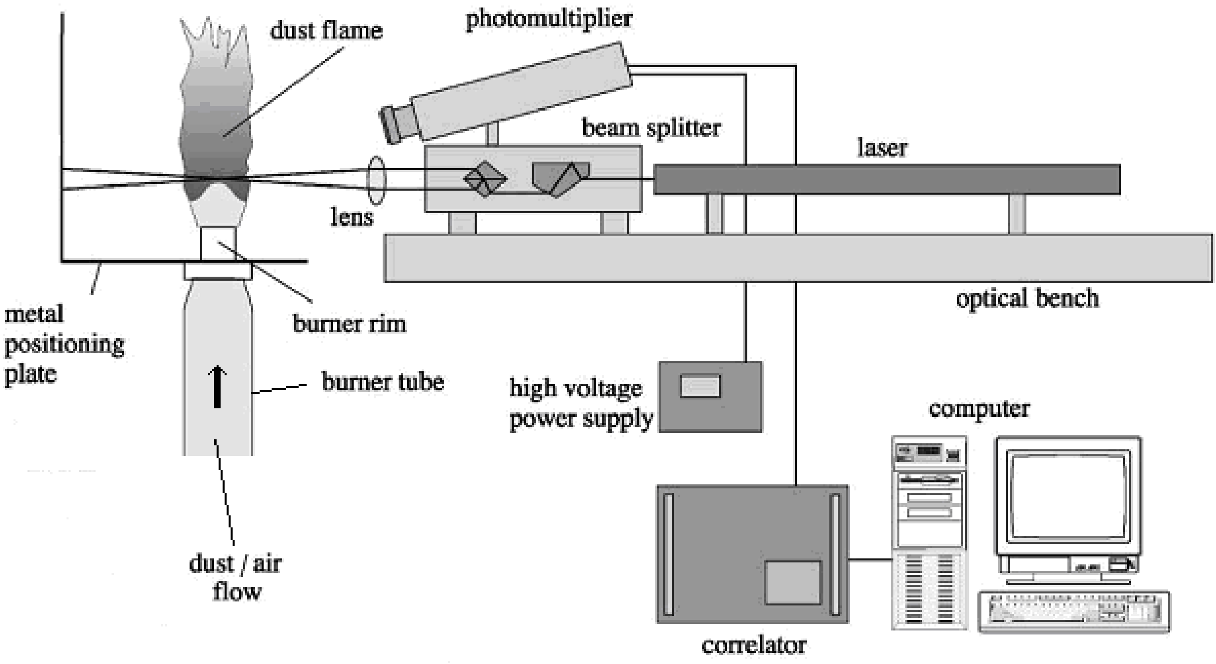


Laser Doppler Velocimetry

The flowing out velocity of the dust particleis measured by laser doppler system.

In our building, it will use the flowPOINT Laser velocimeter. It’s a no intrusive, highly accurate instrument for measuring flow velocities and is based on the principle of Laser Doppler Velocimetry. The optical accessibility of the flow is the main assumption for making measurements, as well as the existence of particles(0,5-100 mm) in the fluid.
The next drawing show this system with its different parts.

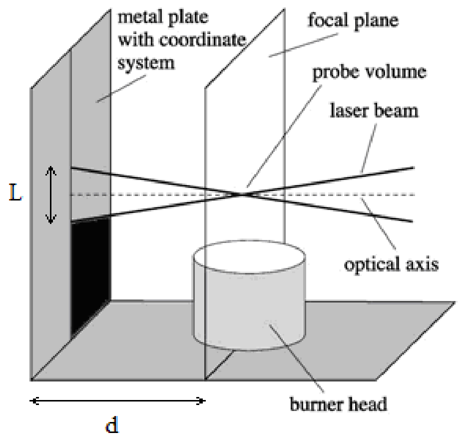
Laser Doppler Velocimetry

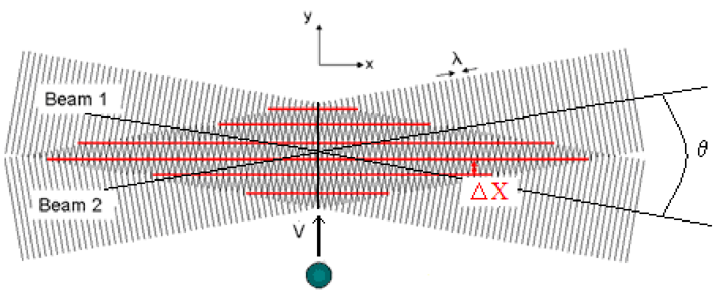


Laser Doppler Velocimetry

A pattern of interference fringes is produced in the crossing region of two converging laser beams. This region is the measurement volume. The distance of the interference fringes is defined by the wavelength of the laser light and the angle between the two laser beams. The calculation of the interference distance, and then the flowing out velocity of the dust particle can be made using the following equations:

Laser Doppler Velocimetry





$$\tan \theta / 2 = \frac{L/2}{d} \qquad \Delta X = \frac{\lambda}{2\sin\ (\theta/2)}$$

$$V = \Delta X \times f_D$$

Doppler frequency determined by the FFT processing of the signal come from the backscattered light.

θ : crossing angle of the laser beams
ΔX : fringe distance
λ : wavelength (i.e. HeNe 632,8 nm)

Laser Doppler Velocimetry

Microscopic particles present in the flow backscatter the laser light at a frequency proportional to the flow velocity when passing through the measuring volume (MV).

The backscattered light is transformed into a voltage signal by a photodetector, then filtered and amplified in the controller.
The Doppler frequency contained in this signal is determined by FFT processing.

Experimental device study

- Initial experimental device
- Anti-deflagration safety system
- Flame stabilizer
- Burner nozzle design
- Dust seeder

In the continuation of this sommary, we will explain the chronological modifications made on the experimental device on all this parts.

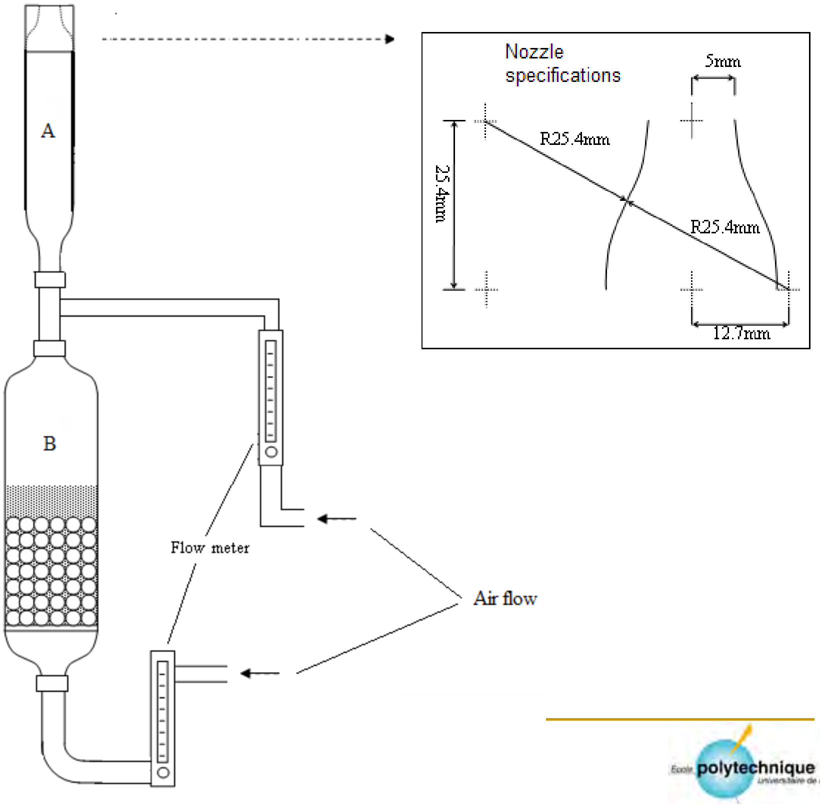
Initial experimental device

The initial experimental device was constitued of a long tube like burner and a fluidized bed built is using small glass beads inside a dust container tube in contact of a vibrating moteur which shakes the dust and improves the creation of the dust cloud.

The next drawing shows the assembly of this parts and gives theirs dimensions and specifications of the burner nozzle used.

We will begin this study in using cornstarch as dust.

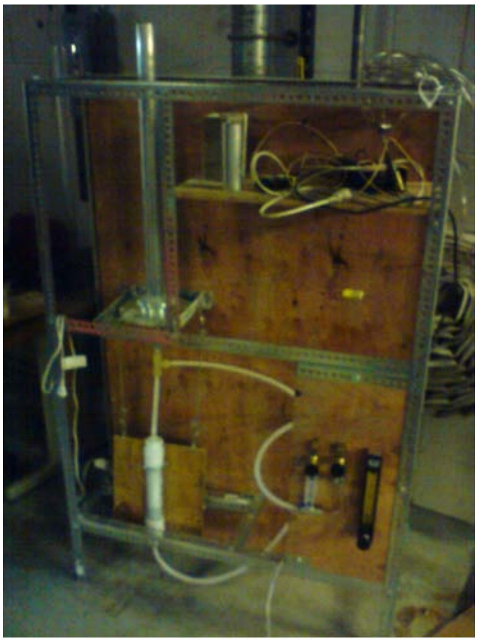
Initial experimental device



A : Burner
500 mm length, 25mm ID

B : Fluidized bed
- 300 mm length, 30mm ID
- glass beads, 6 mm D

Initial experimental device



Experimental system using a fluidized bed and cornstrach

Anti-deflagration safety system

To finish this first building, it was necessairy to equip the burner of a anti-deflagration safety system. Indeed, it could be dangerous if the deflagration go down as far as the fluidized bed (explosion risk with the dust stockage).

To obtain this safety system, we chose to cut the « activation energy » of the fire reaction in putting a quenching system inside the burner tube.

The next pictures show the quenching aluminium plates made with 2 different sizes (rf : « Quenching Distance of Laminar Flame in Aluminum Dust Clouds » S. Goroshin,M. Bidabadi, and J. H. S. Lee.) and tested (« short form » and « sign up » sheet was written for this different testes).

NB: After several testes, we decided to don't use this quenching plates because leading lot of charge (presure) losses. A diameter reduction zone in the pipe circuit will be suffisante to act as anti-deflagration safety system.

Anti-deflagration safety system

<u>Quenching plates assembly in aluminium</u>

Flame stabilizer

With the device built at this moment, we had a first problem. Indeed, the flame was not in correctly establish at the burner exit.
In order to keep the flame above the burner nozzle we needed to find a stabilizer system.

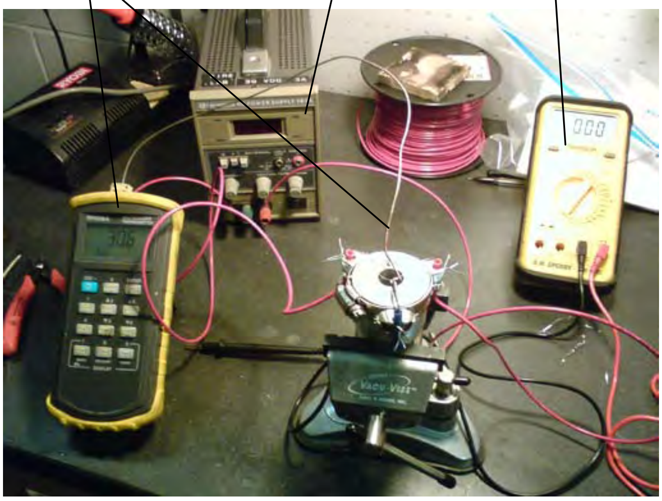
So in a first time, we tried to use an hot wire ring as show on the next pictures.
A power supplier equiped with dimming switches permit to adjust the current and voltage in the wire to reach the temperature wished (like a resistance).

Flame stabilizer

Hot wire ring (~500°C)

Burner nozzle

Thermocouple Power supplier Current Tester



Burner nozzle design

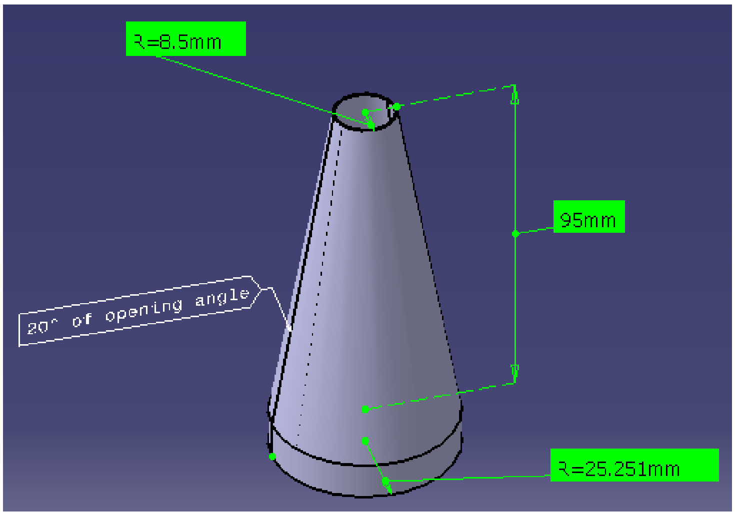
After serveral testes failled just with this system on the first burner, we decided to change an other burner nozzle design to decrease the air flow velocity which likes be the main problem whit regard to the stabilization of the flame.

So, we modified the shape of the nozzle profile in a revolution cone and increased the diameter of the burner exit.

The next party presents the cone with theirs dimensions (CATIA drawing) then the new hot wire ring circle adapted for this nozzle.

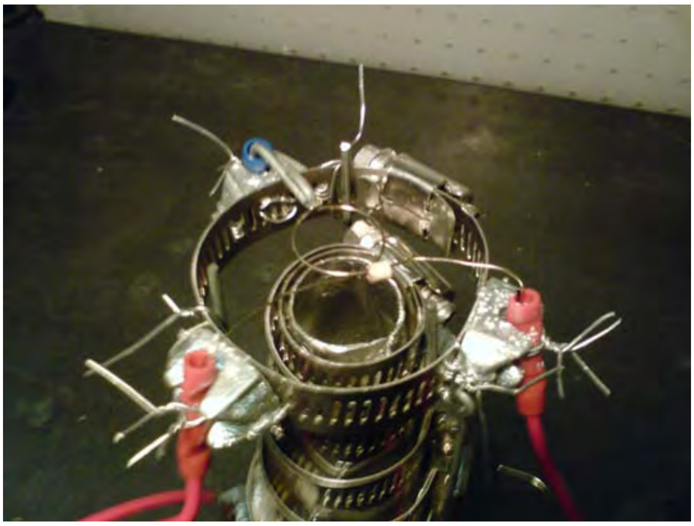
Burner nozzle design

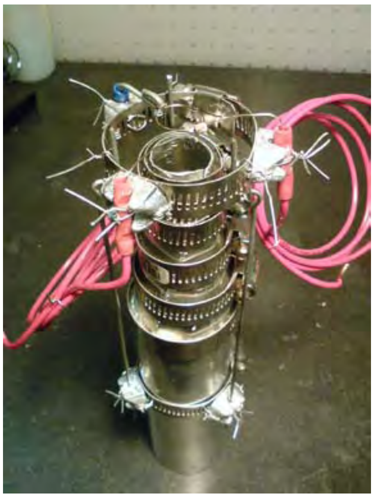
<u>Cone shape</u>



Burner nozzle design

Cone shape





Flame stabilizer

This last change was not suffisant to have a stabilised flame above the burner nozzle. The next idea has been to create a recirculation zone in using a deflector system (rf : research paper).

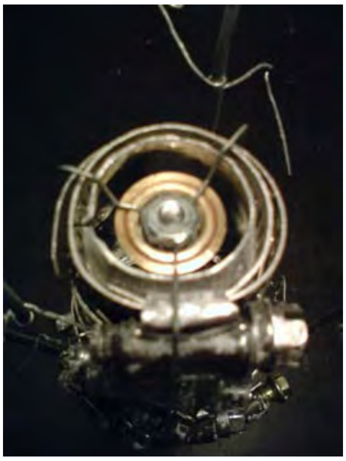
For this, as it's show on the next pictures, we made different deflector shapes to have different recirculation profils and try to stabilize a flame in putting it on different place at the end of the cone.

During a test using the 3rd deflector profil (the bigger cone on the picture), we obtained a stabilized flame located on the recirculation zone during a short time.

It was a good beginning but we cann't use this flame type because the dust/air mixture flow profil is not laminar. Too bad…

Flame stabilizer

Deflector system



Burner nozzle design

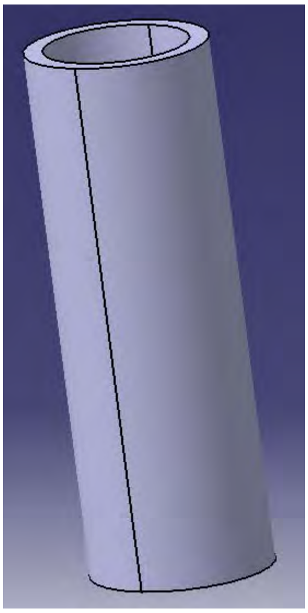
Before to modify the burner nozzle, we tried to create a flame in using just the burner tube (the same that the one used before to fix the different nozzles after the air circuit).

With this configuration (diameter, 5cm ; lengh 15cm), we obtained a stabilized flame as it's shown on the next picture.
The main problem with this resulat is that the flame begins inside the tube and is not formed just above the top of the tube. We cann't visualize all the flame shape by camera and so, neither we can determine the characteristic dimensions of the flame cone by image processing, nor we can measure the flowing out velocity of the dust by laser doppler system.
More over, the dust stick on the interior wall of the tube and block it after accumulation. It disturbs the flow and changes the tube diameter during the test.

So, this result is not satifactory for us and we have to find a new system.

Burner nozzle design

<u>Burner tube only : lengh 15cm, diameter 5cm</u>

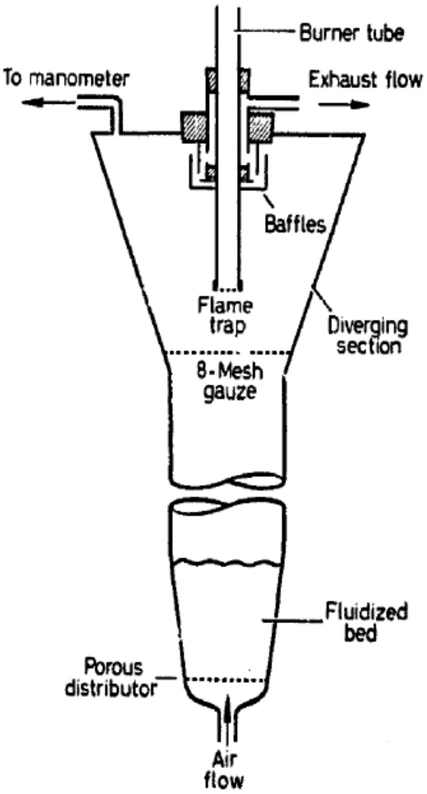


Burner nozzle design

The new burner nozzle chosen was the one built by W. E. MASON and M. J. G. WILSON.

Here a drawing of their bruner which consists in using an exhaust flow system to create an depression inside the diverging cone to try to keep the flame stabilized above the burner tube. The mesh dispositif permit to trap the flame in case of delfagration.

The next pictures and drawing show the burner that we built with its different dimensions (approximately the sames that the Mason&Wilson burner) using the same method to obtain a stabilized flame in adjusting the different flows.

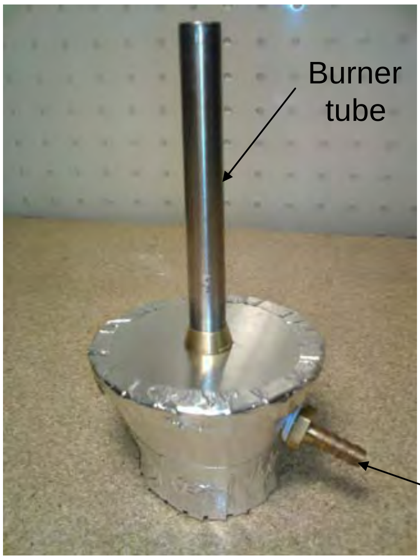


WPI

polytechnique

Burner nozzle design

Diverging cone used by W. E. MASON and M. J. G. WILSON



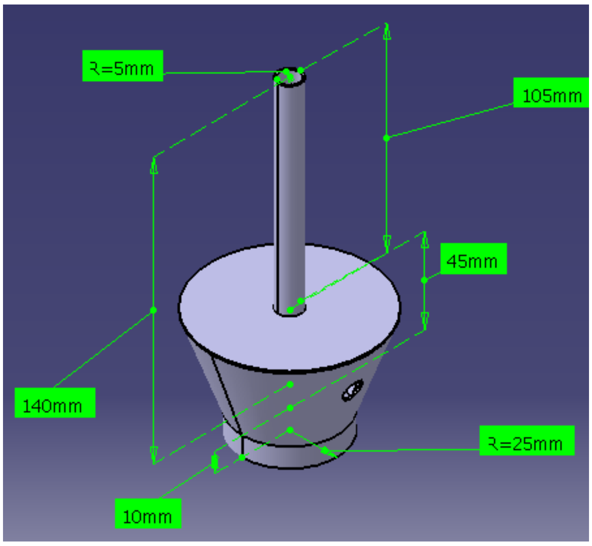
Exhaust flow

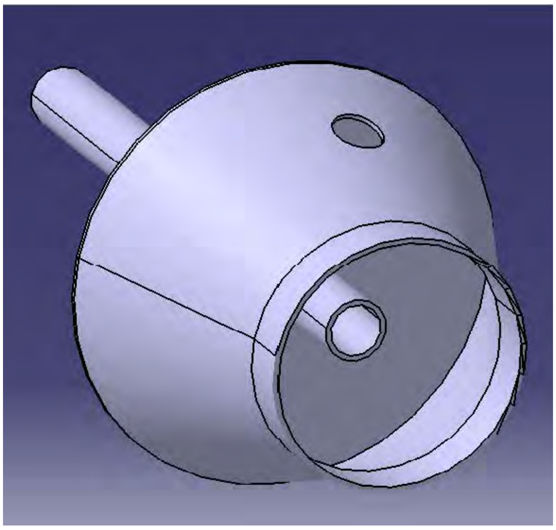
WPI

polytechnique

Burner nozzle design

Diverging cone used by W. E. MASON and M. J. G. WILSON





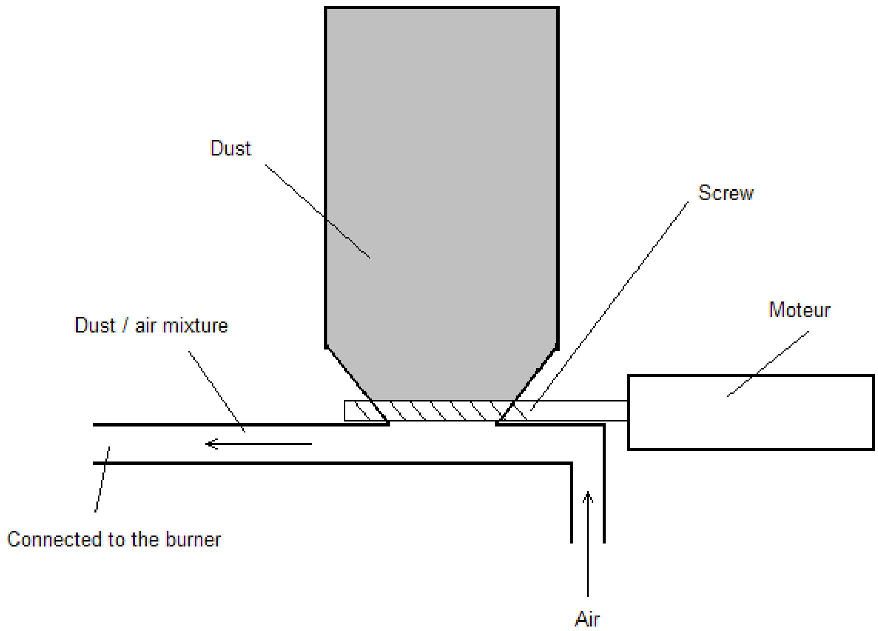
Dust seeder

After several testes with this new burner,we obtained interrestant results, but we noted that the dust concentration in the mixture cloud wasn’t enough constant to create a satisfactory flame not only because the cornstarch is too sticky and stay inside the burner but also because the fluidized bed isn’t a good system to inject the dust in the air flow.

So we have to change of dust and above all find an other dust injector system. So we tried to build an « screw dust seeder system » like it’s shown on the next drawing permitting to inject the dust in the air flow independently of the flow velocity. Indeed with this method, we can adjust and control the quantity of injected dust just with the rotation velocity of the screw.

Dust seeder

<u>Screw dust seeder system</u>



Dust seeder

The next pictures present the building of this system which uses a funnel as dust container, a drill as motor system and a vibrating motor to involve the dust distribution. The funnel and the pipe are put together and separated by a slot. The pipe circuit is complex because we need to put this system inside an aluminium box to protect the outside environnement of the leaks.

After several testes using different dustes (cornstarch and coal dust) with this system during whom we had congestion problem in the pipe, we decided to modify the circuit as it's shown later. This new building permit to clean up inside the pipe if necessary and use a cylindrical brush (as the one used to clean up inside a test tube) to replace the screw in order to involve the dust injection (the screw wasn't adapted for this distribution).

The actual system give very interresting resultes : we can have a constant mixture flow compare to the old system using fluidized bed and we can change the velocity and the concentration as we want with the drill and the different valves. But we don't manage to obtain a stabilized flame…

Dust seeder

Screw dust seeder system

Dust seeder

Screw dust seeder system

Dust seeder

Screw dust seeder system

Dust seeder

<u>Screw dust seeder system</u>

Actual system

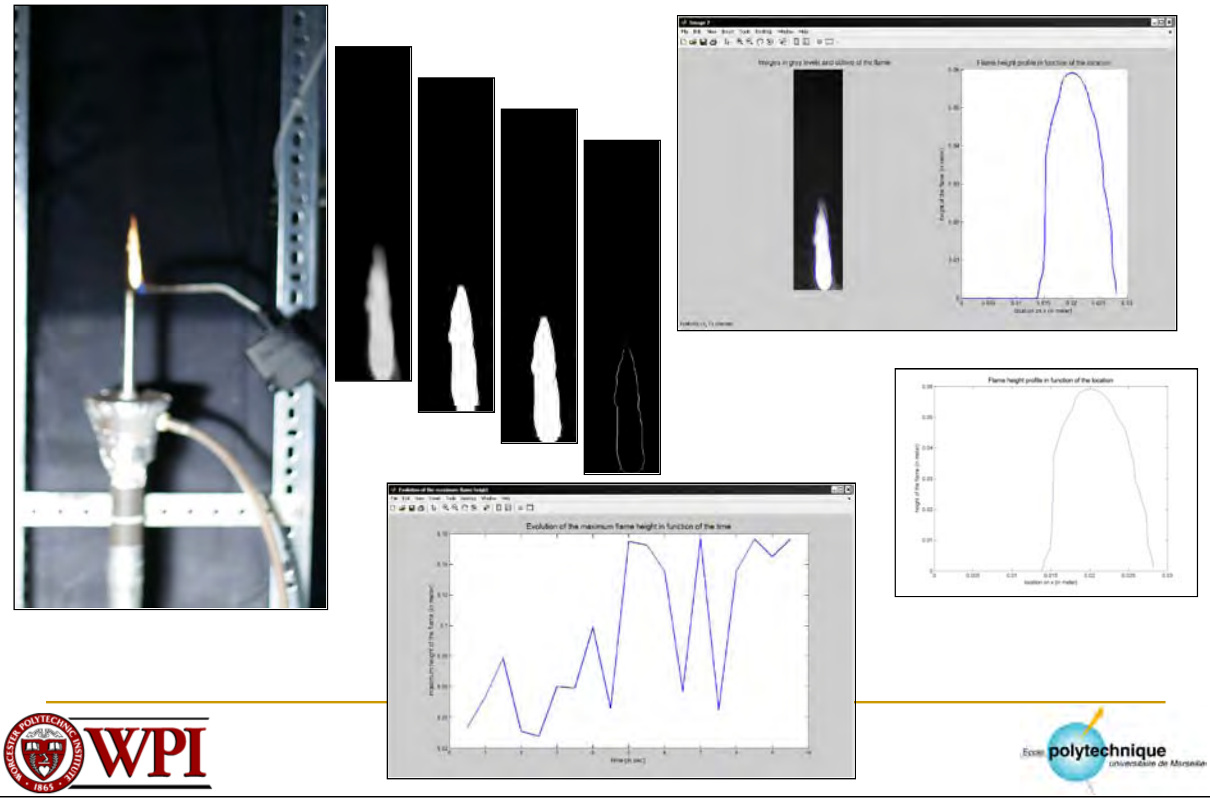
Actual system

Instructions to use the rotative bruch dust seeder system :

- Open the aluminium box in unscrewing the four screw and put the dust inside the funnel.
- Close the aluminium box and open the air flow before to check if there is no leaks.
- Start the vibrating motor (1st velocity) then the drill with a slow rotative velocity and adjust the air flow (also with the vacuum system) to obtain the good mixture and the good velocity to the ignition.
- Light the ignition system and try to adapt the concentration (with the drillvelocity) and the flow velocity (with the air valve and exhaust air valve) to have a stabilized flame.

- To finish the test, stop the vibriting motor and the drill in first time then the air flow and finally the vaccum after openning the exhaust air valve to clean the air circuit.

MATLAB : Image Processing Software.



MATLAB : Image Processing Software.

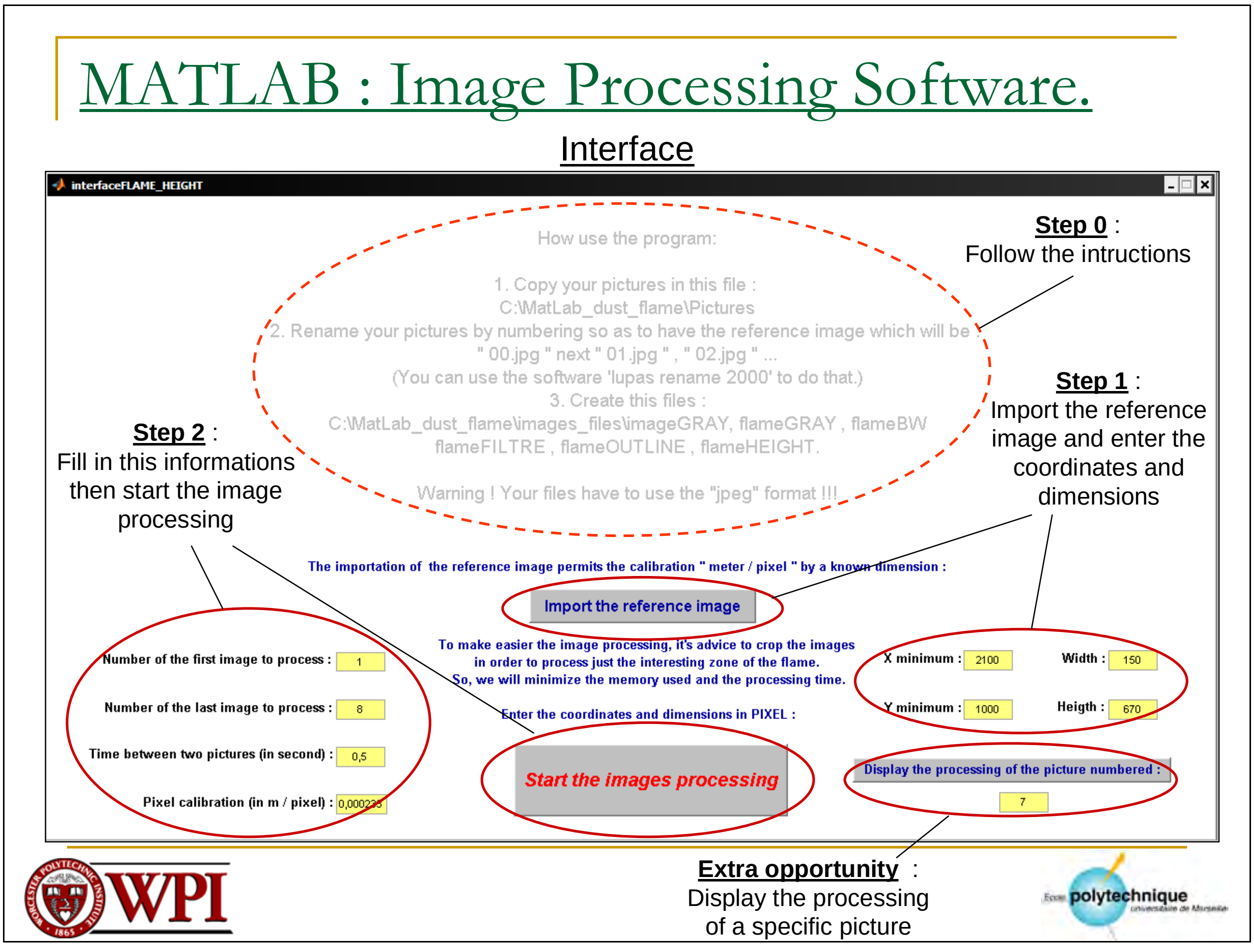
To calculate automaticly the height of the flame in order to know the β angle and then to determine the burning velocity, I used MATLAB to create an Image Processing Software which work with the pictures taken during the test.

The instructions to use this software are given in the file named « readme » in the file « Matlab ». (open the program with Matab then run the code.)

The next pictures show :

- The interface which permit to communicate with the user.
- The window of the reference image importation (for the calibration and the image cropping : use « pixel info » to know the coordinates).
- The view of the image processing.
- The result of the image processing for all the test.
- The processing for a specific image (a number wanted).

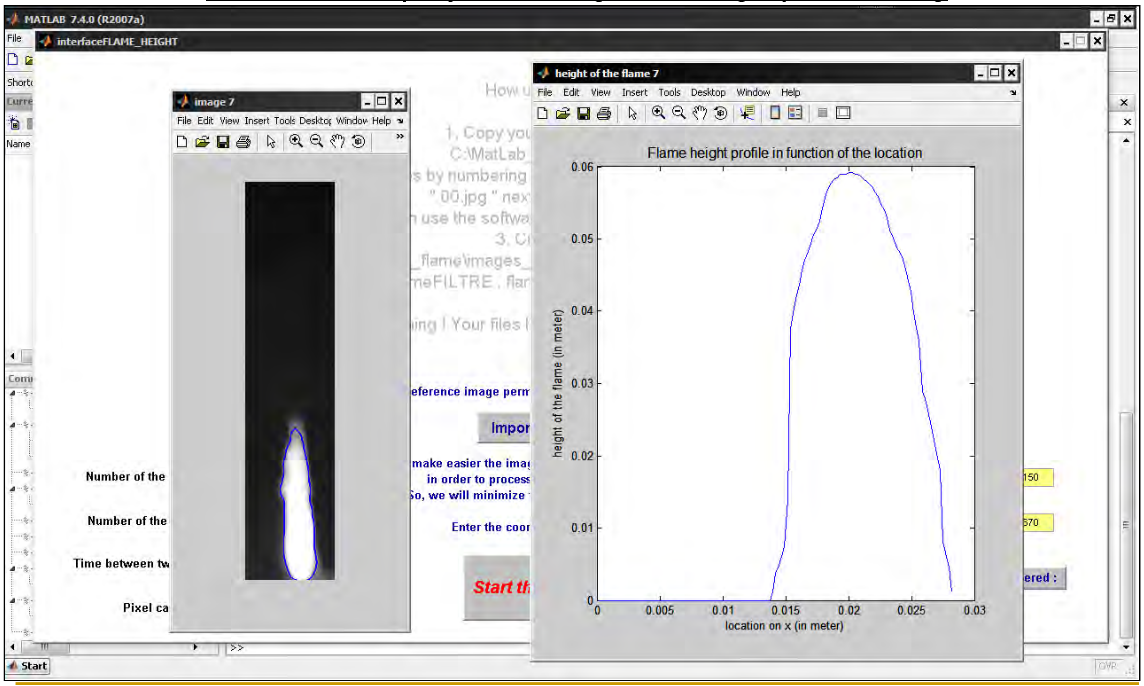
Nb *: to work on the Matlab figure, use the very interresting tools bar.*


MATLAB : Image Processing Software.
Interface
interfaceFLAME_HEIGHT
How use the program:
1. Copy your pictures in this file :
C:\MatLab_dust_flame\Pictures
2. Rename your pictures by numbering so as to have the reference image which will be " 00.jpg " next " 01.jpg " , " 02.jpg " ...
(You can use the software 'lupas rename 2000' to do that.)
3. Create this files :
C:\MatLab_dust_flame\images_files\imageGRAY, flameGRAY , flameBW
flameFILTRE , flameOUTLINE , flameHEIGHT.
Warning ! Your files have to use the "jpeg" format !!!
Step 0 : Follow the intructions
Step 1 : Import the reference image and enter the coordinates and dimensions
Step 2 : Fill in this informations then start the image processing
The importation of the reference image permits the calibration " meter / pixel " by a known dimension :
Import the reference image
To make easier the image processing, it's advice to crop the images in order to process just the interesting zone of the flame.
So, we will minimize the memory used and the processing time.
Enter the coordinates and dimensions in PIXEL :
X minimum : 2100
Width : 150
Y minimum : 1000
Heigth : 670
Number of the first image to process : 1
Number of the last image to process : 8
Time between two pictures (in second) : 0,5
Pixel calibration (in m / pixel) : 0,000235
Start the images processing
Display the processing of the picture numbered :
7
Extra opportunity : Display the processing of a specific picture
WPI
Ecole polytechnique universitaire de Marseille


MATLAB : Image Processing Software.
Importation of the reference image
Tools bar
reference image
Reference image: picture taked before to run the experiment
Pixel info
Pixel info: (X, Y) [R G B]
WPI
Ecole polytechnique universitaire de Marseille

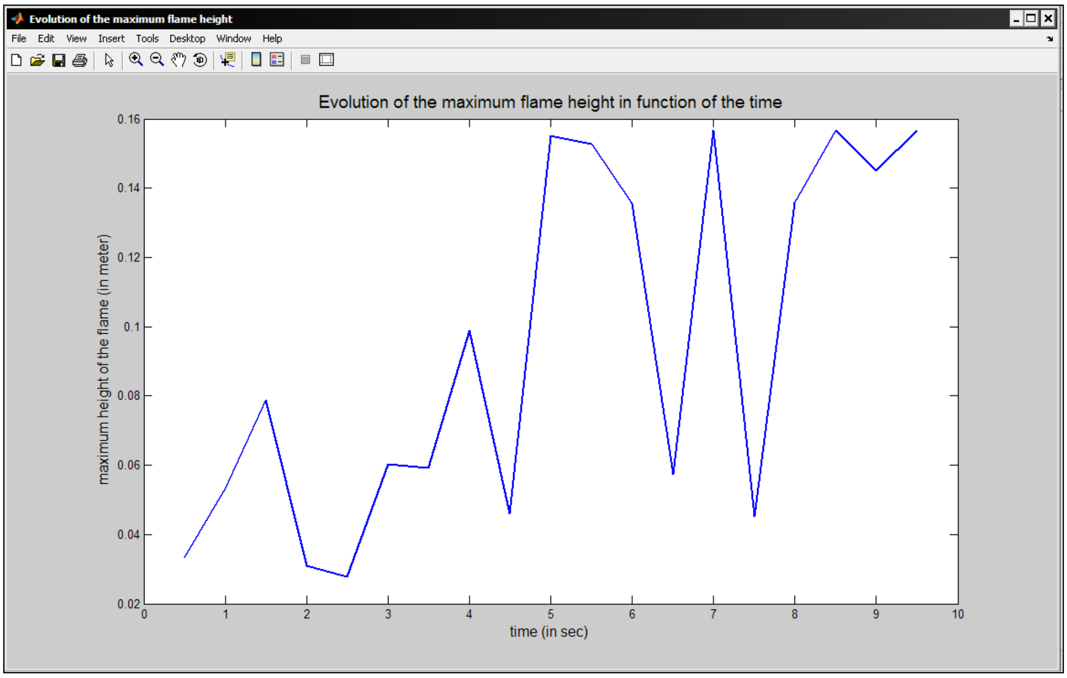
MATLAB : Image Processing Software.

Windows displayed during the image processing



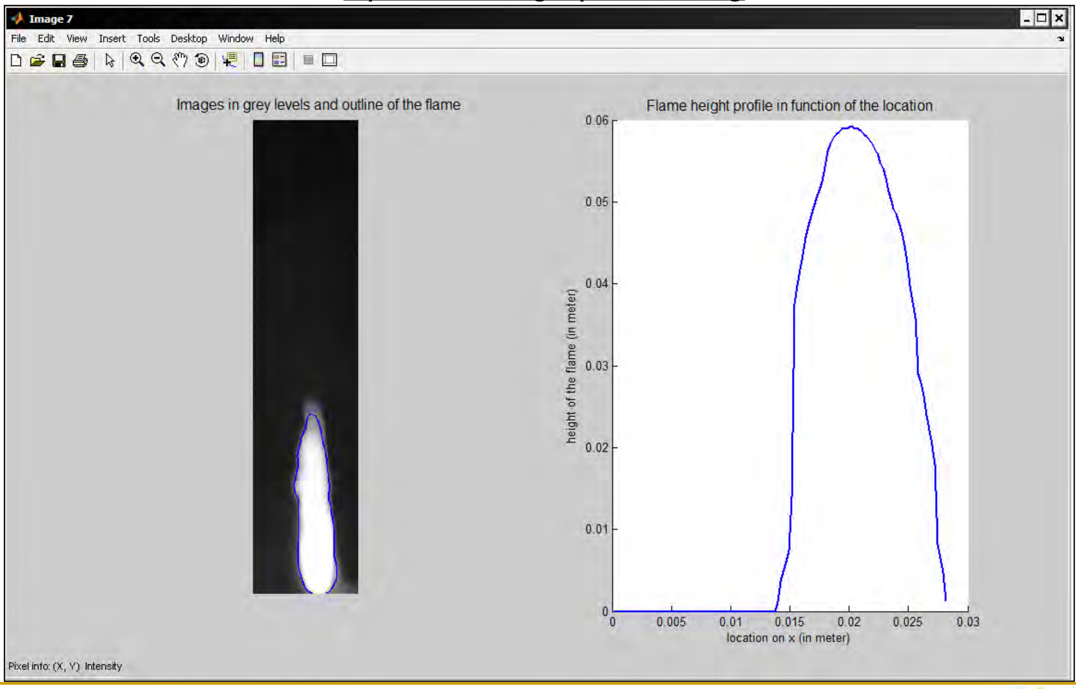
MATLAB : Image Processing Software.

Final result



MATLAB : Image Processing Software.

Specific image processing



CONCLUSION

According to the first testes done with the the rotative bruch dust seeder, this dust injector system seems to work as all the actual device.
The last problem is the **flame stabilization**. I think that the hot wire ring can be an interresting system but we need to change the size of the wire because the actual system is to fragile and breaks inside the flame owing to the very high temperature. We have also to increase the wire temperature to hope to manage to have a stabilized flame.
We can equally try to use a new dust as Lycopodium (used by Mason and Wilson) and a new flow being made up of a air/oxygen mixture.

With regard to the concentration calibration, use a filter at the burner exit to mesure the dust weight in function of the time and with the flow velocity and the nozzle section, determinate the concentration in kg/m3 for different configurations of flow valves opening and drill rotative velocities.

NB : *I would advise to try different changes before to modify the device (burner, dust seeder…).*