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VALIDATION OF AN INFRARED EXTINCTION METHOD FOR FUEL VAPOR CONCENTRATION MEASUREMENTS TOWARDS THE SYSTEMATIC COMPARISON BETWEEN ALTERNATIVE AND CONVENTIONAL FUELS FOR AVIATION

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ABSTRACT

Due to an increasing oil price and the obvious influence of the combustion of fossil fuel-derivatives on climate change on one hand and the steady growth of transportation needs on the other, it is necessary to develop alternatives to oil for aviation. For this purpose a specific research program on the investigation of adequate alternative fuels for aviation has been founded by the European Commission's Framework Program. The project Alfa Bird (Alternative Fuels and Bio-fuels in Aircraft Development) focuses on an identification of possible alternative fuels to kerosene, the investigation of the adequacy of the selected ones, an evaluation of the environmental and economical impact of those and finally the creation of a future perspective for the industrial use of the "best" alternative. The main part of the investigation activities at TU Graz, in cooperation with ONERA Centre de Toulouse and Fauga-Mauzac on these specific topics consists of the analysis of the evaporation of the previously chosen fuel types in comparison to Fully Synthetic Jet Fuel (FSJF). Therefore qualitative measurements to obtain vapor concentration gradients will be done using the Infrared Extinction (IRE) measurement method. Based on a simplified Beer-Lambert-Law the integral vapor concentrations can be obtained. The main hypothesis is that if the line-of-sight extinction due to Mie-scattering is similar for both infrared and visible wavelengths because of the presence of the spray, only infrared light will be absorbed by the fuel vapor, being transparent to visible light. This contribution focuses on the validation of the infrared measurement technique on a well characterized spray. The tests are performed under controlled boundary conditions. Therefore an existing IRE test arrangement at ONERA Toulouse using an ultrasonic atomizer injecting n-octane at atmospheric conditions has been analyzed. Error sources related to misalignments in the hardware have been considered and an iterative alignment method of the laser beams followed by a beam diameter and diffraction analysis have been performed. Optimizing the setup to obtain a stable operation point has been successful. Improved experimental results at this operation point were compared with existing simulation results for the evaporation of the used ultrasonic atomizer. The achieved data has shown good accordance to the existing simulation results. This work has been supported by the Eccomet project (Efficient and Clean Combustion Experts Training) in the framework of Alfa Bird.

INTRODUCTION

In order to predict the distribution of local concentration values of fuel vapor, a large number of numerical models have been developed in the past years. With increasing complexity and accuracy of this modeling tools experimental investigations on the fuel concentration have become more and more important.

Commonly used techniques such as LIF (Laser Induced Fluorescence) and its enhancements (PLI(E)F, FARLIF, etc) have shown weaknesses concerning acquisition speed and sensitivity towards concentration gradients in two phase flows (Blooming).

In the frame of the European Commissions FP7 project named Alfa Bird and the Eccomet project (Efficient and Clean Combustion Experts Training) which is part of the Marie Curie fellowship (FP6), a complementary measurement technique to analyze fuel vapor concentrations in monocomponent sprays has been investigated. This particular technique is called IRE (Infrared Extinction Method). Therefore, a test bench has been built up at ONERA Centre Toulouse (Office National d'Études et de Recherches Aérospatiales) using this method to analyze a monocomponent, monodisperse and a monocomponent, polydisperse fuel spray [6]. These spray types have also been modeled using the code CEDRE developed at ONERA which is based on an Eulerian-Lagrangian stochastic approach [8].

This contribution deals with the development of this technique analyzing the fuel concentration of a monocomponent polydisperse n-octane spray by using an ultrasonic atomizer and the comparison of the achieved testing results with the simulation results.

TECHNICAL FUNDAMENTALS

The Infrared Extinction method is a line-of-sight, non-intrusive laser method that provides the relative fuel vapor concentration in a two-phase flow with evaporation by comparing intensity values of two laser beams (visible λ = 633 nm and infrared λ = 3390 nm) directed through the investigated medium [1]. A few different configurations have been carried out since it was originally developped by M.S.A. Skinner in the late 70's [7]. The latest configuration known has been tested in the past three years at ONERA in Toulouse (Wagner et al. [6]) to investigate the fuel vapor concentration on droplets (Fig. 5). The principle is based on a simplification of the Beer-Brouguer-Lambert-Law (Eq.1).

$$\frac{\overline{I}(x)}{I_0} = e^{-\int_0^L \alpha(\lambda,p,T)\cdot c_m(x)\cdot dx}$$

Eq. 1: Beer-Brouguer-Lambert-Law (BBL law)

Knowing the length L of the penetration through a medium and the specific absorption coefficient α for the ambient conditions (p,T) the integral molar vapor concentration c_m can be determined by measuring the intensity ratio I/I_0.

Taking the extinction mechanisms for scattering on droplets, the absorption in the liquid phase and the fuel vapor absorption into consideration, an extended formulation of the Beer-Brouguer-Lambert-Law can be obtained (Eq. 2) (Drallmeier et al. [3]).

$$\left(\frac{\overline{I}_{(x)}}{I_0}\right)_{\lambda_{abs}} = \exp\left[-\overline{C}_n \cdot L \cdot \frac{\pi}{4} \cdot \int_0^\infty Q_{sca} \cdot D^2 \cdot N(D) \cdot dD\right] \text{ Scattering}$$
$$\cdot \exp\left[-\overline{C}_n \cdot L \cdot \frac{\pi}{4} \cdot \int_0^\infty Q_{abs} \cdot D^2 \cdot N(D) \cdot dD\right] \text{ Liquid Absorption}$$
$$\cdot \exp\left[-\int_0^l \alpha_{(\lambda,p,T)} \cdot c_m(x) \cdot dx\right] \text{ Vapor Absorption}$$

Eq. 2: extended Beer-Brouguer-Lambert-Law for absorbing wavelength

$\overline{C_n}$ stands for the line-of-sight averaged number density, *N(D)* for the drop diameter distribution. Q_{sca} and Q_{abs} are the scattering and absorption efficiencies. Consequently, the determination of the vapor concentration $c_m(x)$ (or, after integration, of its integral value c_m) requires knowledge of the drop diameter distribution *N(D)*, the two extinction efficiencies Q_{sca} and Q_{abs} and the line-of-sight averaged number density $\overline{C_n}$. The first one can be measured by the use of a laser diffraction technique. The extinction efficiencies are determined by Mie-theory computations, knowing the wavelength dependent refractive index of the droplets from literature. The number density may be obtained with an extinction measurement at a non-absorbing wavelength λ_{na} since it is wavelength-independent and in this case scattering by the droplets is the only mode of extinction.

The IR (absorbing) wavelength has been chosen due to the absorption spectrum of most common hydrocarbons which has its maximum at about λ = 3,39 µm [9].

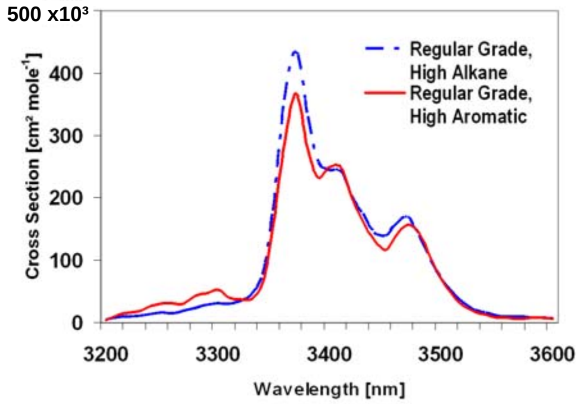


Fig. 1: Absorption Spectrum of Gasoline [9]

As a conclusion we can note that for a determination of the mean concentration value of the fuel vapor c_m, two extinction measurements, one absorption measurement and two calculations for averaged number density $\overline{C_n}$ would be necessary. This represents a lot of experimental and numerical effort for just one measurement and would render the IRE practically impossible to use for daily research or for industrial application. In 1994 Drallmeier published a simplification to the IRE evaluation process [3]. The main hypothesis is that if the line-of-sight extinction due to Mie-scattering is similar for both infrared and visible wavelengths because of the presence of the spray, only infrared light will be absorbed by the fuel vapor, being transparent to visible light. A comparison between line-of-sight intensities I_{IR} ,I_{VIS} of both wavelengths allows to estimate the vapor concentration.

The simplification is based on a mathematical reformulation of the BBL law firstly for the absorbing wavelength (IR). The optical thickness τ_{ABS} replaces the first two parts of the equation which represent the extinction by scattering and liquid absorption. The absorption efficiencies are combined as Q_{ext}.

$$\tau_{ABS} = \overline{C}_n \cdot L \cdot \frac{\pi}{4} \cdot \int_0^\infty Q_{ext} \cdot D^2 \cdot \overline{N}(D) \cdot dD$$

$$Q_{ext} = Q_{abs} + Q_{sca}$$

$$\overline{c}_m(x) = \frac{1}{\alpha \cdot L}\left[-\tau_{ABS} - \ln\left(\frac{\overline{I}_{(x)}}{I_0}\right)_{\lambda_{ABS}}\right]$$

Eq. 3: Optical thickness and molar vapor concentration for the absorbing wavelength

For the non absorbing wavelength (NA) it is assumed that there is no extinction of the laser beam due to the vapor and the liquid phase, the beam intensity is only reduced by droplet scattering.

$$\tau_{NA} = \overline{C}_n \cdot L \cdot \frac{\pi}{4} \cdot \int_0^\infty Q_{sca} \cdot D^2 \cdot N(D) \cdot dD = \ln\left(\frac{I}{I_0}\right)_{NA}$$

Eq. 4: Optical thickness for the non absorbing wavelength

The optical thickness for the non-absorbing wavelength can be introduced into the equation of the molar vapor concentration for the absorbing wavelength. The ratio τ_{ABS}/τ_{NA} is defined as optical thickness ratio R (Eq. 5).

$$\overline{c}_m = \frac{1}{\alpha \cdot L}\left[-\tau_{NA}\left(\frac{\tau_{ABS}}{\tau_{NA}}\right) - \ln\left(\frac{I}{I_0}\right)_{ABS}\right]$$
$$= \frac{1}{\alpha \cdot L}\left[-\ln\left(\frac{I}{I_0}\right)_{NA} \cdot R - \ln\left(\frac{I}{I_0}\right)_{ABS}\right]$$

Eq. 5: Molar vapor concentration with optical thickness-ratio R

Several Mie-scattering calculations [3] varying the real and imaginary part of the refractive index m for drop sizes between 1 and 200 µm have shown that the optical thickness ratio R can be assumed being 1.0 if the area mean drop diameter is D_{20} > 20 µm (Fig. 2) implying a measurement error of 10 %.

$$D_{20} = \left[\frac{\sum N(D) \cdot D^2 \cdot dD}{\sum N(D) \cdot dD}\right]^{1/2}$$

Eq. 6: Definition area mean drop diameter

As a result, no more separate scattering measurements or Mie-calculations are required to determine the line-of-sight vapor mole fraction. Taking the mentioned measurement error into account the IRE is reduced to two extinction measurements at the employed wavelengths and presents the basis for real-time analysis of sprays with this technique.

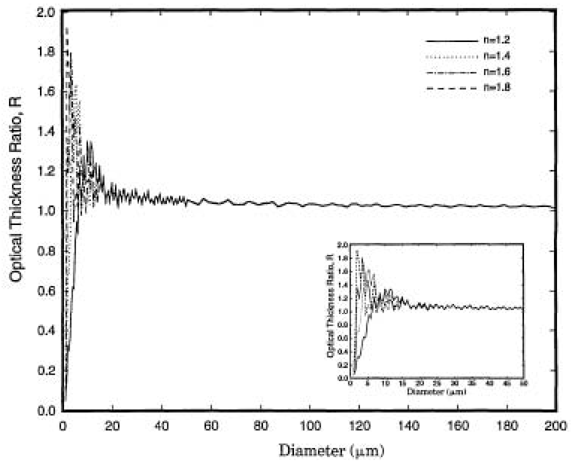


Fig. 2: Optical thickness ratio / Area mean diameter [3]

For an extinction characterization only the intensities for both wavelengths have to be measured. These intensities will always be normalized with a reference signal in absence of the spray, which represent the direct transmission intensities that are marked with a "0" underscript. As a consequence the line-of-sight intensities I_{VIS}, $I_{0\ VIS}$, I_{IR} and $I_{0\ IR}$ have to be measured. α_{IR} is the vapor absorption coefficient in the IR range, and L is the length of the laser penetration through the medium. While the product $\alpha_{IR} * L$ is constant at isothermal conditions, the relative concentration can be computed.

Since the IRE is a line-of-sight-type technique, the obtained results are integrated over the whole length of the measured area. To get spatially resolved results, deconvolution procedures have to be applied to the data. One of the classic deconvolution schemes for axisymmetrical geometries such as sprays or spherical objects is the 'Onion-peeling-scheme' as presented by Hammond 1980 [4].

$$c_{m-n} = -\frac{1}{L_n \cdot \alpha} \cdot \left(\ln\frac{I_n}{I_0} + \sum_{i=1}^{n-1} \alpha \cdot L_{i,n} \cdot c_{m-i}\right)$$

Eq. 7: Onion-Peeling algorithm

The main idea of this technique is to separate the axis-symmetric spray into n concentric rings of equal width dx in which the concentrations are assumed as being constant. x represents the stepsize of the measurement series. The algorithm shown in Eq. 7 results in n equations for n unknown concentrations.

TEST SETUP

Based on a setup originally used at DLR Cologne [1] a test bench has been built up at Onera Toulouse in order to investigate fuel concentrations in a monodisperse as well as in a polydisperse fuel spray. In this contribution only results connected to the latter will be discussed.

Fig. 4 shows the principle of the measurement setup. Two Laser light sources from Thorlabs, one for the visual range at 633 nm and one for the Infrared wavelength at 3390 nm are employed (Table 1).

Description	H339P2	HRP050
Wavelength [*nm*]	3392	632,8
Polarisation	linear> 500:1	linear> 500:1
Power [*mW*]	2	5
Beam diameter [*mm*]	2.02	0.8
Operating Voltage [*VDC*]	2800	2400
Operating Current [*mA*]	6,5	5,25
Length [*mm*]	533,4	425,5
Diameter [*mm*]	44,5	44,5

Table 1: Technical data of the laser sources

These two light paths are centered using semitransparent mirrors. A signal chopper rotating with a tunable frequency range from 1 Hz to 6 kHz produces a time dependent signal which is used as main trigger source. The temporal resolved signal is detected by photo diodes. The visible detector is a Si-type photodiode which operates at ambient temperature with an output signal of 0,42 *A/W* and an optimal spectral range from 600 to 900 *nm*. Due to the low power output of the laser, the diode is connected to an integrated low-noise preamplifier/evaluation circuit. The transimpedance is 15 *kV/A*.

To measure the amount of infrared radiation a PbSe-photoconductive detector is employed. Its output signal reaches a maximum at an optimal wavelength range between 3 and 3,7 *µm*. To minimise thermal noise it is embedded in a thermoelectric heat sink which regulates the operating temperature. Again, due to the low laser power, a pre-amplifying device follows the diode. The transfer, conditioning and storage of the pre-amplified signals are assured by a three-component acquisition system from National Instruments. It consists of a connector box, which bundles the incoming signals, the acquisition hardware, for digitalisation and conditioning, and the acquisition software to control the hardware parameters and to store the processed data.

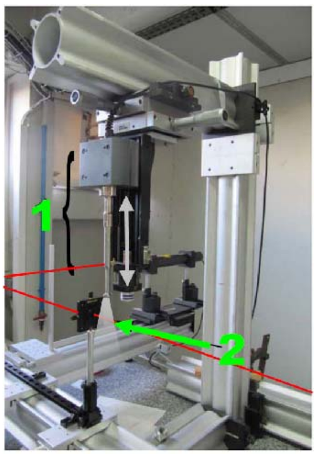
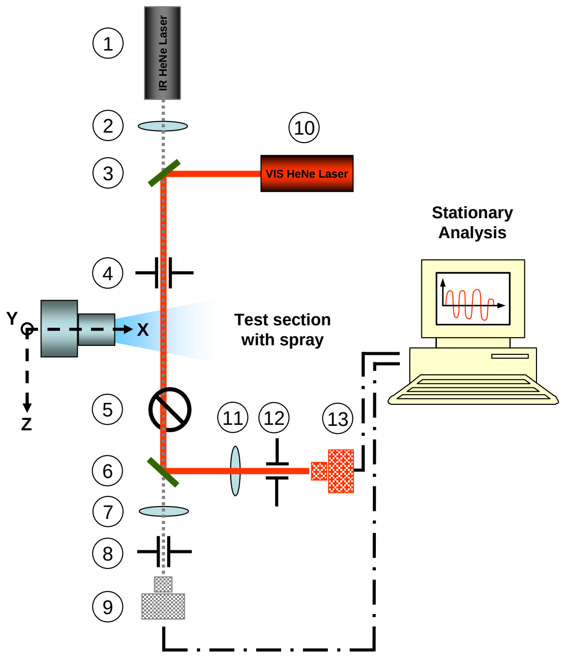


Fig. 3: (1)Injector (2)Pinhole

The last element in the acquisition chain is a Labview-based software tool which allows the experimenter to control the main acquisition parameters and to store the data. The acquainted data is stored in the Labview-native .tdms format [6]. The polydisperse spray cone is passed through the concentric laser beams (VIS and IR) which are static. The atomizer nozzle is moved from the left end to the right end of the cone varying horizontal and vertical positions. The fuel supply pressure is denoted with 1.5 bar and is delivered by a pressurized air reservoir which avoids pressure oscillations. The fuel temperature is held at 60 °C using a continuous flow heater. The temperature is measured at the injector head before and after each testing series using a thermocouple. The fuel is injected into ambient conditions of approximately 1 bar air pressure at a temperature of 20°C. The spray is generated using an ultrasonic atomizer from Sonics (USVC 130 AT) (Fig. 2). This atomizer is equipped with a flat tip nozzle allowing a maximum volume flow rate of 1.67 ml/s.



1	IR He-Ne laser λ=3.39 µm, P=2 mW
2	IR collimation lens f=400 mm, CaF type
3	Semi-transparent mirror
4	Pin-hole d=1.4 mm
5	Chopper
6	Semi-transparent mirror
7	IR collection lens f=50 mm, CaF type
8	IR pin-hole d=400 µm
9	IR filter + photodetector PbS diode
10	VIS He-Ne laser λ=632.8 nm, P=5 mW
11	VIS collection lens f=100 mm
12	VIS pin-hole d=150 µm
13	VIS filter + photodetector Si diode

Fig. 4: Schematic of the test bench

The injector uses a piezoelectric ceramic to generate an oscillation with ultrasonic frequency (20 kHz). The oscillation is transferred to the liquid film which covers the injector head (see Fig. 5).

This film, submitted to the high frequency oscillations, creates a wave pattern at the surface. When critical amplitude is reached, the waves degenerate and droplets of liquid are ejected from the liquid surface. The size distribution and the spray expansion are controlled by the amplitude of the generator excitation and by the liquid flow rate.

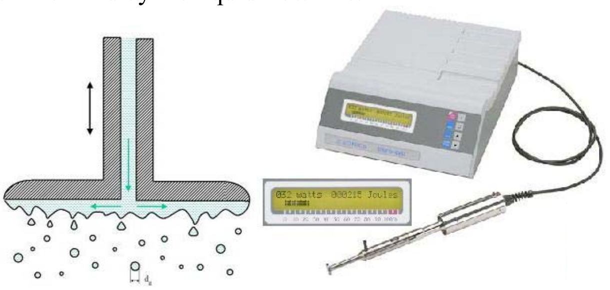


Fig. 5: Ultrasonic atomizer Sonics USVC 130 AT

The amplitude which regulates the spray cone angle is tunable in percentage steps. Higher amplitude produces a bigger spray-cone angle. The optimum referring to the stability of the cone has been found between 28 % and 35 % amplitude. The liquid flow is regulated by a manually tunable rotameter. It has to be calibrated for different liquid types.

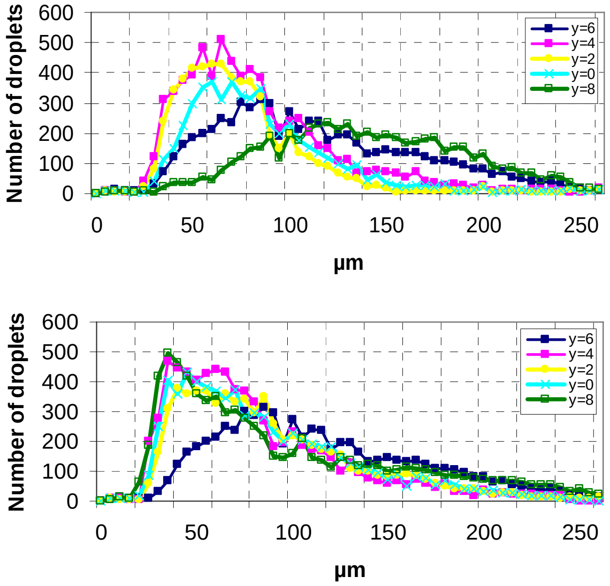


Fig. 6: Radial Evolution of Droplet size distribution at x=20mm (top) and x =75mm (bottom) n-octane m=35 ml/min

Fig. 6 shows the droplet size distributions of the injector varying the radial distance (y) from the spray center (y = 0) and Fig. 7 shows the diameter mean values as a function of radial distance which had been measured in the frame of investigations of Bodoc [8].

The diagrams demonstrate that the injector fulfills the assumption of a droplet mean size distribution higher than 20 µm for flows ≥ 35 ml/min. The measurements in Fig. 6 have been done at a vertical position of 20 mm and 75 mm from the injector head varying ten radial positions. For illustration reasons only five postions are presented. In Fig. 7 the resulting mean diameter values of the particular radial positions are diagrammed also at a vertical position of 20 mm and 75 mm from the injector head.

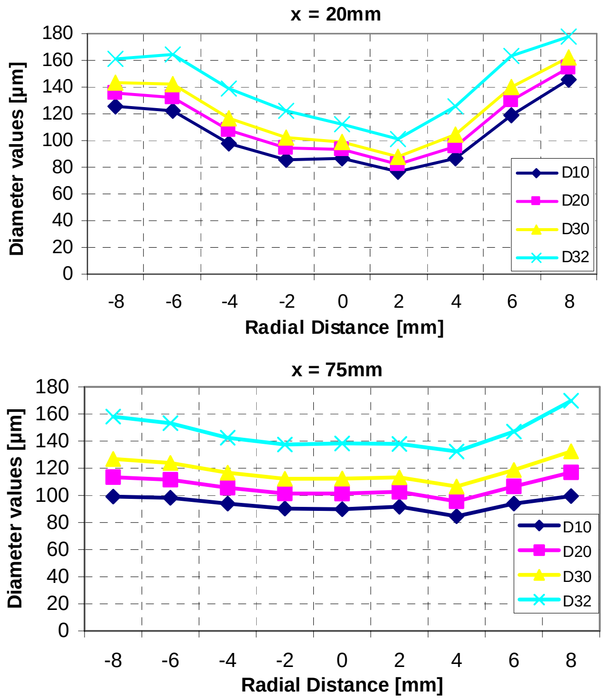


Fig. 7: Mean values of the droplet diameters determined by PDA at x=20mm (top) and x=75mm (bottom) n-octane m=35 ml/min

For the position x = 20 mm also a simulation of the fuel evaporation has been done for this particular injector [8]. In order to compare the results of the extinction measurements with the simulation results it was especially focused on this position.

BEAM ANALYSIS

The prepared optical setup has been assembled and tested. A very important requirement to guarantee the certainty of the measurement results is a precise alignment of the laser beams. Therefore the lasers have been aligned several times iteratively, using the visual part of the IR device. The methodology was to position the IR beam first by using a cross line which is mounted on a movable carrier on the measurement rail. The IR laser has been moved that way that the visual part of the light was concentric with the cross line on several positions of the rail. The mirrors (Fig. 4) were disassembled because of the

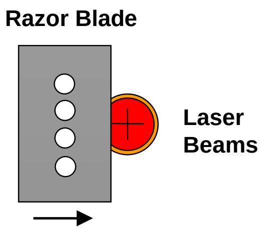


Fig. 8: Beam diameter measurement

reflection of the visual part of the IR light. After this alignment the mirrors were remounted and the visual laser beam was positioned the same way as the IR laser before by using the cross line. After this alignment the pinhole was mounted and the laser diodes were moved to the position with the maximum signal intensity, then the pinholes in front of the laser diodes were remounted and moved to the maximum intensity position. This procedure has been repeated several times in order to improve the concentricity of the beams. In order to analyze the beam diameter and the concentric and parallel positioning of the laser paths, a razorblade method (Fig. 8) has been used with a stepwise displacement (dx = 0.1mm) towards the laser light and the extinction of the beam was measured at several axial position.

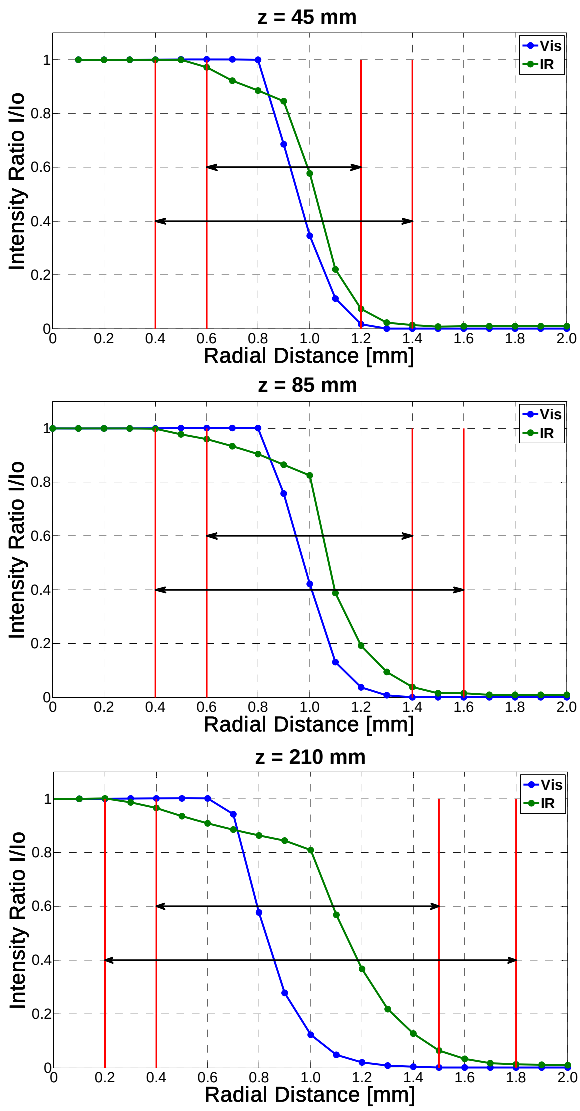
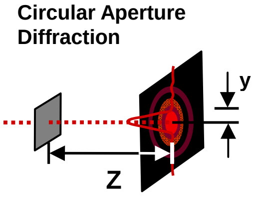


Fig. 9: Beam diameter / diffraction analysis with razorblade

The measurements have been done at horizontal positions 45 mm, 85mm and 210 mm distance from the pinhole (Fig. 9). Leading laser light through a circular aperture such as a pinhole, results in a diffraction of the beam which is characterized by intensity rings around the main light profile (Gaussian). The first ring around the profile determines the limit of the Airy disk. Preliminary calculations for the expected diameter of this ring have been done (Fig. 10).

Distance Pinhole	Beam diameter IR [mm]	Beam diameter VIS [mm]
Calculated beam diameters		
45 mm	1,36	1,07
85 mm	1,7	1,13
210 mm	2,736	1,324
Measured Beam diameters		
45 mm	1	0,6
85 mm	1,1	0,7
210 mm	1,6	1,1



$$\sin\Theta = \frac{1.22 \cdot \lambda}{d}$$

$$y = D\frac{1.22 \cdot \lambda}{d}$$

Fig. 10: Calculation of the circular aperture diffraction / comparison with measurements

The results show that there is a difference between the measurements and the calculation which is assumed to be caused by an unprecise focalization between the lens and the pinhole as well as in the diffracted shape of the beam due to the use of only one collection lens.

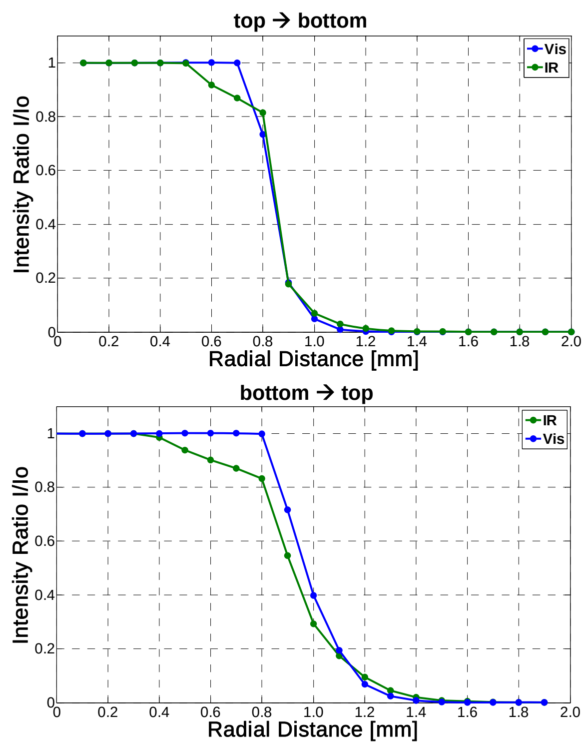


Fig. 11: Laser beam analysis with razorblade in vertical direction

In order to analyze the concentric positioning this measurement procedure was repeated at an axial distance of 45 mm from the pinhole for all directions (top → bottom, bottom → top, left → right, right → left) (Fig. 11 and Fig. 12).

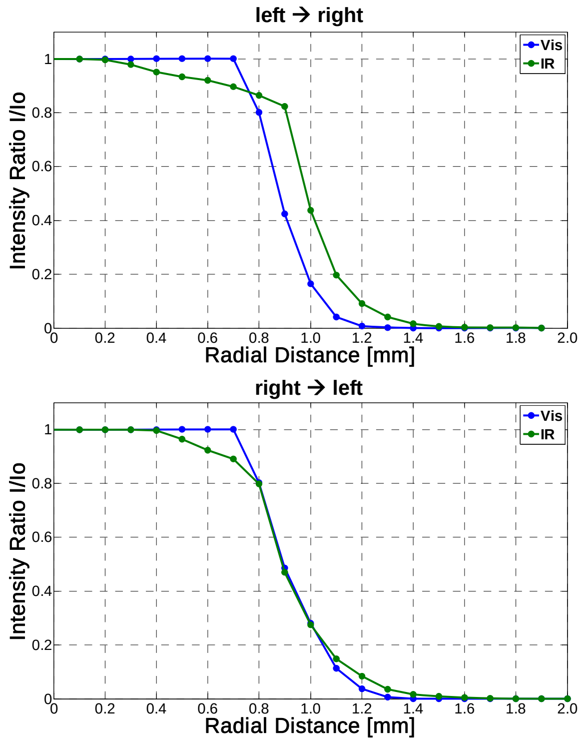


Fig. 12: Laser beam analysis with razorblade in horizontal direction

The trend of the measured extinction values is asymmetric for the VIS as well as for the IR range. Especially for the visual range the curves have an unsteady run at about 0.7 mm. This effect occurs for all four directions, which neglects the assumption that the beam shape could have an influence on this. There is no reasonable explanation for this tendency. However, the results have shown a very good alignment with a maximum excentricity of 0.05 mm.

TESTS ON THE FUEL SPRAY

After the iterative alignment and the positioning analysis results, the tests on the real fuel vapor spray have been started. As a testing fuel n-octane has been used. The methodology was to vary the injection parameters such as fuel mass flow, amplitude excitation of the piezo-actuator, horizontal distance from the main pinhole (Fig. 4 Nr. 4) and vertical distance from the beam center in order to investigate the influencing parameters on the concentration value measurement. The laser devices are stationary while the injector is movable in three axes. The presented measurement series have been produced by passing the spray cone through the laser beams from one end to another. The Injector has been displaced stepwise with dx = 1 mm including a radial range of 40 mm (-20 mm → 20 mm radial distance). Fig. 13 shows the first variation of the fuel mass flow. It can be seen that at low fuel mass flows the intensity ratio I/I0 for the visual range is smaller than for the IR range which would lead to a negative vapor concentration calculation → Eq. 5. This tendency is detectable over the whole range of the spray cone. Increasing the mass flow resulted in a different intensity ratio at 30 ml/min and further in an inversion of the results at 35 ml/min.

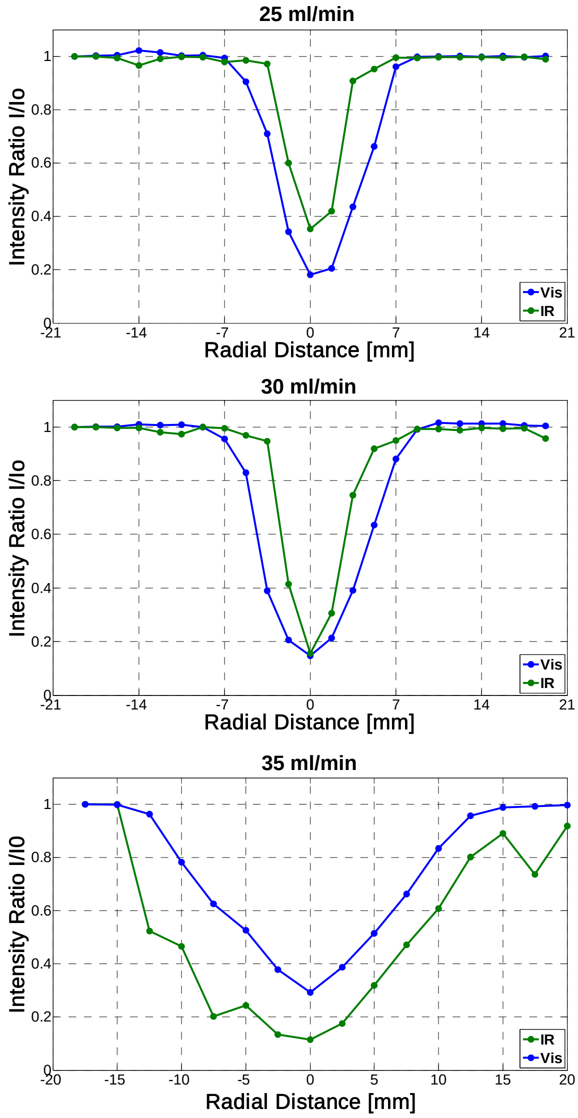


Figure 13: Extinction measurements of a n-octane spray produced by an ultrasonic injector / variation of the fuel mass flow (25 / 30 / 35 ml/min) at 20 mm vertical distance from the beam center to the injector head and 45 mm horizontal distance from the spray center to the main pinhole.

It is assumed that for very low mass flows the area mean diameter D_{20} (Eq. 6) of the spray does not fulfill the assumption of being higher than 20 µm. The inversion of the extinction results takes place at 35 ml/min which is exactly the value that has been investigated in the anticipated injection simulation analysis of ONERA Toulouse. This allows a direct comparison with the simulation results which is going to be presented later.

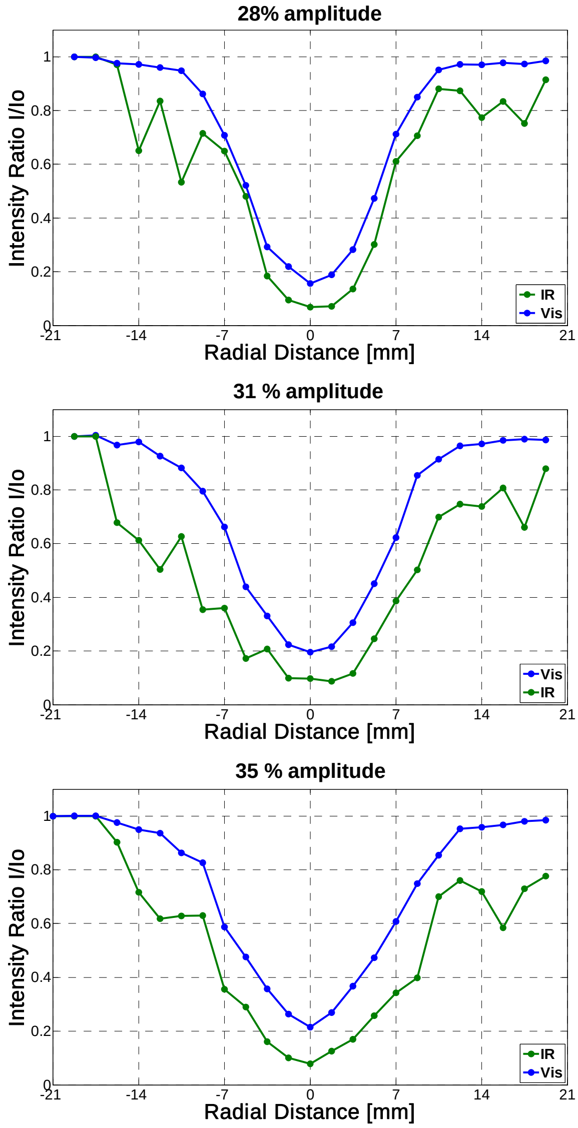


Figure 14: Extinction measurements of a n-octane spray pro-duced by an ultrasonic injector / variation of the in-jection parameter (28 / 31 / 35 % amplitude) at 20 mm vertical distance from the beam center to the injector head and 45 mm horizontal distance from the spray cen-ter to the main pinhole.

The variation of the excitation amplitude parameter of the injector is presented in Figure 16. It can be seen here that it seems to influence only the spray cone shape as it is described in the injector manual. A higher excitation amplitude results in a broader spray cone, which can be identified focusing on the transition of the curve form from 28% to 31% amplitude. The difference between 31% and 35% is not significant. It is assumed that the area mean diameter D_{20} fulfills the boundary condition of being higher than 20 µm due to the tendency of the extinction to be in a correct relation, which means a positive vapor concentration over the whole spray cone in all amplitude variation series.

Further measurement series focused on the mass flow rate at 35 ml/min. Also, the influence of the polarization has been investigated by a systematical changing of the polarization direction of the visible laser beam. The polarizator has been installed between the laser and the first mirror of the visible light path. There were no influences detectable concerning the polarization direction.

Having found this stable injection parameter configuration, more measurements have been done to be able to present homogenous curve results, which was difficult due to the instability of the injector. However there has still been a divergence on the right side of the curve (Fig 15). The extinction for the IR range remained at a certain level. The explanation for this phenomenon is that the peripheric vapor concentration reaches a non-negligible level after the duration of half an hour for one measurement series.

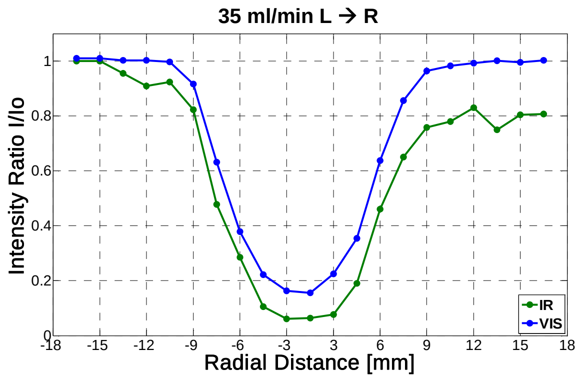


Fig. 15: Stable extinction measurement at 35 ml/min from left to right

For the following series the movement of the injector has been changed from the left side of the spray cone to the center and then from the right side of the cone to the center. The remaining vapor was blown outside of the detection area by pressurized air in the middle of the series before changing the direction. Fig. 16 shows the suchlike achieved results. There is a significant change on the right side of the curve noticeable.

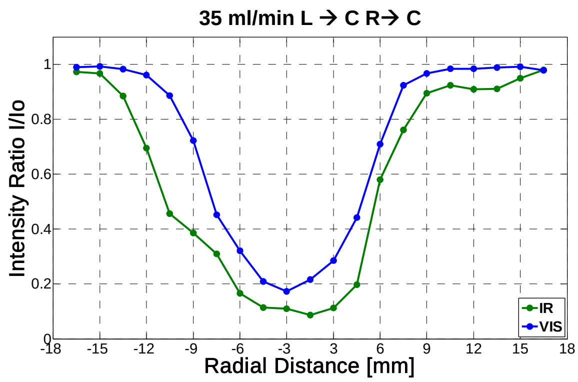


Fig. 16: Stable extinction measurement at 35 ml/min from left to center and right to center

The measurements presented in Figure 16 have been repeated several times with the same fuel mass flow rate (35 ml/min) and the same ambient and boundary conditions. The suchlike achieved results have been deconvoluted by the above presented Onion-Peeling algorithm and the most homogeneous results (concerning the injector stability) have been compared with the simulation results of Bodoc [8] achieved with CEDRE code at Onera Toulouse.

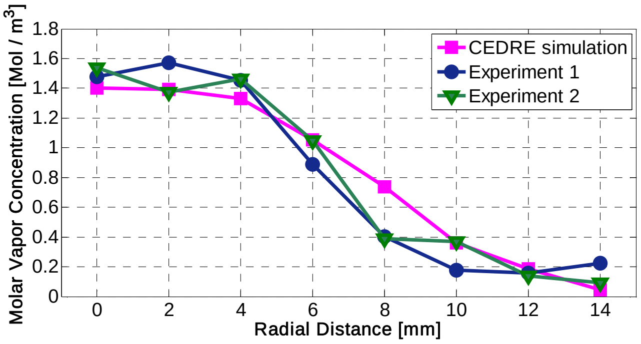


Fig. 17: Comparison of deconvolution results with simulation results

Figure 17 shows the deconvoluted results of the measurements performed at the very end of the investigation. Experiment 1 (blue marked) and Experiment 2 (green marked) have been performed serially. The absolute values of the vapor fraction between these two series show a difference of about 10 % to 12 % (except for points at radial distance 10 mm and 14 mm with 50 %), which is in quite good accordance taking into account an assumed measurement error of about 10 % for the complete IRE measurement chain. The comparison of the numerical simulation results (margenta) achieved by Bodoc [8] using preheated (60°C) n-octane at a fuel mass flow rate of 35 ml/min and the experiments 1 and 2 shows a similar tendency with a difference of approximately +/-0,2 Mol/m³ between the point results, except for point 8 mm radial distance with +/-0,35 Mol/m³ difference.

CONCLUSION

Summing up the anticipated results, the validation of the IRE experimental setup on a spray configuration for the needs of a qualitative fuel comparison has been successful. However, there has to be taken into account a measurement error of approximately ten percent based on the assumptions presented in the chapter ''Technical Fundamentals''. Additionally, particular boundary conditions have to be guaranteed, which reduce the practicability in an immense extent. Even if a good coherence of the suchlike obtained measurement results with the anticipated simulation results has been achieved, for reproducible measurements, improvements to the existing test bench have to be done concerning injector stability, the photodiode stability, the post-processing and the hardware related to problems with peripheric vapor. Future investigations in the frame of the Alfa Bird project will focus on a qualitative comparison of the evaporation of different alternative fuels, therefore the technique is assumed to be adequate. For these test series the design of the measurement setup is modified. Instead of laser diodes, CCD cameras are going to be employed which will result in a less displacement and diffraction sensitivity. This setup is under construction and investigation results will soon follow.

NOMENCLATURE

$\overline{C_n}$	Line-of-Sight Averaged Number Density
$N(D)$	Drop Diameter Distribution
Q_{sca} and Q_{abs}	Scattering and Absorption Efficiency
c_m (x)	Integral Vapor Concentration
α_{IR}	Absorption Coefficient
L	Length of Laser Penetration through medium
λ_{abs} and λ_{na}	Absorbing and Non-absorbing Wavelength
f	Focal Length
p	Pressure
T	Temperature
τ_{ABS} and τ_{NA}	Optical Thickness
D_{20}	Area Mean Diameter
D_{32}	Sauter Mean Diameter

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