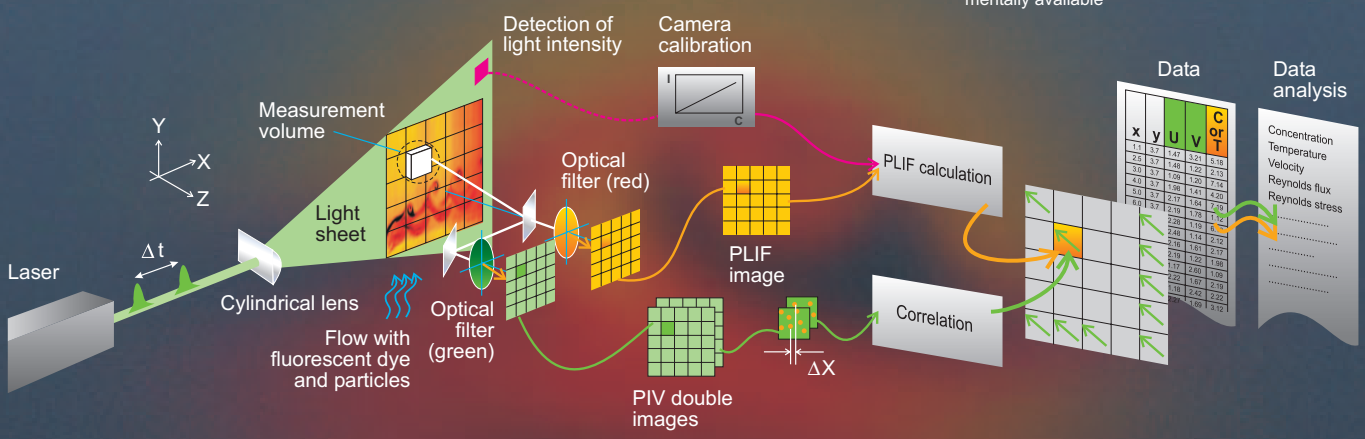
Planar Laser-Induced Fluorescence

Introduction

Planar laser-induced fluorescence (planar-LIF) is an optical measuring technique used to measure instant whole-field concentration or temperature maps in liquid flows.
Applications can be found in process engineering (e.g. mixing in stirring vessels, heating and cooling systems), biomedical engineering (e.g. transport of drugs in biological flows such as in model veins) and fluid dynamics research (e.g. turbulent mixing and heat-transfer modelling, indoor climate etc.)

Features

- Non-intrusive technology
- Quantitative, precise and accurate measurements of concentration or temperature fields
- In combination with velocity measurements, transport properties (e.g. Reynolds flux, turbulent diffusion coefficients and other parameters) are made experimentally available



Experimental set-up

The basic equipment needed to carry out planar-LIF measurements is:

- A laser source (typically Nd:YAG or Argon-ion lasers) with the appropriate optics to form a thin sheet of light
- A fluorescent dye that marks the fluid and that is traced during the measurements. This chemical compound absorbs the laser light energy and re-emits light at a longer wavelength that can be detected by a photodetector. Commonly used dyes for measurements in liquids are rhodamine 6G (for concentration measurements), rhodamine B (for temperature measurements) and fluorescein disodium (for concentration or temperature measurements)
- A CCD camera equipped with a sharp cut-off or narrow-band filter, so that only the fluorescent light is recorded. This camera acts as an array of light detectors (pixels)

Calibration

The level of fluorescence is known to vary with the concentration or the temperature and several other experimental parameters.

- With rhodamine 6G as marker and the concentration as measured variable, S is defined as:

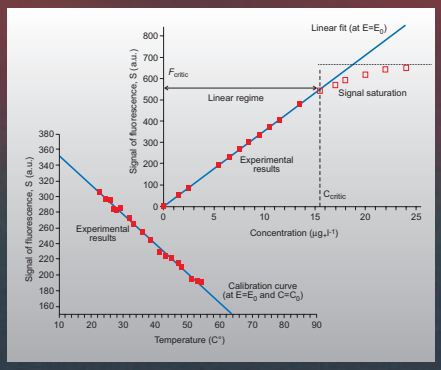
$$S = f_{optic} \cdot A_C \cdot (EV_c \cdot Q_\lambda) \cdot C \quad where \quad A_C = e^{-\varepsilon L \cdot C}$$

- With rhodamine B as marker (for constant concentration, C_o) and the temperature as measured variable, S is defined as:

$$S = f_{optic} \cdot A_T \cdot (EV_c \cdot C_o) \cdot Q_\lambda(T)$$

Where:

- C and T are the dye concentration and the temperature, respectively
- E is the laser light intensity
- Q_λ is the quantum efficiency of the dye (at the laser excitation wavelength λ)
- f_{optic} corresponds to optical factors
- V_c is the sampling volume
- A_C and A_T represent absorption phenomena integrated on the light path (L) in the fluid characterised by absorption index (ε)



Typical single-pixel temperature and concentration calibration curves

At low concentration levels, absorption phenomena are negligible (A_C, $A_T \approx 1$), which leads to a linear relationship between the signal (S) and (C,E,α) or (T,β) - with (α, β) two constants that characterise all experimental parameters. In such conditions, concentration (or temperature) is accurately measured as the amount of light received by the detector. The calibration procedure consists of determining α (or β) at every pixel of the camera.

Signal processing

Signal processing consists of converting the recorded raw images of fluorescence to concentration or temperature maps, via the calibration map determined previously. For liquid-liquid mixing, one of the fluids is marked with the dye, whereas the other is fresh fluid. When passing through the laser sheet, the dye is excited and re-emits fluorescent light. The light intensity is then processed as follows to give concentration:

$$C \cong \frac{S}{\alpha E}$$

For temperature measurements, the dye is first mixed with the fluid and the fluorescence level re-emitted varies with the local temperature. In this case, temperature is determined as follows:

$$(T - T_{ref}) \cong \frac{(S - S_{ref})}{\beta}$$

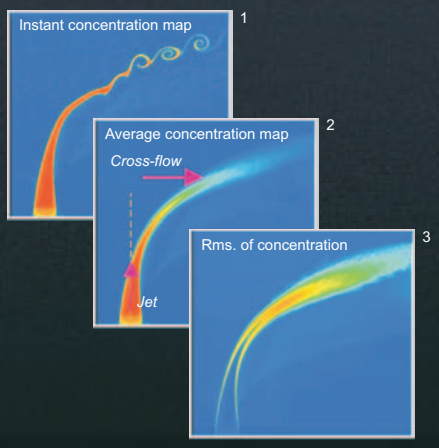
where S_{ref} is the reference fluorescence signal at $T=T_{ref}$

Synchronised planar-LIF and PIV measurements

Combining concentration or temperature with velocity measurements enables mixing or heat transfer to be studied at the scalar transport level. In this case, a second camera picks up the laser light scattered by small particles through an optical narrow-band filter. The signal is processed to measure velocities, as in standard PIV. The two LIF and PIV receivers are brought to observe the same locations by means of beam splitter optics and geometrical calibration.

Example: Jet mixing in a cross-flow

A laminar water-jet flow is established in a semi-enclosed mixing chamber with a water cross-flow loop. A Nd:YAG green laser light sheet illuminates the centre plane of the jet and excites the rhodamine 6G that is added to the fluid. The LIF camera collects the bright orange light and the images are processed to give instant concentration maps. Eddy structures issued from the jet are clearly identified on the instant concentration map (image 1). Statistical analysis of the data such as average (image 2) and rms (image 3) of concentration further provide meaningful information on the mixing process.



Example of instant and statistical maps of concentration obtained with planar-LIF measurements

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