

Two-color laser-induced fluorescence thermometry in model fuels under transcritical conditions

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ABSTRACT

This work presents two-color laser-induced fluorescence (2c-LIF) using 1-methylnaphthalene (1-MN) as a tracer for thermometry in trans- and supercritical isooctane. The experiments are conducted in an optically accessible high-pressure flow cell at 3 MPa ($p_r = 1.10$), where in a nitrogen atmosphere an isooctane/1-MN mixture is heated in a quartz-glass cuvette from liquid conditions through a transition regime into the supercritical state. Fluorescence is excited at 266 nm by a pulsed Nd:YAG laser and detected simultaneously in two spectral channels using intensified sCMOS cameras equipped with different longpass filters. Additional spectrometer measurements are used to characterize the temperature-dependent spectral behavior of the 1-MN fluorescence emission. A calibration of the normalized LIF signal ratio is established for the supercritical regime between 600 K and 779 K, corresponding to reduced temperatures of $T_r = 1.10$ to $T_r = 1.43$. Within this range, the calibration shows an average sensitivity of approximately 8 % per 100 K and enables the spatial evaluation of local temperature gradients. In the liquid phase and the transition region such a dependence is not found. The results demonstrate the feasibility of 1-MN-based 2c-LIF thermometry in supercritical pure fluids and provide calibration data for isooctane under transcritical operating conditions. These findings form a basis for future investigations of fuel-rich mixtures in sprays, other model fuels, and combined diagnostic approaches for distinguishing liquid, transitional, and supercritical regions. Further investigations will focus on measurements in droplets and sprays, different model fuels and techniques to discriminate between the different phases.

1. Introduction

Transcritical spray processes are highly relevant to technical systems operating at elevated pressures and temperatures, particularly in energy and process engineering applications (Lamanna, 2024). Under such conditions, fluids may exceed their critical point and transition into a supercritical state. Therefore, understanding how injection conditions affect phase change, diffusive mixing, and mixture formation is essential (Crua et al., 2017). This includes transcritical

injection regimes, in which the ambient pressure is above the critical pressure of the fluid mixture (Traxinger et al., 2019).

Previous studies have demonstrated the use of two-color laser-induced fluorescence (2c-LIF) with 1-methylnaphthalene (1-MN) as a tracer for determining temperature and fuel distribution. The method has been applied to gas-phase measurements in a flow cell, to injection experiments in a larger injection chamber (Lind et al., 2017), and to mixing investigations in a rapid compression machine (Retzer et al., 2022). Despite these developments, the separation of LIF signals originating from liquid, gaseous, and supercritical regions during transcritical injection remains unresolved and is therefore a central objective of current and future work. Earlier studies have shown that reliable measurements in the vicinity of droplets and sprays require a clear separation of fluorescence signals originating from the liquid and gas phases. This distinction is essential because signals from liquid structures can interfere with the LIF response assigned to the vapor phase or supercritical region. If the liquid contribution is not identified and excluded, the evaluated spray temperature may be artificially biased toward unrealistically low local values (Lind et al., 2017). To simplify the experimental boundary conditions and enable more controlled investigations under transcritical conditions, a compact flow cell has been developed and implemented at the Universität der Bundeswehr München.

Due to the transient nature and complexity of transcritical injection processes, well-defined pressure and temperature conditions are required to investigate phase-transition phenomena and the formation of supercritical fluid states. As a first step, the phase behavior of the model fuel was therefore examined by means of backlight imaging in a quartz-glass cuvette mounted inside the heated and pressurized flow cell. These preliminary measurements demonstrated that the developed setup is suitable for visualizing and resolving the phase transition during fluid heating, as shown in Figure 1. The experiments were carried out with isooctane in a nitrogen atmosphere at a pressure of 3 MPa, corresponding to a reduced pressure of $p_r = p/p_{c,\text{isooctane}} = 1.16$. The maximum temperature reached during these initial measurements was 588 K, which is only slightly above the critical temperature of isooctane ($T_r = T/T_{c,\text{isooctane}} = 1.03$). Isooctane was selected as a model fuel because it serves as a surrogate component representative of different boiling fractions found in multicomponent fuels such as gasoline, kerosene, and diesel.

At the beginning of the heating process, shown in images A–C, the liquid expands and density variations become visible. Increased heat transfer occurs near the outer regions of the cuvette and at the bottom, where the cuvette is fixed in the metal holder. As a result, regions of lower density form and rise through the liquid. With further heating, the fluid transitions toward the

supercritical state. This transition is indicated by the gradual disappearance of the phase boundary and an increase in light extinction, as visible in images D–H.

Compared with the 2c-LIF measurements discussed later in this work, these preliminary experiments were performed at lower temperatures and with a reduced heating rate. This allowed more homogeneous conditions to develop inside the cuvette. The measurements were conducted without fluorescent tracer and served to characterize the heating behavior and phase transition of pure isooctane under controlled operating conditions. Building on these observations, the subsequent experiments focus on the further development of 2c-LIF for pure-fuel and very fuel-rich conditions in the supercritical regime. In the present work, the calibration of the 2c-LIF signal and its applicability for thermometry measurements in supercritical fluids are investigated.

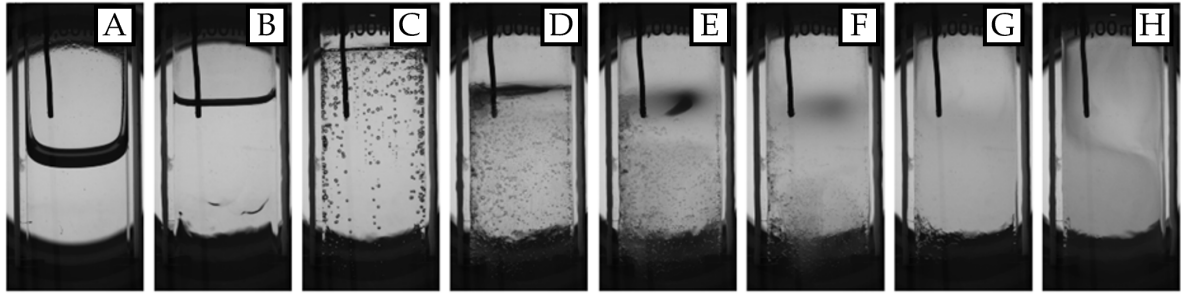


Figure. 1 Backlight imaging for studying the phase change of isooctane in a supercritical nitrogen environment; temperature is increased from A–H.

2. Methods and Experimental Setup

This study uses two-color laser-induced fluorescence (2c-LIF) as a measurement method (Retzer et al., 2022). The tracer in the cuvette emits a fluorescence signal S_{fl} which can be related to the thermodynamic state via its dependence on temperature and density:

$$S_{fl} \sim \eta E n_{\text{tracer}} \sigma_{\text{abs}}(\lambda_{\text{ex}}, T) \Phi_{fl}(\lambda_{\text{ex}}, T, p, \chi_i) \quad (1)$$

In this relation η is the efficiency of the optical system, E is the laser fluence, n_{tracer} the tracer number density, σ_{abs} the absorption cross section and Φ_{fl} the fluorescence quantum yield, which is dependent on the excitation wavelength λ_{ex} , temperature T , pressure p and the bath gas composition (mole fraction χ_i).

For thermometry, i.e., temperature measurement, a two-color approach is employed. This method is based on the temperature-dependent broadening and spectral shift of the 1-MN fluorescence spectrum. The two intensified sCMOS cameras are equipped with different spectral filters,

providing two separate detection channels. From the signals recorded in these channels, a ratio is calculated according to the following equation:

$$S_{\text{ratio}} = \frac{S_{\lambda_1}}{S_{\lambda_2}} = \frac{[\eta_1 E n_{\text{tracer}} \sigma_{\text{abs}}(\lambda_{\text{ex}}, T) \Phi_{\text{fl}}(\lambda_{\text{ex}}, T, p, \chi_i)]_{\lambda_1}}{[\eta_2 E n_{\text{tracer}} \sigma_{\text{abs}}(\lambda_{\text{ex}}, T) \Phi_{\text{fl}}(\lambda_{\text{ex}}, T, p, \chi_i)]_{\lambda_2}} = \frac{[\eta_1 \Phi_{\text{fl}}(\lambda_{\text{ex}}, T, p, \chi_i)]_{\lambda_1}}{[\eta_2 \Phi_{\text{fl}}(\lambda_{\text{ex}}, T, p, \chi_i)]_{\lambda_2}} \quad (2)$$

Since the same laser excitation is used for both channels, the laser fluence cancels out. Similarly, the absorption cross section is eliminated from the equation. Normalization using a reference image is performed to eliminate the optical efficiency η . This yields a LIF ratio $S_{\text{ratio, norm}}$ which is now solely a function of the temperature-dependent fluorescence quantum yields of the two camera channels equipped with filters:

$$S_{\text{ratio, norm}} = \frac{S_{\lambda_1}/S_{\lambda_1, \text{ref}}}{S_{\lambda_2}/S_{\lambda_2, \text{ref}}} = \frac{S_{\lambda_1, \text{norm}}}{S_{\lambda_2, \text{norm}}} = \frac{[\eta_1 \Phi_{\text{fl}}(\lambda_{\text{ex}}, T, p, \chi_i)]_{\lambda_1} / [\eta_1 \Phi_{\text{fl}, \lambda_1, \text{ref}}]}{[\eta_2 \Phi_{\text{fl}}(\lambda_{\text{ex}}, T, p, \chi_i)]_{\lambda_2} / [\eta_2 \Phi_{\text{fl}, \lambda_2, \text{ref}}]} = \frac{[\Phi_{\text{fl, norm}}(\lambda_{\text{ex}}, T, p, \chi_i)]_{\lambda_1}}{[\Phi_{\text{fl, norm}}(\lambda_{\text{ex}}, T, p, \chi_i)]_{\lambda_2}} \quad (3)$$

Based on this dependence, a calibration curve can be generated from the experimental data and subsequently used to determine the temperature.

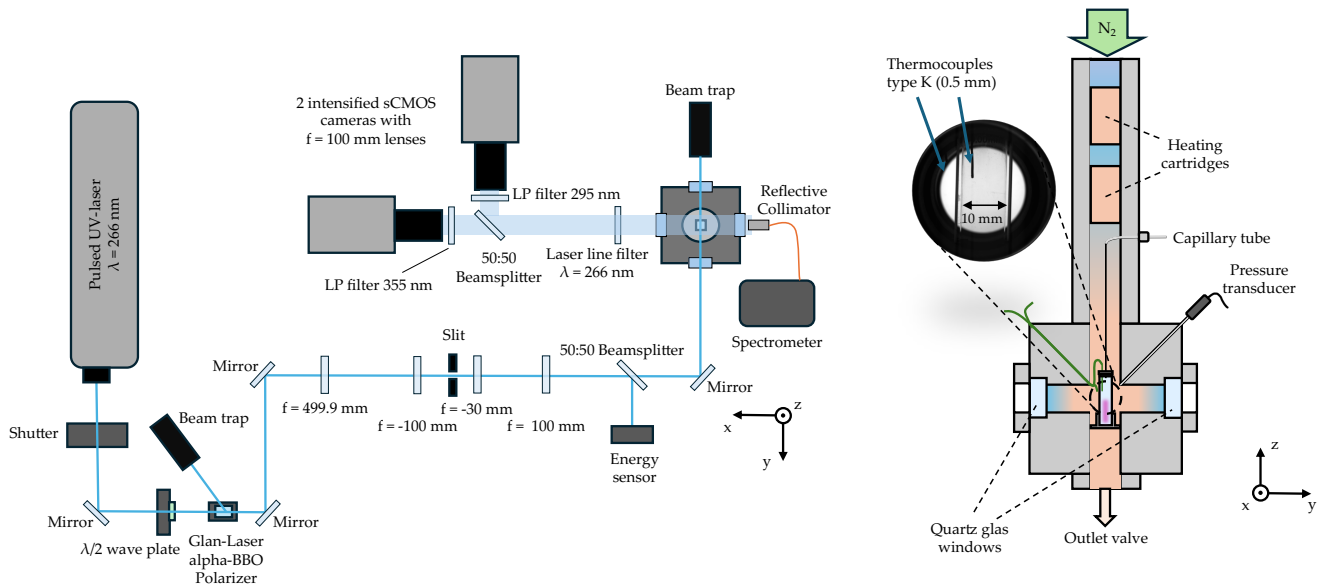


Figure. 2 Left: Optical setup for 2c-LIF, Right: cross section of the flow cell with the cuvette

A schematic diagram of the flow cell used to study the model fuels under transcritical conditions is shown in Figure 2. The experimental LIF setup is built around a steel chamber that features four quartz-glass windows, enabling optical access from multiple directions. The chamber is designed

for continuous-flow operation and can withstand pressures up to 4 MPa. To maintain an inert atmosphere and avoid undesired ignition of the fuel-gas mixture, nitrogen is employed as the carrier gas. The gas flow is controlled by a mass flow controller (El-Flow, Bronkhorst), which provides a maximum flow rate of 200 l_n/min , where l_n refers to norm liters at 273.15 K and 1013.25 hPa. The operating pressure is set by means of a manual outlet valve (Swagelok) and recorded using a pressure transducer (PAA-35HTCX, Keller). Upstream of the optical accessible measurement region, the nitrogen stream is heated using two 3300 W heating cartridges (Leister), allowing main-flow temperatures of up to 900 K to be reached.

The model fuel is investigated in a quartz-glass cuvette (Typ 101-QS, Hellma), which is positioned inside the flow cell, as shown in Figure 2 on the right. The cuvette has internal dimensions of 10 mm x 10 mm x 43.75 mm and a wall thickness of 1.25 mm. It is supported by a stainless-steel mount, whereas a titanium cover is used to reduce leakage and to balance the pressure between the cuvette interior and the surrounding flow cell. The cuvette is filled at ambient pressure through a 1 mm diameter capillary tube.

Isooctane (2,2,4-trimethylpentane, $\geq 99.8\%$, SPECTRONORM®, CAS: 540-84-1, VWR) is used as the model fuel in this work. Its critical point, given as $T_c = 543.9$ K and $p_c = 2.57$ MPa according to REFPROP (Lemmon et al., 2018), falls within the operating limits of the flow cell and therefore allows measurements under transcritical conditions. Following previous investigations, 1-methylnaphthalene (1-MN) (CAS: 90-12-0, Sigma-Aldrich) is introduced as a fluorescent tracer at a concentration of 0.1 vol-%. The temperature inside the cuvette is monitored with a type K thermocouple with a diameter of 0.5 mm. An additional thermocouple placed next to the cuvette records the temperature of the surrounding nitrogen flow.

The optical arrangement is shown schematically in Figure 2. Excitation of the fluorescent tracer is achieved using a pulsed Nd:YAG laser (Q-Smart 850, Quantel) operating at a wavelength of 266 nm in the ultraviolet range. The pulse energy is controlled by a combination of a $\lambda/2$ wave plate and an alpha-BBO Glan-laser polarizer (both Thorlabs). The mean energy varies in the experiments from 172 μJ up to 260 μJ and is monitored shot-by-shot with a pyroelectric energy sensor (PE50BF-C, Ophir). To shape the laser beam into a light sheet, four cylindrical lenses (Thorlabs) are employed, resulting in a sheet height of about 20 mm and a thickness of approximately 1 mm. Optical access to the cell is provided by quartz-glass windows with a diameter of 25 mm, while a beam trap is positioned on the opposite side of the cell.

The fluorescence emission is detected with two intensified sCMOS cameras (iStar-sCMOS-18F-E4, Andor), which are equipped with UV-lenses ($f = 100$ mm, B. Halle Nachfl. GmbH). To prevent

scattered laser light from reaching the cameras, a 266 nm longpass filter (Raman Filter RET 270 LP, AHF) is placed in the detection path. The filtered emission is then separated into two optical paths by a 50:50 beamsplitter and imaged onto the two cameras. Spectral separation is achieved by equipping the cameras with different longpass filters. One detection channel uses an LP 295 nm filter (SCHOTT LP N-WG-295, Edmund Optics), while the second channel is fitted with an LP 355 nm filter (RazorEdge LP 355 RU, AHF). The LP 295 nm filter, referred to as λ_2 in Eq. 3, covers the major part of the 1-MN fluorescence emission. In contrast, the LP 355 nm filter, denoted as λ_1 in Eq. 3, transmits only the red-shifted part of the spectrum, which is more sensitive to temperature changes.

Synchronization of the two cameras with the laser is realized using a pulse delay generator (9520 Series, Quantum Composer) referenced to the Q-switch signal. The intensifier photocathodes are operated with a gate width of 300 ns, allowing the complete fluorescence signal to be integrated. Image acquisition is carried out at 10 Hz, corresponding to the repetition rate of the laser system. In addition to the camera-based measurement, a spectrometer (MAYA2000Pro, Ocean Optics) is used to acquire spectral information from the fluorescence emission. The emitted light is collimated using a UV-enhanced aluminum-coated reflective collimator (RC04SMA-F01, Thorlabs) and guided to the Maya2000Pro via a multimode fiber patch cable ($\varnothing$ 600 μ m, M114L01, Thorlabs). The spectrometer is also triggered by a signal from the pulse delay generator.

The measurement procedure is the same for all six individual experiments conducted as part of this study. Under ambient conditions approximately 3 ml of the prepared isooctane/1-methylnaphthalene (1-MN) fuel-tracer mixture is filled inside the cuvette via a capillary tube.

A constant nitrogen flow rate of 150 l_n/min is set using the mass flow controller. This flow rate is maintained throughout the experiment. The valve downstream of the cell is closed until a pressure of 3 MPa is established in the measurement chamber. The laser is turned on and its energy is adjusted to the desired level using the polarizer setup. Image acquisition is initiated via the delay generator 10 s prior to the start of heating. During the heating phase, the temperature inside the cuvette is monitored continuously. Heating is stopped approximately 2 min 5 s after the start of image acquisition, when a temperature of 779 K is reached. The analysis in this paper focuses on the heating phase; therefore, the cooling process after turning off the heater is not considered further here. Temperature, pressure, and mass-flow data are acquired using MATLAB (Mathworks).

Post-processing is performed in MATLAB as well. First, the images acquired by the two cameras are spatially registered and aligned. For calibration, a region of interest (ROI) is defined. Since the thermocouple inside the cuvette is used as the temperature reference, the ROI should be located close to the measurement position. The thermocouple is positioned in the left quadrant of the cuvette (see Figure 3), rather than at the center, in order to avoid interference with the laser sheet. Assuming a symmetric flow and temperature field within the cuvette, the ROI is placed on the opposite side of the image, where a “virtual thermocouple” can be defined. Temperature gradients in the lateral direction, from the center of the laser sheet to the thermocouple position, are neglected. Positioning the ROI near the laser entry side is advantageous, as the signal intensity in both camera channels is highest in this region, resulting in an improved signal-to-noise ratio. The ROI has dimensions of 100 by 100 pixels (see Figure 3), corresponding to a total of 10,000 pixels.

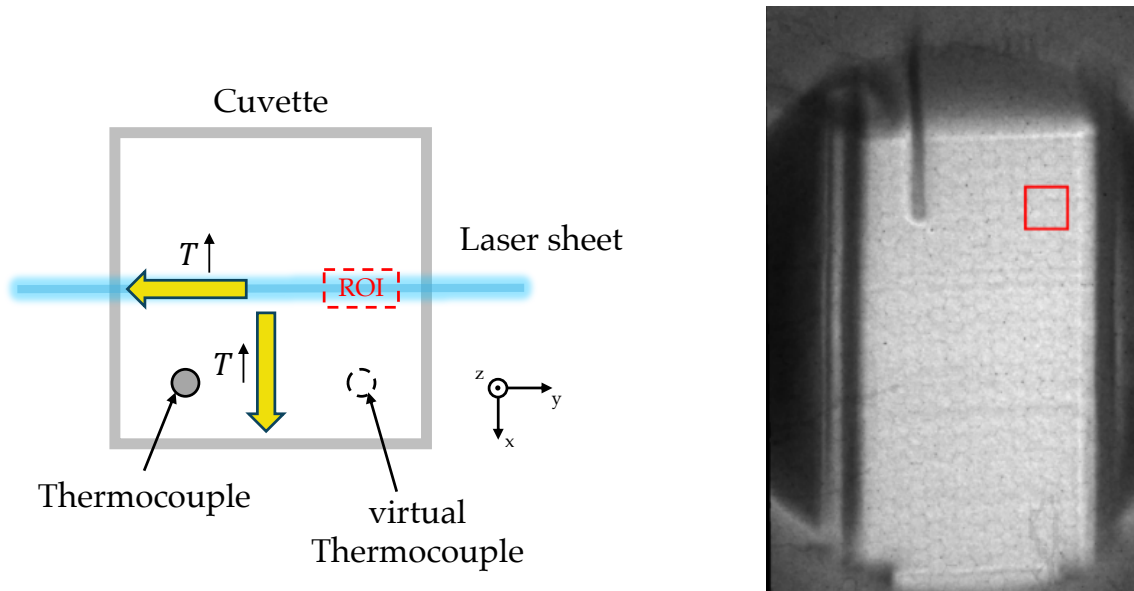


Figure. 3 Left: Top view of the cuvette with the position of the thermocouple, laser sheet and ROI.

Right: Example raw image of the camera channel with the ROI (100 x 100 pixels).

To reduce noise and mitigate the influence of the microchannel plate structure of the intensifier, a 3 x 3 median filter is applied to both image channels. The fluorescence signal ratio is then calculated on a pixel-by-pixel basis according to Eq. 2. To correct for the spectral sensitivity and efficiency of the optical system, the ratio images are normalized by a reference images (see Eq. 3). For this purpose, a frame recorded under supercritical conditions at $T = 600$ K is selected as the reference for each camera channel. Subsequently, the mean ratio within the ROI is determined for each of the frame. The normalized ratios are then average over the six individual experiments.

The spectra recorded with the spectrometer are also averaged and normalized across the various experiments at the measured temperatures. A spectrum for a given temperature, which was already averaged over five laser pulses during recording, comprises five spectra within that temperature range, so that the temperature spectra (in 10 K increments) each include 25 laser pulses or images.

3. Results and Discussion

In this section we present the results of the thermometry measurements of the isooctane/1-MN fuel-tracer mixture under transcritical conditions using the 2c-LIF technique. As described in the previous section, six individual experimental runs were performed and the data is averaged.

The averaged temperature curve for the cuvette temperature T_{Cuvette} is shown in Figure 4 (Left). After the heater is turned on (after 10 s), a rapid heating process of the fluid begins. In the range of the critical temperature of isooctane ($T_c = 543.9$ K) a plateau can be seen after that the temperature in the supercritical phase increases further again. Here, the slope of the curve continues to decrease and at maximum a temperature of 779 K ($T_r = 1.43$) is reached.

Figure 4 also shows the temperature-dependent fluorescence spectrum of the excited fuel-tracer mixture at a pressure of 3 MPa. These measurements serve as a qualitative supplement to the data from the camera images. The shape and position of the peaks in the spectrum correspond to the values from previous studies (Retzer et al. 2019, Lind et al. 2017). The spectra are shown only starting at a temperature of $T_{\text{Cuvette}} = 600$ K, since no acceptable signal-to-noise ratio was achieved for lower temperatures in the liquid phase. For the measurements above 600 K, the maximal averaged signal ranges between 90 and 175 counts. The diagram clearly shows the temperature-dependent shift toward higher wavelengths. At a normalized intensity of 0.5 (half maximum), the right edge of the spectrum shifts by 9 nm between 600 K and 780 K, which corresponds to a shift of 5 nm per 100 K. This is consistent with the values reported by Lind et al. (2017), who observed a red shift of 3–4 nm per 100 K. To illustrate the measurement principle of 2c-LIF, the filter ranges used in this work are plotted. Here, λ_1 corresponds to the range of the longpass filter starting at 355 nm, and λ_2 corresponds to the entire spectral range (including wavelength > 355 nm) of the longpass filter starting at 295 nm. It is also possible to calculate a LIF ratio from the spectrum integrals for these filters (not shown here). Furthermore, it should be noted that the field of view of the spectrometer collimator, which covers the center of the cuvette, does not exactly correspond to the region of interest used for the camera-based measurement.

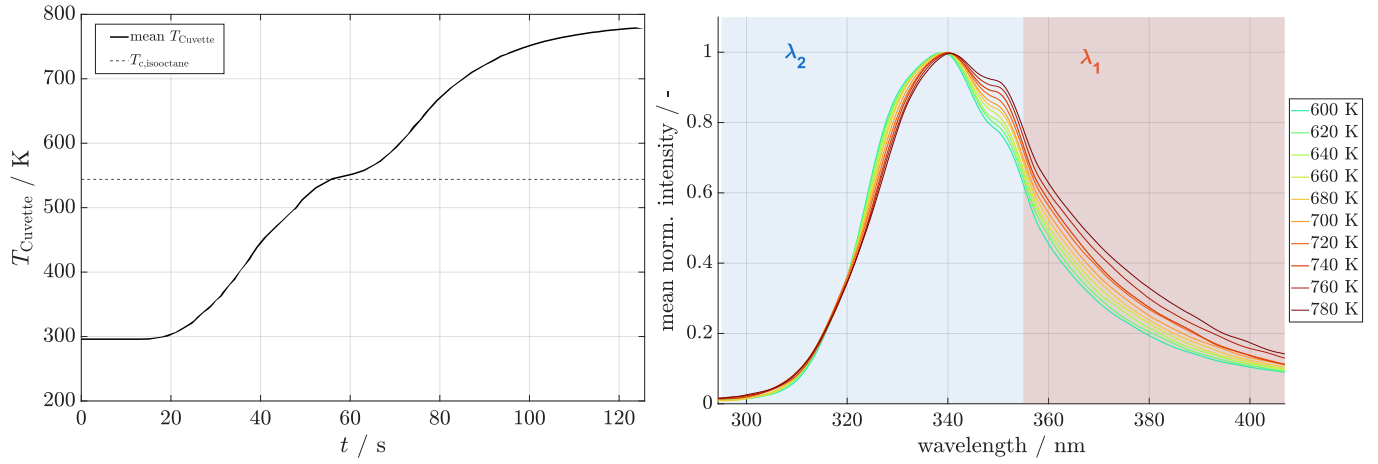


Figure. 4 Left: Mean T_{Cuvette} over time (heating starts at 10 s), $T_{\text{c, isooctane}} = 543.9 \text{ K}$;
 Right: Fluorescence spectra of 1-MN at 3 MPa at different T in the supercritical regime.

To analyze the temperature based on the LIF signal derived from the two camera signals, a ratio is calculated using Equation 3. This mean LIF signal ratio $S_{\text{ratio, norm}}$ is plotted against the temperature in the cuvette in Figure 5. As described, the signals from the different experiments are normalized using a reference image at $T_{\text{Cuvette}} = 600 \text{ K}$ before averaging. A vertical dotted line denotes the critical temperature of pure isooctane and the grey area encompasses one standard deviation resulting from the averaging over the six experiments.

Similar to the qualitative representation of the heating process shown in Figure 1, different regions can also be identified in the LIF signal ratio. Initially, the fluid is in the liquid phase with a clear phase boundary and expands as the temperature rises. $S_{\text{ratio, norm}}$ increases, rising sharply at first and then remaining at a plateau until approximately $T_{\text{Cuvette}} = 480 \text{ K}$.

At this stage, no distinct correlation between the increasing temperature and the LIF ratio can be identified. An examination of the individual channel signals, which are not shown here, reveals that their intensities reach only about 20 % to 60 % of the values observed in the supercritical regime. The reduced signal level in the liquid phase is attributed to strong absorption as well as changes in the fluorescence behavior. When considering the fluorescence signal recorded in the λ_2 (295 nm) channel, which covers nearly the entire emission spectrum, a pronounced signal is visible in the camera images only in the immediate edge region on the right side of the cuvette. As a result, the measurable signal remains comparatively weak within the ROI, although it was intentionally positioned slightly closer to the cuvette wall.

Within the temperature interval from $T_{\text{Cuvette}} = 480 \text{ K}$ to $T_{\text{Cuvette}} = 600 \text{ K}$, the signal ratio decreases rapidly, indicating the transition from the liquid state to the supercritical regime. In this range, the critical temperature of isooctane ($T_c = 543.9 \text{ K}$) is exceeded, which is accompanied by a pronounced reduction in density. The effects of nitrogen dilution and the fluorescent tracer 1-MN

on the critical point of the mixture are assumed to be negligible. This assumption is supported by previous measurements, which showed that the transition to supercritical conditions occurs close to the critical temperature of pure isooctane, as illustrated in Figure 1, frames D–H. Accordingly, the fluid inside the cuvette is treated here as pure isooctane with respect to its phase behavior. During the transition, the density change causes spatial inhomogeneities within the cuvette, which are also visible qualitatively in the shadowgraph images shown in Figure 1. These can be attributed to the vicinity of the critical point. For the fluorescence measurement, the decreasing density reduces laser absorption, allowing the excitation light sheet to penetrate deeper into the cuvette and to generate a stronger signal within the ROI in both detection channels. The LIF ratio reaches a minimum at $T_{\text{Cuvette}} = 600$ K at the end of the transition region, which is used as a reference value for signal normalization.

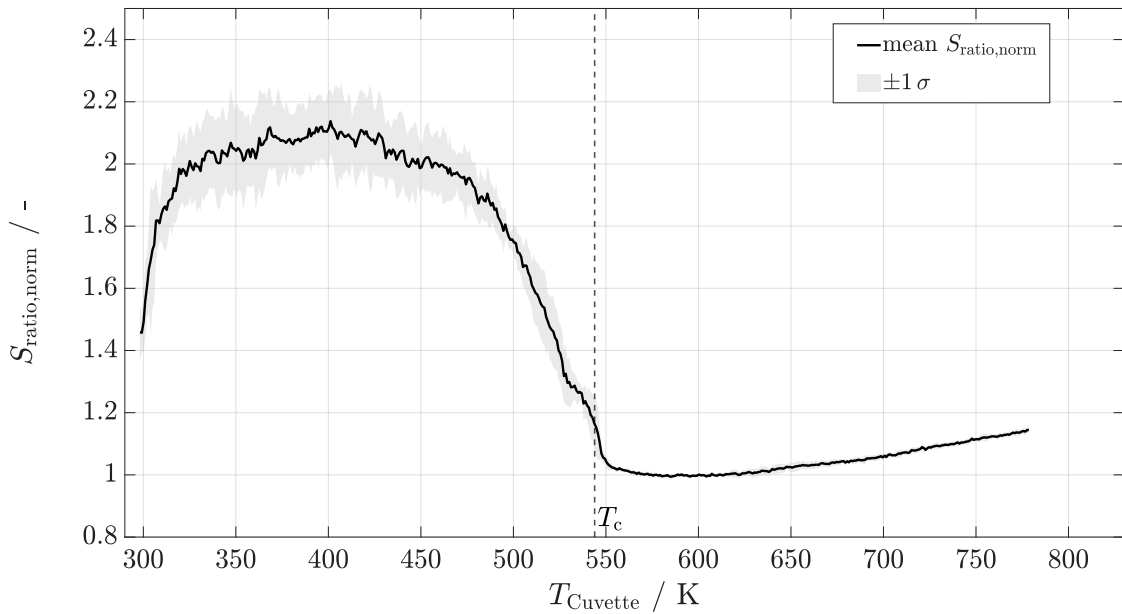


Figure. 5 Mean LIF-Signal ratio $S_{\text{ratio, norm}}$ over temperature inside the cuvette T_{Cuvette} . Standard deviation σ for the averaging over six experiments is marked in grey.

For the application of 2c-LIF in thermometry, the range starting at $T_{\text{Cuvette}} = 600$ K is of particular interest. In this range, a clear relationship can be observed between the increase in temperature and the rising LIF ratio. This trend, which increases monotonically on average up to a maximum temperature of 779 K, is used to calibrate the LIF signal. For this purpose, a quadratic fit is applied in this range. Using the inverse function of this fit, a relationship between temperature and the signal ratio $S_{\text{ratio, norm}}$ can be established.

The calibration curve exhibits an average slope of approximately 8 % per 100 K. In comparison, earlier measurements by Lind et al. (2017) reported a considerably higher value of about 20 % per 100 K within a similar temperature range. This deviation can be attributed to the different experimental conditions. In the study by Lind et al., the LIF measurements of 1-MN in isooctane were carried out in lean fuel-tracer mixtures diluted with nitrogen, using very low fuel and tracer concentrations. Although those experiments were performed at 1 MPa, only a weak pressure dependence was observed. Therefore, it is assumed that the photophysical behavior of 1-MN differs in pure isooctane compared with lean isooctane–nitrogen mixtures.

Figure 6 illustrates the calibrated relationship between temperature and signal ratio. The local temperature distribution within the ROI is shown for eight temperatures (T_{Cuvette}). The image at $T_{\text{Cuvette}} = 600$ K is homogeneous because it is used as a reference, which causes the structures to be lost. The temperature rise is clearly visible. In the range up to approximately 700 K, the signal ratio and therefore the temperature distribution is more homogeneous than at the highest temperatures. Particularly at $T_{\text{Cuvette}} = 775$ K, a clear temperature gradient from the right (i.e., near the wall) to the left toward the center of the cuvette can be observed. This distinct temperature gradient, especially at higher temperatures, could be explained by significantly altered heat transfer properties at the indirectly heated cuvette wall.

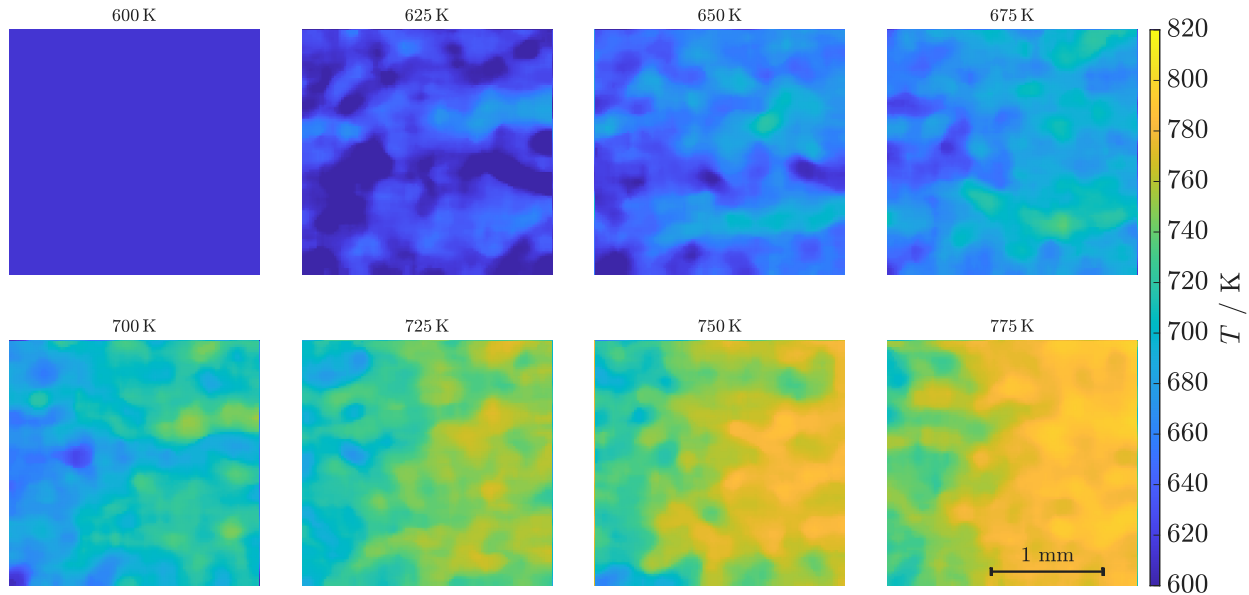


Figure. 6 Temperature signals in the ROI for different measured temperatures (T_{Cuvette})

A major limitation of the present approach is that the LIF thermometry method applied in this study is currently restricted to the supercritical regime of the pure fluid. Nevertheless, the corresponding calibration data in the pure fluid had not been available previously and therefore provide an important basis for further development. The calibration curve spans a temperature

range of approximately 180 K, while the present 2c-LIF measurement principle cannot be applied in the liquid phase and during the phase transition. Further investigations of the photophysical behavior of 1-MN are therefore required, particularly for very fuel-rich mixtures. In addition, a simultaneous determination of fuel density using the LIF technique would be necessary to clearly identify supercritical mixing conditions.

4. Conclusion and Outlook

In this study, the applicability of two-color laser-induced fluorescence (2c-LIF) using 1-MN as a tracer for thermometry in the supercritical regime of a model fuel is demonstrated. For the isooctane/1-MN mixture, a temperature-dependent calibration of the LIF signal ratio is established in the range from $T_{\text{Cuvette}} = 600 \text{ K}$ ($T_r = 1.10$) to $T_{\text{Cuvette}} = 779 \text{ K}$ ($T_r = 1.43$), yielding a sensitivity of approximately 8 % per 100 K. To the best of our knowledge, the presented LIF measurements are the first to be performed in this pure model fuel under transcritical conditions. The results further demonstrate that local temperature gradients can be resolved using the derived calibration function, providing a basis for extended spatial temperature analysis in future studies. However, the present measurements also reveal several limitations. A clear temperature-dependent behavior of the LIF signal ratio is only observed above a certain temperature within the supercritical regime. With the current setup configuration, a reliable calibration in the liquid phase cannot be established. This limitation is particularly relevant for future investigations of sprays and droplets, where liquid and supercritical regions may coexist. To apply the developed thermometry approach to two-phase flows, it will therefore be necessary to combine it with an additional diagnostic technique, such as Mie scattering, in order to distinguish the different phase regions and restrict temperature evaluation to the supercritical domain. Future work will focus on extending the method to other model fuels, such as n-heptane, as well as to fuel-rich mixtures diluted with ambient gases.

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