Investigation of laser induced phosphorescence properties of acetone

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Abstract An experimental investigation of the phosphorescence properties of liquid and vapour acetone is presented with the goal of introducing a novel technique for improved two-phase flow visualization. Commonly applied laser induced fluorescence (LIF) investigations of two-phase flows are challenging, in particular because of the large disparity in fluorescence intensity between the two phases and the ensuing effect of halation around the liquid droplets. The phosphorescence properties of liquid and gaseous acetone are utilized in order to decrease this disparity and acquire more quantitative images of the vapour phase surrounding the droplets. For this purpose, the phosphorescence lifetimes of acetone vapour in air and nitrogen bath gas, as well as those of liquid acetone was investigated. A 308nm XeCl excimer laser was used as the excitation source.

Acetone vapour in air does not emit phosphorescence due to strong oxygen quenching; however, in nitrogen, a slowly decaying signal with a lifetime of around 920ns is observed. Liquid acetone phosphorescence is strongly affected by self-quenching, as well as the amount of oxygen dissolved in it. The phosphorescence lifetime of liquid acetone that has been exposed to ambient air for a prolonged period of time is around 73ns. When, instead, liquid acetone is degassed (purged with nitrogen in order to remove any dissolved oxygen), its lifetime increases to 213ns. Introducing liquid acetone that has not been previously purged in a nitrogen atmosphere allows for the on-going diffusion of oxygen out of the liquid to be directly imaged. The phosphorescence intensity varies depending on the degree of oxygen diffusion out of the liquid and thus, a well-defined condition required for two-phase flow imaging is only achieved for the degassed liquid acetone in nitrogen case.

Direct comparison of the phosphorescence intensities of liquid and vapour acetone along with their respective decays has revealed the potential to optimize the disparity between the two signals for two-phase flow imaging. In order to examine the effectiveness of visualizing the phosphorescence rather the fluorescence, experiments with an acetone droplet stream were conducted in different environments. The phosphorescence images allow for the liquid-vapour interface to be accurately located and for the vapour phase to be clearly visible in contrast to standard LIF images, which show strong halation around the droplets resulting in both an apparent increase in the spatial extent of the droplets and an over-prediction of the vapour phase concentration near the interface.

1. Introduction

Laser diagnostics are well established powerful tools for experimental investigations of flow and combustion phenomena. Laser induced fluorescence (LIF) is the most commonly used technique for planar measurements of species concentrations, such as the intake air or the evaporated fuel in internal combustion engines (Löffler et al. 2010; Williams et al. 2010). The excited species can be either the evaporating liquid itself, or a co-evaporating tracer, for example acetone or 3-pentanone, which is added to a non-fluorescing parent fuel (Thurber and Hanson 2001; Rothamer et al. 2009). Acetone, in particular, has been widely employed due its low toxicity, broadband absorption in the UV and high vapour pressure, which allows for high seeding...
concentrations without the need for preheating. In two-phase flows, such as evaporating sprays, LIF can be used to visualize both vapour and liquid phases. Acetone is often employed in evaporating droplet stream or liquid jet experiments as its physical and spectral properties facilitate such studies (Bazile and Stepowski 1995; Connon et al. 1997).

Despite the fact that acetone fluorescence dependencies in flow properties such as temperature, pressure and composition are very well investigated (Thurber et al. 1998; Thurber and Hanson 1999; Braeuer et al. 2006), few data is available regarding the phosphorescence emission from its triplet state. Prior to discussing this data, it is essential to introduce the processes involved in the excitation-deexcitation mechanism of acetone (Schulz and Sick 2005). This is most clearly described by means of a Jablonski diagram (Fig. 1). The absorption of a photon leads to electronic excitation from the ground electronic state \( S_0 \) to the first excited singlet state \( S_1 \), attributed to the symmetry-forbidden \( \pi^* \leftarrow n \) transition; a non-bonding electron is transferred to a higher energy, anti-bonding orbital. Following excitation to \( S_1 \), the first excited triplet state \( T_1 \) is readily populated by a process called inter-system crossing. This process describes the transfer of population between states of different multiplicity and occurs with almost 100% efficiency for acetone. Alternatively, the excited molecule can emit fluorescence (radiative transition to a state of the same multiplicity) and return to \( S_0 \), vibrationally relax to a lower vibrational level, or decay non-radiatively by internal conversion which is, however, rather inefficient for acetone. From \( T_1 \), the molecule can vibrationally relax, decay radiatively to \( S_0 \) by emitting phosphorescence (radiative transition to a state of different multiplicity), or give up its energy to another molecule via collisionally-induced quenching (mainly self- quenching or oxygen quenching).

![Jablonski diagram](image)

**Figure 1.** Jablonski diagram illustrating the radiative and non-radiative processes in acetone following light absorption. Radiative processes are shown as straight lines and non-radiative processes as wavy lines

For an excitation wavelength of 313nm at near ambient conditions, the fluorescence quantum yield is only of the order of \( 10^{-3} \) (Heicklen 1959; Halpern and Ware 1971), suggesting that virtually all the excited molecules are transferred to \( T_1 \). The fluorescence lifetime is very short (around 4ns) and is at atmospheric pressures relatively unaffected by quenching. Instead, the phosphorescence from \( T_1 \) to \( S_0 \) is slow, due to violation of the spin selection rule, and strongly subjected to oxygen quenching. In a collisionless environment in the absence of oxygen, the phosphorescence lifetime of acetone vapour is around 200µs (Kaskan and Duncan 1950; Groh et al. 1953), compared to virtually no phosphorescence when oxygen is present. At ambient pressure, molecular collisions reduce the lifetime to several microseconds.

The phosphorescence properties of liquid acetone have been assessed by Seitzman and co-
workers (Ritchie and Seitzman 2004; Tran et al. 2005). They reported that removing any oxygen dissolved in liquid acetone can greatly increase the phosphorescence lifetime; for example, following excitation at 266nm, an increase from 175ns to nearly 1μs was observed. Slightly higher values were presented for 285nm excitation, suggesting that lower vibrational levels display higher phosphorescence efficiency. In addition, longer detection wavelengths were shown to display longer lifetimes suggesting that the phosphorescence spectrum shifts to the red with increasing delay from relative to the initial population of $T_1$. It should finally be noted that the short phosphorescence lifetime of liquid acetone compared to acetone vapour is attributed to self-quenching (Tran et al. 2006).

The aim of this study is to characterize and compare the emission decays of vapour and liquid acetone excited at 308nm, in air and nitrogen bath gases, in order to provide novel phosphorescence emission data for the purpose of two-phase flow imaging. These measurements reveal the potential for better visualizing acetone vapour in the presence of liquid droplets, by addressing two major shortcomings associated with two-phase flow acetone LIF; the extreme intensity disparity between the signals from the two phases that forces the vapour fluorescence to near noise levels, and the ensuing intense halation that obstructs the location of the liquid-vapour interface and introduces a significant error in the vapour phase measurement. Following a brief overview and a demonstration of the challenges associated with two-phase flow imaging using acetone, a series of emission decay measurements will be presented. The visualization of a droplet stream and its surrounding vapour will be used to demonstrate the advantages of monitoring the phosphorescence rather than the fluorescence.

### 2. Simultaneous vapour and liquid phase acetone laser induced fluorescence

A major challenge in visualizing the evaporated tracer by acetone LIF is that the liquid phase fluorescence is typically around two orders of magnitude stronger than the gas phase (Ritchie and Seitzman 2001). This is mainly attributed to the large number density disparity between the two phases. Since the commonly utilized intensified CCD cameras have a limited dynamic range, the experimental parameters must be adjusted so that the intense liquid phase signal does not saturate the detector. This, in turn, results to a vapour phase signal which is close to the noise level of the camera. An additional problem in discriminating between the two phases is intense halation. The very strong signal from the liquid introduces a crosstalk with the neighbouring pixels (which contain the weak vapour phase signal), and results in an apparent increase in the spatial extent of the liquid or in an over-prediction of the vapour phase concentration near the interface (Orain et al. 2005). It has been reported, for example, that reliable measurement of vapour concentrations is not feasible to within 1 droplet diameter for 235μm and 122μm droplets (Sahu 2011). For 230μm droplets, the extent of halation is of the order of 1-1.5 droplet diameters (Orain, Mercier et al. 2005). In tackling this issue, the practice of establishing a cut-off signal to distinguish between the vapour phase and the liquid phase plus halation signals has been introduced (Bazile and Stepowski 1995). Many researchers have adopted this method (Ammigan and Clack 2009; Hardalupas et al. 2010), most commonly by calibrating the saturated acetone vapour signal independently. The use of simultaneously acquired Mie scattering images from ethanol droplets in order to obtain the radial profile of halation has also been proposed (Orain, Mercier et al. 2005).

An alternative method for determining the location of the liquid-vapour interface of acetone droplets in air was proposed by Seitzman and co-workers (Ritchie and Seitzman 2004; Tran, Kochar et al. 2005), based on simultaneous phosphorescence and fluorescence imaging of acetone. The combined technique utilizes the phosphorescence signal from liquid acetone to locate the boundaries of the liquid phase and the fluorescence signal from the vapour phase to measure the concentration. Since even trace amounts of oxygen can quench the vapour phase phosphorescence very effectively, the liquid phosphorescence measurement provides an “uncontaminated” liquid
phase signal. However, this technique was never demonstrated in two-phase flows and moreover, the problems associated with the vapour phase concentration measurement, namely the low signal intensity and halation contamination would remain unresolved.

In order to demonstrate the aforementioned effects of halation and large signal disparity between the two phases, fluorescence images of an acetone droplet stream in saturated acetone vapour in air are presented in Fig. 2. For comparison, the droplet stream was also imaged using diffuse white light illumination from the background, (Fig. 2a). Fig. 2b shows a fluorescence image of the droplet stream where only the droplets are visible because of the weak vapour fluorescence. The same image is presented in Fig. 2b with a different dynamic range that allows both vapour phase and halation to be visible.

![Images](a) (b) (c)

**Figure 2.** Results from a stream of acetone droplets in saturated acetone vapour in nitrogen. (a) White light image of a droplet stream under diffuse background illumination. (b) Fluorescence image of the stream with 0-1000 counts dynamic range (c) The same fluorescence image presented with 0-100 counts dynamic range.

The challenges induced by halation in determining the location of the liquid-vapour interface and the evaporated tracer concentration near the droplets are evident in Figure 2c. The droplets appear to be approximately 1.5 times larger than in the other two images (500μm instead of 330μm), whilst the vapour regions surrounding the droplets appear brighter, suggesting locally higher acetone vapour concentrations. However, since the images are obtained in a saturated acetone vapour environment the vapour concentration is constant, and this apparent increase is purely an artefact attributed to halation. The “shadow” region to the right of the droplets where most of the laser beam has been absorbed by the liquid acetone is affected in a similar manner, with a brighter region extending to approximately a droplet diameter away from the droplet. The real fluorescence from the acetone vapour can be clearly seen farther away from the droplets. In order to solve these problems, the following experiments are set up.

### 3. Experimental setup

Two sets of experimental measurements will be presented; the emission decay curves of liquid and vapour acetone in air and nitrogen, and a comparative evaluation of fluorescence and phosphorescence images of a droplet stream and the surrounding vapour. The experimental setup employed in both studies is presented in Fig. 3. A Radiant Dyes XeCl excimer (308nm) was used for excitation. The acetone was investigated in a flow cell equipped with three windows for optical access. Fluorescence and phosphorescence images were collected using a CCD camera (LaVision Imager Intense) attached to an intensifier with an S20 multi-alkali photocathode and a fast P43 phosphor screen, and equipped with an 85mm f/1.4D IF Nikkor lens. Three neutral density filters,
of 20% (OD 0.7), 1% (OD 2.0) and 0.1% transmittance (OD 3.0) were used to prevent saturation of the collected signal when necessary. The camera lens prevents the collection of UV light and hence, no additional filter was used to block any scattering of the excitation pulse. A beam sampler was placed at 45° to the plane of propagation of the laser sheet, directing 10% of the excitation energy to a pyroelectric energy sensor (ES245C from Thorlabs) connected to a power meter (PM100D from Thorlabs). Pulse energies were recorded for all collected images. An f=500mm plano-convex lens was used to focus the laser sheet down to a thickness of 350μm. A custom-made droplet generator equipped with a piezo-electric oscillator was set up on top of the cell. The droplet generator electronics are comprised of a Thurby Thandar Instruments TG210 function generator and an amplifier allowing for different frequency signals to be applied to the piezoelectric crystal with adjustable intensity. Depending on the acetone flow rate to the droplet generator and the input signal frequency, droplet streams of different droplet sizes and different inter-droplet separations can be obtained. The droplet generator was supplied with liquid acetone via a PTFE line from a pressure vessel, where bulk acetone was slightly pressurized with nitrogen (0.5 bar). Four gas lines were used for purging the cell with nitrogen, saturated acetone vapour in air or saturated acetone vapour in nitrogen. The acetone vapour was supplied from a seeder purged with nitrogen. When purging the cell, approximately 5 minutes were allowed for the cell to fill with the respective gas.

Figure 3. Optical setup used throughout the emission decay and droplet stream imaging experiments

When conducting the liquid phosphorescence decay measurements, a smooth continuous stream rather than a droplet stream was set up by switching off the piezo control electronics (frequency generator and amplifier) and adjusting the nitrogen pressure to the vessel. The initially used setup employing a quartz cuvette filled with liquid acetone was abandoned due to the presence of an intense background signal emanating from the cuvette itself. Ritchie and Seitzman (Ritchie and Seitzman 2004) reported this particular issue as well, when obtaining an unrealistic estimation of the liquid phase phosphorescence lifetime of 39.5μs. Therefore, great care was taken in isolating the phosphorescence signals by checking the background signal intensity when collecting images. Two pinholes of 600μm and 200μm diameter were used, the former in the emission decay experiments and the latter in the droplet stream experiments.
4. Results and discussion

4.1 Emission decay measurements

The emission decay of acetone vapour in air and nitrogen was examined by purging the fluorescence cell with the respective gases and imaging the emission over a 3000ns range. The excitation energy was set to 35mJ per pulse, and the detection delay was varied from 0ns to 2900ns after the start of fluorescence emission. The IRO gate and gain were set to 200ns and 70%, necessitating the use of an OD 2.0 neutral density filter for the fluorescence measurements. The first set of phosphorescence images was collected at a delay of 200ns after the start of fluorescence emission, in order to ensure the fluorescence signal would not affect the phosphorescence measurements through electronic jitter. The rest of the phosphorescence measurements were performed in 100ns steps throughout the examined delay range. Each data point on the decay curves of Fig. 4 corresponds to a 50 image average of a 350x200 pixel region of interest. All data points were normalized to the fluorescence intensity, and their position on the plot relative to the x-axis corresponds to the IRO delay setting plus half of the gate time.

In examining the emission decay of liquid acetone, three different cases were considered; a liquid acetone stream in air, a previously degassed liquid acetone stream in nitrogen and a liquid acetone stream in nitrogen (Fig. 5). The reason for conducting three different emission decay measurements is that the phosphorescence intensity and phosphorescence lifetime of liquid acetone have been shown to increase as a result of the removal of dissolved oxygen from the liquid. In this study, acetone degassing was performed by repeatedly bubbling nitrogen through the bulk acetone supply vessel via a pipe equipped with a sintered end cap. In the case of liquid acetone in nitrogen, the diffusion of oxygen out of the liquid is ongoing within the imaging region and, as will be shown later on, cause a noticeable variation in phosphorescence intensity along the stream. Despite the fact that for the purposes of two-phase flow imaging the conditions of the particular experimental case are not very well defined, the obtained direct imaging evidence of the effect of oxygen diffusion out of the liquid stream is considered worth presenting.

The emission decay measurements were performed by setting up a 600μm stream and collecting images in 100ns steps using 70% intensifier gain. For the degassed liquid acetone in nitrogen case, data were collected in 200ns steps since the decay time is substantially longer. As before, each data point on the decay curves corresponds to a 50 image average, and its position on the plot relative to the x-axis corresponds to the IRO delay setting plus half of the gate time. A 200ns exposure time starting 100ns before the laser pulse was used to collect the prompt fluorescence signals. The first phosphorescence measurement was set to 200ns delay as before. The gate time for all phosphorescence measurements was 200ns. An OD 3.0 and an OD 0.7 grey filter was used for the collection of all fluorescence images, while an OD 0.7 filter alone was used for the collection of 200ns delay images (liquid acetone in nitrogen and degassed liquid acetone in nitrogen), as well as 400ns delay images (degassed liquid acetone in nitrogen). All liquid phase measurements were performed using the same energy (35mJ).

4.2 Acetone vapour emission decay

The normalized acetone vapour in air and acetone vapour in nitrogen emission decay curves are presented in Fig. 4. The measured fluorescence intensities agree to within 2%, an outcome that fits the theoretical description of vapour acetone deexcitation presented in the introduction. For acetone vapour in air, the signal collected at 200ns delay is more than 3 orders of magnitude lower than the prompt fluorescence signal and any phosphorescence was too weak to be detected, an effect attributed to very effective oxygen quenching of the triplet emission. In contrast, the early phosphorescence signal intensity of acetone vapour in nitrogen is approximately two
orders of magnitude lower than the prompt fluorescence signal, and drops one order of magnitude over the next 3μs. Both results agree well with recent data published for acetone vapour in nitrogen excited at 320nm (Weckenmann et al. 2011).

Figure 4. Normalized vapour acetone emission decay in nitrogen and air

As it has already been noted, vapour acetone phosphorescence decays exponentially when measured in a molecular beam (collision-free environment) with a lifetime of 200μs. At ambient conditions, however, where molecular collisions are frequent, the phosphorescence spectrum shifts to longer wavelengths with increasing detection delay (Tran et al. 2005). This trend is attributed to phosphorescence emission from lower vibrational levels populated by vibrational relaxation. Vibrational relaxation occurs more readily for liquid acetone than for vapour, suggesting that the particular effect could be even more pronounced for the latter. The phosphorescence decay of acetone vapour in nitrogen is consequently expected to be comprised of a series of exponential components corresponding to deexcitation from different vibrational levels with different lifetimes. Hence, it is not practical to fit a single exponential function to the entire data range. For the purposes of this study, however, the range of interest is confined to the first few microseconds of the decay, where the phosphorescence is more intense and the obtained signals are useful for imaging purposes. A single exponential can be fitted to this range with a lifetime of 920ns.

4.3. Liquid acetone emission decay

Normalized emission decay curves for liquid acetone in air and nitrogen and degassed liquid acetone in nitrogen are presented in Fig. 5; for comparison, the vapour phase emission decay in nitrogen is also included. All data points are normalized to the prompt fluorescence intensity of degassed liquid acetone in nitrogen. The intensity of acetone vapour fluorescence in nitrogen is two orders of magnitude lower than that of liquid acetone in air, and, as noted before, almost identical to the fluorescence of acetone vapour in air. Liquid acetone fluorescence, however, increases substantially when any dissolved oxygen is removed; the intensity of liquid acetone fluorescence in air corresponds to approximately half of the fluorescence emitted by the degassed liquid acetone. This effect is most probably attributed to fast quenching by the dissolved oxygen, as a result of the high frequency of molecular collisions. At 300ns after the start of fluorescence emission, the intensity of liquid acetone phosphorescence in air is only 2.7 times higher than the vapour in nitrogen, whilst 100ns later, the vapour phosphorescence is already more intense. The degassed liquid acetone phosphorescence remains higher for the entire range, however, the liquid to vapour...
emission intensity ratio drops from around 100 for the fluorescence over 16 at 200ns delay to only 3.2 at 1μs delay. The liquid acetone in nitrogen decay falls between these two cases, however as mentioned above this case is not a very well defined experimental condition since the oxygen content of the liquid changes.

Figure 5. Normalized degassed liquid acetone in nitrogen, non-degassed liquid acetone in nitrogen, liquid acetone in air and vapour acetone in nitrogen emission decay curves

The phosphorescence lifetime of liquid acetone in air is 73ns, and that of degassed liquid acetone in nitrogen is 214ns; a threefold increase over the non-degassed case. Longer degassing could result in slightly longer lifetimes; however, the phosphorescence intensity along the degassed stream in the experiments for Fig. 6 is reasonably constant, suggesting that the liquid is nearly depleted of all oxygen. This is clearly not the case for non-degassed liquid acetone in nitrogen, where the effect of oxygen diffusion out of the stream can be clearly visualized in the phosphorescence images. The removal of any dissolved oxygen along the stream at a given exposure time results in an increase in phosphorescence intensity the further the stream travels inside the cell. In order to demonstrate this effect, two average images are presented (Fig. 6), one showing the phosphorescence of a stream of liquid acetone in air and the other in nitrogen. Both images were acquired at 300ns delay after the start of fluorescence emission with 200ns gate, and corrected for laser sheet inhomogeneities.

Figure 6. Phosphorescence images from a liquid acetone stream at 300ns delay (a) in air and (b) in nitrogen

Close inspection of the liquid acetone in air phosphorescence image reveals that the
emission intensity distribution along the stream is fairly constant. The average intensity is 231 counts/pixel. In comparison, the emission intensity of liquid acetone in nitrogen already starts off at a higher value (since the imaged area is some distance downstream of the droplet generator pinhole) and increases all the way to the bottom of the image. The average intensity rises to 413 counts/pixel.

5. Two-phase flow acetone laser induced phosphorescence

For the purposes of two-phase flow imaging using acetone phosphorescence, the use of degassed liquid acetone in a nitrogen atmosphere is considered to be the optimal choice; the signal disparity between the two phases is large enough to clearly identify the liquid/vapour interface but small enough to prevent the emergence of any halation. Also, the boundary conditions for this case are well defined as no change in oxygen concentration is occurring anywhere in the experiment and so the lifetimes of liquid and vapour acetone are constant. In order to demonstrate the improvements of this technique for two-phase flow visualization, two cases are examined. Firstly, a droplet stream (330μm average droplet diameter) is set up in a saturated acetone vapour environment. The fluorescence is initially collected and the same instantaneous image is presented in Fig. 7 with two dynamic ranges (0-1000 counts and 0-100 counts) as the intense halation and large signal disparity between the two phases prevent the saturated vapour and real droplet sizes to be shown simultaneously. Phosphorescence is collected over 400ns, starting off at 300ns after the fluorescence, with a gain of 70%. In this case a single dynamic range suffices as the signal disparity is sufficiently reduced and no halation is observed. The excitation energy is 45mJ. Both fluorescence and phosphorescence images have been background-subtracted and corrected for laser sheet inhomogeneities and dark noise. For comparison we show a white light image with diffuse background illumination, indicating their real sizes and inter-droplet distances.

![Figure 7](image_url)

**Figure 7.** Results from a non-evaporating stream of acetone droplets in saturated acetone vapour in nitrogen (a) White light image of a droplet stream under diffuse background illumination. (b) Fluorescence image of the stream with 0-1000 counts dynamic range (c) The same fluorescence image presented with 0-100 counts dynamic range (d) Phosphorescence image of the droplet stream

The adverse effects of halation have already been discussed in Sec. 2; an apparent increase in vapour phase concentration around the droplets is observed, along with an increase in the spatial extent of the droplets by at least 50% (Fig. 7(c)). When increasing the dynamic range, the glow around the droplets subsides, but the vapour phase is now completely indiscernible due to the low fluorescence intensity (Fig. 7(b)). Instead, when monitoring the phosphorescence, no halation around the droplets is observed and the saturated vapour is clearly visible and discernible from the liquid (Fig. 7(d)). The droplets sizes also match those of the shadow image (Fig. 7(a)). The liquid
phase intensities range between 1000 and 2000 counts for both fluorescence and phosphorescence images, whilst the vapour phase fluorescence to the left of the stream has average intensity of 19 counts and the phosphorescence an average intensity of 420 counts.

The two imaging techniques are also compared under conditions more relevant to two-phase flow investigations. In Fig. 8, fluorescence and phosphoresce images of a free-falling monodisperse droplet stream in pure nitrogen bath gas are presented. The same excitation energy, collection optics settings and dynamic ranges as for Fig. 7 are used.

![Figure 8](image)

**Figure 8.** Results from a stream of evaporating acetone droplets in pure nitrogen (a) White light image of a droplet stream under diffuse background illumination (b) Fluorescence image of the stream with 0-1000 counts dynamic range (c) The same fluorescence image presented with 0-100 counts dynamic range. (d) Phosphorescence image of the droplet stream

It is clearly impossible to evaluate the vapour phase signal from the fluorescence image (Fig. 8(c)) as the majority of the evaporated tracer lies within the spatial extent of halation. In contrast when monitoring the phosphorescence, a vapour cloud forming around the droplet stream can be clearly observed.

### 6. Conclusions

Two-phase flow visualization using acetone fluorescence has been shown to present two significant challenges; the large intensity disparity between the two phases that forces the vapour phase signal to near noise levels, and the ensuing effect of halation around the liquid droplets. For the purpose of improving two-phase flow imaging, a strategy using the phosphorescence emissions of acetone, rather than the fluorescence emissions is presented. Phosphorescence lifetime data is collected by examining the emission decays of vapour and liquid acetone at different boundary conditions, following excitation at 308nm. In air, the decay of liquid acetone phosphorescence was shown to be extremely fast (73ns) due to the presence of dissolved oxygen in the liquid. By purging liquid acetone with nitrogen, the effect of oxygen quenching was reduced, and the lifetime in a nitrogen atmosphere was increased to 213ns. Care must be taken when non-degassed acetone is used in air bath gas since the oxygen diffusing into the liquid changes the liquid lifetime.

The phosphorescence from acetone vapour in air is completely quenched by oxygen. In nitrogen, however, the vapour phosphorescence signal falls relatively slowly (radiative lifetime of 920ns). Since the phosphorescence intensities of liquid and vapour acetone are much more similar than the fluorescence intensities, and additionally the vapour phosphorescence decays slower, much better quality images of two-phase flows can be obtained. In order to demonstrate the advantages of this strategy, two experiments were performed. A non-evaporating droplet stream in saturated
acetone vapour in nitrogen was investigated as well as a stream of droplets in pure nitrogen where the droplets evaporate. These experiments clearly show that using the phosphorescence, both effects, the disparity of the liquid and vapour phase intensities as well as the halation disappear and the liquid-vapour interface can be clearly recognised.

References


