

Advanced Measurement Techniques in Fluid Mechanics and Heat Transfer

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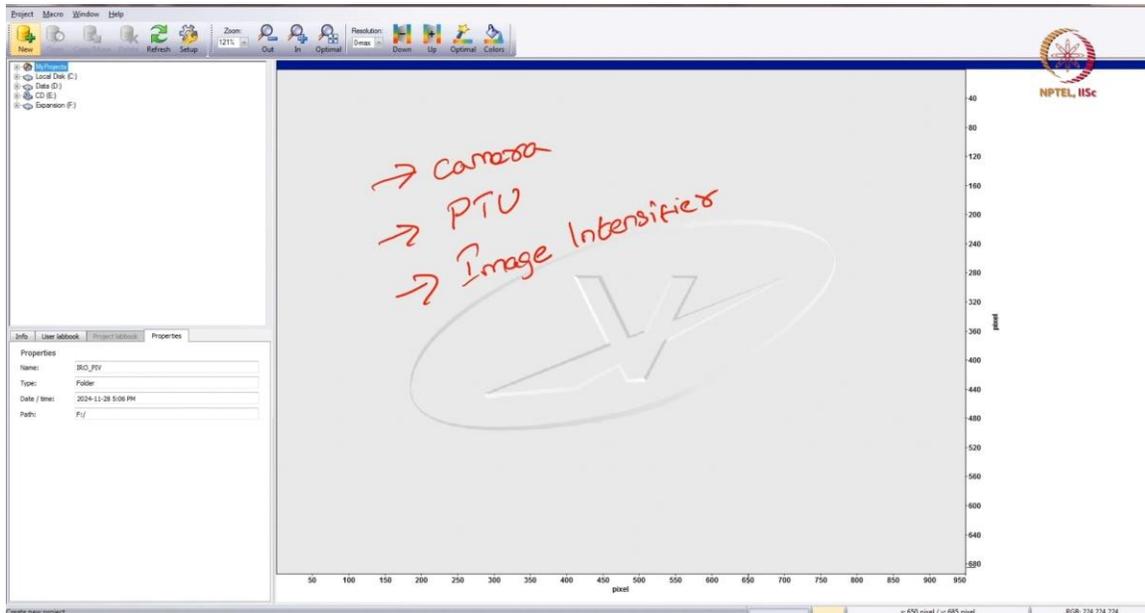
Indian Institute of Science, Bengaluru

Week – 11

Lecture - 52

Chemiluminescence Measurements – 2

Welcome to this session. In this session, we will be exploring the calibration process in Davis software and learning how to record flame images effectively. We will also briefly explain the importance of various components used during this process and analyze their impact on the resulting images by the end of this session. You will have a comprehensive understanding of how calibration works and how each component contributes to capturing high-quality and meaningful data for recording the high-speed chemiluminescence images. We are going to use the Davis software, so when you open the Davis software, This is how it looks initially. First, we need to add all the important components to the software.

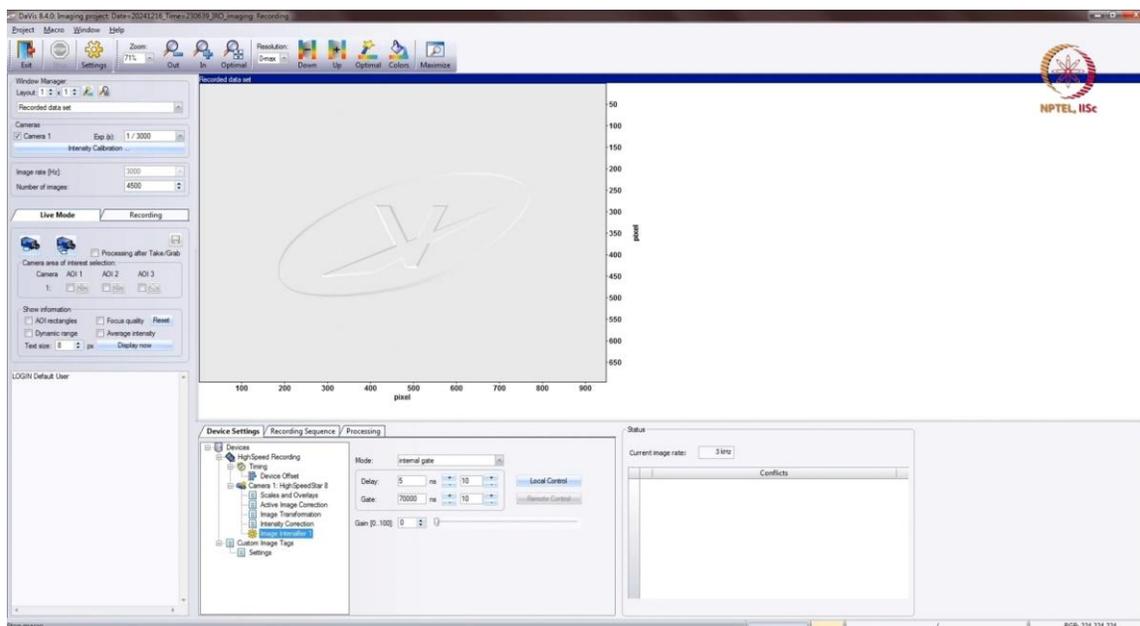


So, the key components are a camera, a PTU, and an image intensifier, which is nothing but IRO. As a first step, we need to click on this setup icon that I am highlighting here. Once you click on the setup icon, the device list will appear to be empty. Here, we will be adding all the components necessary for our experimental demonstration.

To do that, click on the add symbol as I'm pointing out here. Once you press the add symbol, you will see an Add Device window. So, a predefined list of components within the software will appear in this "Add Device" window. For our demonstration, we need to add a camera, a PTU, and an image intensifier. So we have to add them one by one and then click OK.

Once we added all the required components, the interface looked like this. Next, we need to select the devices icon and then press the initialize symbol. This step allows the software to detect all the components for controlling each of them from the software itself. After pressing the initialization symbol, we can verify whether the software has detected all the components or not. If everything shows "OK," as shown here.

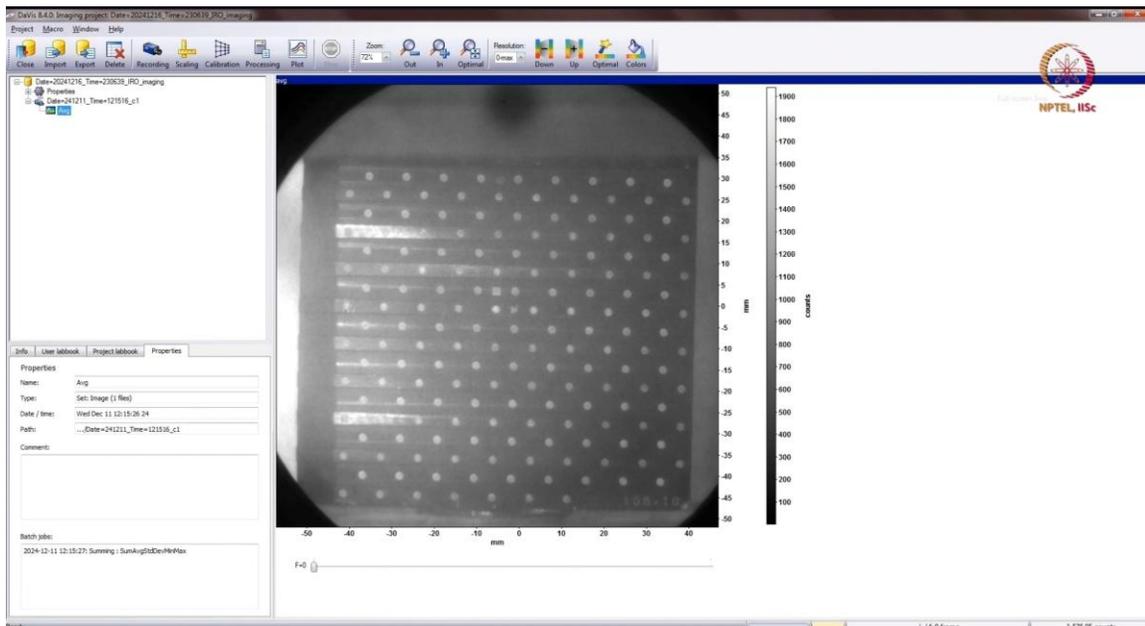
We are good to proceed. Finally, press "Exit" to complete the initialization setup. Now, let's record the calibration plate that is already positioned in the center of the combustor. To start recording the calibration plate, we need to create a new project in the Davis software. For this reason, we have to press this new icon as I am showing it here.



Once we click the new icon, you will be prompted to select the type of project. Since we are going to record only OH Chemiluminescence imaging, select imaging under the type of project and then press OK. Once we click OK, we will be taken to the imaging project workspace. This is where all of our recorded files will be stored. Next, click on the recording icon to enter the adjustment window for the camera and IRO.

Here we can fine-tune the settings for the camera and the image intensifier, as shown here. The exposure time of the camera can be adjusted based on the respective lighting conditions for individual experiments. Since we are recording the calibration plate, we can set the exposure slightly higher as it is a static object, and here we can change the number of images that are supposed to be recorded for individual cases. You can also modify the image rate of the camera by selecting the timing option. Which is measured in frames per second, and here it is shown as kilohertz to allow the camera to capture more light.

You can reduce this frame rate; lowering the frame rate increases the exposure time for each frame, which enhances the visibility of low-intensity signals. Additionally, we can adjust the intensifier settings to clearly visualize the calibration plate. To brief the settings inside the intensifier, gain is nothing but a multiplier of the incident light signal, and gate is nothing but the exposure time for the IRO. Once both of these options are adjusted for better visualization of the calibration plate, press the recording tab to access the recording option. Once everything is configured properly for capturing the calibration images, press "Record" in the recording tab.

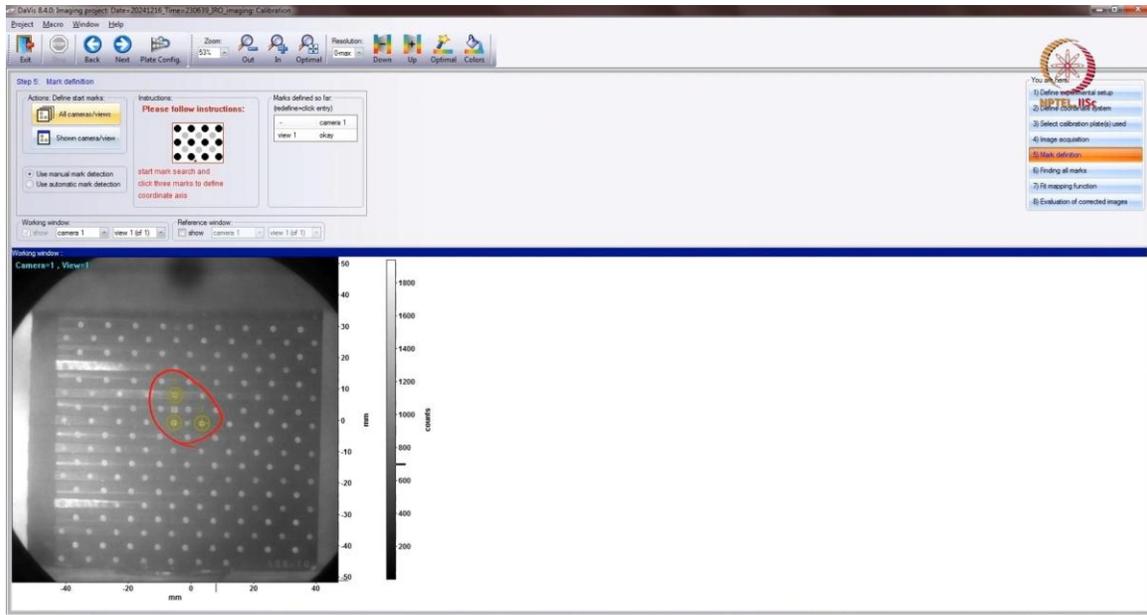


After completing the recording for the predefined number of images set to the camera by the software, we can save the file by clicking the save icon, and once it is saved, press the exit option. Once we exit the recording window, we can see the recorded calibration plate

file that is added to our project folder in the Davis software. Now that we have taken the calibration image, let's apply the calibration to the upcoming image recordings. For this reason, we need to open the same project which the calibration plate was once saved; once it is opened, locate this calibration icon and click on it. Here we see multiple types of calibration in this window; for our demonstration purposes, we have used only one camera.

A single coordinate system; once you enable the option, press next. Next, you will see a list of calibration plates. From this particular drop-down menu, choose the one you are currently using for your experiment. This allows the software to know the predefined dimensions. Of the calibration plate for references, as shown earlier, the calibration plate contains equidistant dots that are already encoded in the particular 106-10 calibration plate chosen in this window.

Now we need to import the recorded calibration plate image for comparison with the already predefined dimensions in the software. For that, click the file icon to locate the saved file of the calibration plate. Once you locate it, select that particular file and then press open.



You will now see the loaded calibration plate image displayed on your screen. Once you are sure about the proper calibration image, press the next option.

Next, we need to define the origin of the image field by marking three key positions, which are $0, 0$, $x, 0$ and $0, y$. To do this, click on all camera/views. For demonstration purposes, I will mark the center of the calibration plate, but you can choose any convenient positions. Once the points are properly marked on the dots, we can press next.

Here, press the start search option. The software will now search for the locations of the remaining dots on the calibration plate. This step is crucial as the software uses the predefined dot distances and positions to detect the alignment of the camera and the focal plane. Once the software searches all the pixels in the calibration plate image, you will notice that the software successfully detects almost all the dots on the calibration plate. Once you confirm that, you can click "Next.

" Now, press the start calibration option. Once the calibration process is finished, press exit. Now that the calibration process is complete, we can remove the calibration plate from the combustor and prepare it for the combustion experiment. Now we will conduct a series of experiments to explore the significance of key components such as IRO, bandpass filter, and high-speed camera. To demonstrate their importance, we will showcase a sequence of experimental videos featuring different combinations of these components.

Let's begin with regular DSLR imaging. This setup captures all the signals emitted from the FLIM. This also includes the entire visible range of the chemiluminescence signals. While this provides a comprehensive view of the flame, our primary focus is on capturing a specific chemiluminescence signal, particularly OH and CH star signals. These signals are critical for understanding the combustion process.

DSLR video



DSLR Image

→ Visible range

→ OH^* & CH^*

→ Oscillations

→ 60 FPS X

→ loss of critical details

High-Speed Imaging

Another important thing we can observe from the flame is that it exhibits significant oscillations, which makes it more dynamic in nature. However, with this DSLR operating at a frame rate of 60 frames per second, it becomes evident that this speed is insufficient to fully capture the intricate dynamics of the flame. This limited frame rate results in the loss of critical details, especially in fast-changing phenomena. This highlights the need for high-speed imaging. Now let's navigate back to the recording option in the Davis software to access the recording window for the next stage of experiments.

Unlike the calibration plate, which is static and predictable in nature, the flame is highly dynamic. This means we need to adjust the camera settings to capture these fast-changing phenomena accurately. Specifically, we will use a lower exposure time or higher frame rates for these experiments. The camera is set at a constant frame rate of three kilohertz this means the camera can capture 3000 frames per second this enables us to observe even the most rapid changes in the flame behavior for this demonstration purpose we will record around 100 images for each experimental conditions.



- stable
 - Flame is highly dynamic
 - lower exposure (or) ↑ FPS
 - 3kHz → 3000 frame per second.
 - Record → 100 images
- (i) without IRO & filter
(ii) without IRO & with filter
(iii) with IRO & without filter
(iv) with IRO & with filter.

In this session, we will also perform a series of experiments under the following configurations. That is, without the IRO and bandpass filter. Second, without IRO but with a bandpass filter. Third is with IRO but without a bandpass filter.

And finally, with IRO. And with a bandpass filter, these series of experiments will help us understand the importance of each component for recording the chemiluminescence signal. Now let's begin with the recording setup without IRO and without a bandpass filter. This means there is no filter attached in front of the UV lens. In this configuration, the recorded video of the flame displays signals similar to those captured by the DSLR images. However, you will notice a significant reduction in signal intensity.

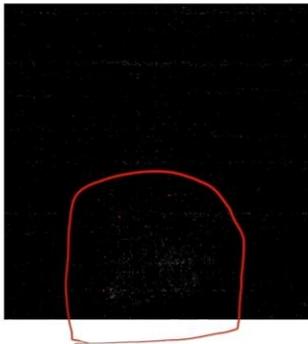
This decrease in intensity occurs because we have increased the camera's frame rates. This allows capturing more frames per second. Even though this helps in capturing the dynamic behavior of the flame more precisely, this higher frame rate results in shorter exposure times. thereby reducing the amount of light that goes into the camera, and this intensity of the flame is on par with the noise level of the image. So it is hard to distinguish between background noise and the flame signals.

Now, for the second test, we will introduce a bandpass filter while still excluding the IRO. By using this bandpass filter, we allow only signals with a specific wavelength range to pass through the UV lens. In this case, we are using a 310 nanometer wavelength. Specifically isolate the OH star chemiluminescence signals; however, as you can see in the video, the results are completely dark. This aligns with our earlier

observation that, without a bandpass filter and without an IRO, in general, the intensity of the OH signals.



Without IRO and without a band-pass filter



No filters \rightarrow UV lens.

\downarrow signal intensity

\uparrow camera FPS

\Downarrow

\downarrow Exposure time



Without IRO but with a band-pass filter



\rightarrow 310 nm

\rightarrow OH* signals

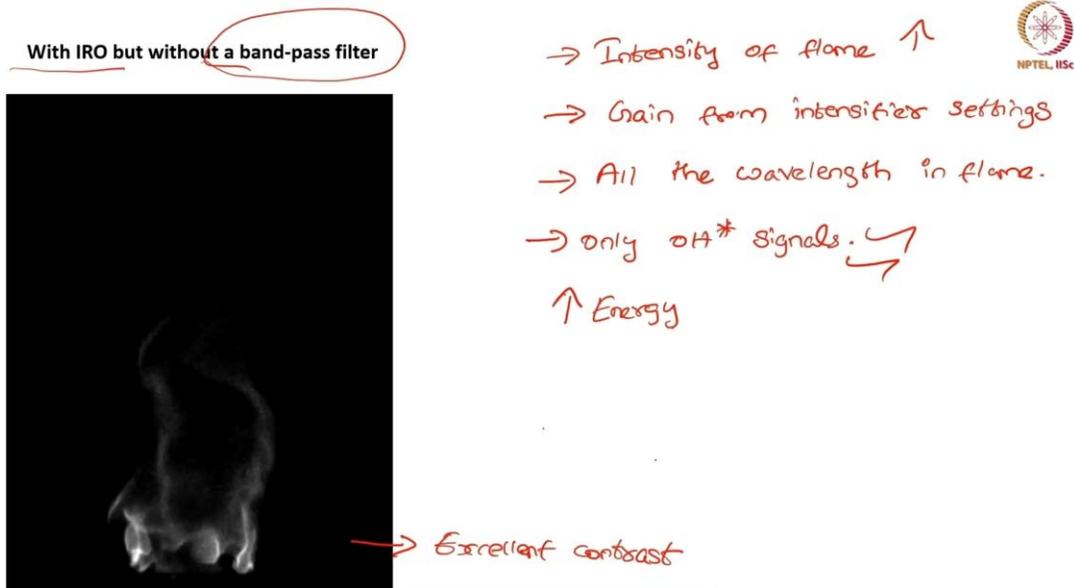
OH* \downarrow

$\downarrow \downarrow \downarrow$

\rightarrow dark

The signal from the flame is inherently very low and cannot be effectively captured without a signal amplifier. By adding the bandpass filter, we have further reduced the already faint signal, allowing only a narrow band of wavelengths to pass through the UV lens. This demonstrates the challenges of capturing specific chemiluminescence signals and highlights the necessity of components like IRO to amplify these low-intensity

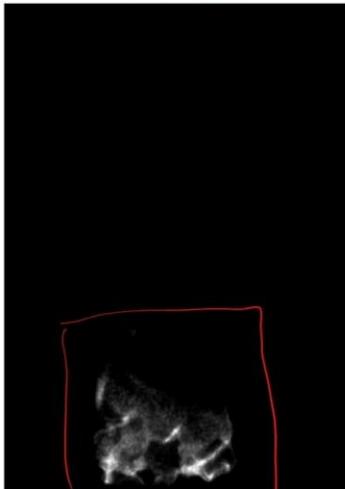
emissions. Here in this experiment, we have used IRO, but without a bandpass filter. In this setup, we can clearly see the flame with excellent contrast compared to the earlier experiments.



This is completely similar to the DSLR video that we captured earlier. The key difference here is that the intensity of the flame is significantly higher. This is possible because we have slightly increased the gain from the intensifier's settings. However, these images still contain all the wavelengths present in the film, but for our specific requirement, we need only OH star chemiluminescence signals. As we discussed in the theory session, signals in the UV range, like OH chemiluminescence, carry a higher energy compared to those in the visible range.

This is why we focus on capturing the OH signals from the flame, and these signals are directly proportional to the local heat release rate of the film. By isolating and analyzing these signals, we can gain valuable insights into the combustion processes, and we can also understand the dynamics of the flame as a final experiment we have performed. Flame chemiluminescence imaging with IRO and a bandpass filter. For this setup, we have configured the IRO with proper gain and gate values according to our flame intensity. As we have used a bandpass filter of 310 nanometer wavelength, we can surely tell that the filter allowed only OH chemiluminescence signals to reach the camera through the IRO and UV lens.

With IRO and with a band-pass filter



IRO \rightarrow Gain & Gate
 \rightarrow 310nm \rightarrow OH* signal

\uparrow incoming signals

The importance of intensifiers & filters

This specific combination is designed to amplify the incoming signals and make them strong enough to be detected by the camera. As a result, we can now clearly see the images, including the OH chemiluminescence signals from the flame. The UV signals that were previously undetectable due to their low intensity are now effectively captured because of the signal intensification provided by the IRO. So this demonstrates the importance of intensifiers and bandpass filters for chemiluminescence imaging. Thank you for joining us in this lab demonstration.

We hope you find this session informative and valuable for your research and experiments in combustion and flame dynamics.