

Simultaneous DTGS and DTS Measurements for Temperature Estimation in a Bubble Column Reactor

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Summary:

This study demonstrates the combined use of DTGS and DTS for temperature estimation in a bubble column reactor. DTS provides absolute temperature, while DTGS precisely detects rapid thermal variations. Results show bubble-induced convection enhances heat distribution, emphasizing the benefits of integrating both techniques for advanced process monitoring.

Keywords: DAS/DTGS, DTS, temperature measurement, bubble column reactor, fiber optics

Introduction

Distributed Fiber Optic Sensing (DFOS) technologies have revolutionized monitoring in harsh environments, offering remote sensing capabilities with high sensitivity, linear response, and discreet deployment. Among these, Distributed Temperature Sensing (DTS) leverages Raman scattering to provide absolute temperature measurements over distances of up to 70 km. However, its temperature resolution is limited to approximately 2°C, and its sampling rate is relatively slow [1],[2]. Conversely, Distributed Acoustic Sensing (DAS) utilizes Rayleigh scattering to detect variations in the optical path caused by strain and refractive index fluctuations. This allows a broadband response from high frequency acoustic signals to low frequency temperature gradients and deformation, supporting the terms low frequency-DAS (LF-DAS) and Distributed Temperature Gradient Sensing (DTGS). Although DAS does not provide absolute measurements, it offers exceptional precision, with sensitivity on the order of $n\varepsilon$ and μK , while maintaining a rapid response time [3]. Previously we have demonstrated the measurement of the movement of bubbles in an experimental column reactor using DAS [4]. In this work, we extend capabilities to temperature estimation combining simultaneous DAS/DTGS and DTS measurements to enhance process control.

Methodology

The bubble column reactor setup (Figure 1) features a 2-m-high acrylic pipe with a 150 mm outer diameter and 5 mm wall thickness, filled

with water and open at the top. Air bubbles were sparged into the reactor through a controlled air inlet at the bottom. The Fiber Under Test is a duplex round cable (9/125 μ G652.D, 3 mm outer diameter), with one fiber dedicated to DAS/DTGS and the other to DTS measurements. Two key sections were instrumented: Outside wrap, a 137 m-fiber helically wrapped around the column's outer surface, covering 85.8 cm in height. The Inside wrap section is 22 m-long fiber, similarly wound near the top inside the column.

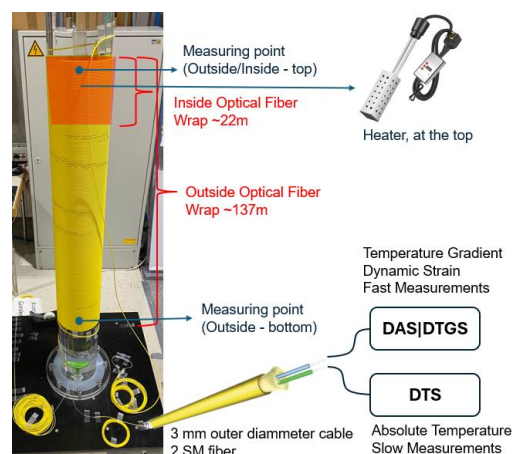


Fig. 1. Experimental setup for the measurement of temperature in a bubble column reactor.

DAS/DTGS and DTS data were acquired using a single interrogator unit at JKU's Institute of Measurement Technology, sampled with a 14-bit, 500 MS/s acquisition card at 10 kHz and a 40 ns spatial resolution. The experiment lasted

600 s. Initially, the column contained still water. At 80 s, a water heater positioned near the top was activated, gradually increasing the temperature. At 260 s, an automated valve periodically opened the air inlet, producing bubbles that ascended to the surface. Their movement induced fluid circulation within the column.

Results

Figure 2 presents the results from both sensing technologies. The DTS signal is depicted in the upper colormap, while the DAS in the lower colormaps. The Outside wrap section extends from 50 to 187 m, while the Inside wrap spans 203 to 225 m. Within these ranges, both signals exhibit a similar trend, showing a gradual increase in intensity over time, though with varying gradient periods. To provide a more detailed analysis, local signals are plotted at three key positions: outside bottom, outside top, and inside top, as indicated in Figure 1. At the start, the DTS signals reflect the outer wall temperature of the column, which is expected to be close to ambient temperature, averaging approximately 23°C, with a variation of $\pm 1^\circ\text{C}$ across different heights. Meanwhile, the inside wrap of the column registers an initial water temperature of approximately 27.5°C due to heating prior to the experiment. In contrast, DTGS signals all start at zero, as they measure relative variations over time rather than absolute temperature. However, DTGS responds more rapidly to thermal changes. At 80 s after the start of the experiment, the water heater was turned on, triggering a temperature increase that is first detected at the inside top position, followed by a delayed response at the outside top measurement points. The bottom measuring points remain largely unchanged until approximately 260 s, when the automated air inlet valve begins periodic operation. Up to this moment, heat propagation within the column is primarily driven by natural convection. However, once air bubbles are introduced, they induce fluid circulation, significantly enhancing heat distribution throughout the column at all levels. This transition is clearly observed in the local signals, where temperature evolution follows distinct gradients at different heights, highlighting the effect of bubble-induced mixing on thermal dynamics. Additionally, DAS data is displayed, where a 20 Hz high-pass filter has been applied to extract vibration and acoustic phenomena. The filtered signal reveals periodic pulse-shaped patterns after 260 s, corresponding to the opening of the air inlet valves and the periodic formation of bubbles. This process is closely aligned with the change in thermal dynamics observed in both DTS and DTGS signals, confirming the strong influence of bubble-induced convection on heat distribution.

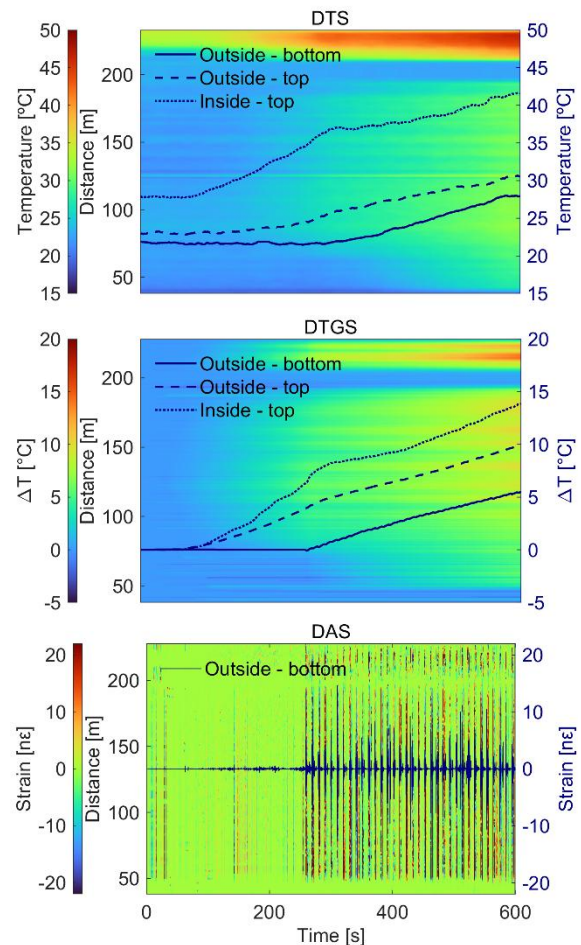


Fig. 2. Simultaneous temperature measurement using DTS (top) and DTGS/DAS (center and bottom).

Conclusion

The integration of DTS and DAS/DTGS enables precise absolute temperature monitoring with fast thermal response and acoustic analysis. This synergy enhances process monitoring and opens new possibilities for data fusion, improving accuracy and real-time insights into thermal and fluid dynamics.

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