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The use of fluorescence thermometry to verify SST measurements made using radiation thermometers: A proposal.

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ABSTRACT

Radiation thermometry is used extensively in Sea Surface Temperature (SST) measurements, yet it suffers from a serious drawback: It requires knowledge of the emissivity of the surface whose temperature is being measured i.e. the sea surface. The emissivity of the emitting surface not only determines the radiance emitted by the surface but also governs the level of background radiation reflected by the same surface. Furthermore, the temperature of the top 10 μm thick layer of the sea surface which is measured using radiation thermometry in the 8 μm to 12 μm wavelength range differs significantly from the bulk temperature of the sea water. The author proposes a novel method of measuring the temperature of the top 10 μm thick film of the surface of the sea using the temperature dependence of the fluorescence characteristics of fluorophores. This method is completely different from radiation thermometry and provides a more direct method for the validation of SST measurements made using radiation thermometry.

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Approved on behalf of NPLML by Teresa Goodman, Principal Research Scientist,
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CONTENTS

1. INTRODUCTION	1
2. FLUORESCENCE THERMOMRTRY	1
3. FLUORESCENCE LABELLING	2
4. SST MEASURENT USING FLUORESCENCE THERMOMETRY	2
5. ISSUES WHICH MUST BE CONSIDERED	3
6. SUMMARY	3
7. REFERENCES	3

1. INTROCUCTION

Radiation thermometry is used extensively in Sea Surface Temperature (SST) measurements, yet it suffers from a serious drawback: It requires knowledge of the emissivity of the surface whose temperature is being measured i.e. the sea surface. The emissivity of the emitting surface not only determines the radiance emitted by the surface but also governs the level of background radiation reflected by the same surface. It is not straightforward to differentiate between the emitted and reflected components of the radiance of the surface being monitored, and the same issue exists in the measurement of SST.

SST measurements using radiation thermometry are used to validate satellite-based SST measurements. Despite the relatively high emissivity of water in the 8 μm to 12 μm wavelength range, there is always a significant solar radiation component which is reflected by the sea surface and detected by the radiation thermometer being used. Further problems arise due to waves and ripples which can be present on the sea surface, making the determination of the component of the radiance originating from the reflected radiation even harder. Finally, the temperature of the top 10 μm thick layer of the sea surface differs significantly from the bulk temperature of the sea water. Contact thermometers cannot be used to measure/verify sea surface temperatures because of the thickness of the sea skin. When measuring the sea surface temperature using 8 μm to 12 μm infrared radiation, it is only the top 10 μm thick water layer that is contributing to the emitted radiation. Measurement of the SST using a radiation thermometer operating in the 8 μm to 12 μm wavelength range is not straightforward, and it requires a number of effects to be considered in order to provide corrections to the measurement as well as calculating the combined uncertainty of the measurement.

The best method of identifying obscure errors in a measurement, as well as identifying systematic uncertainty contributions is to use an entirely different method to measure the same parameter. If the results of the two measurements differ by more than the value of their combined uncertainties, then it can be concluded that there are errors (or additional uncertainty contributions) in at least one of the measurement methods used which have not been considered. This implies that the availability of another, different method of measuring the temperature of the top 10 μm thick layer of the sea surface would be of great benefit.

2. FLUORESCENCE THERMOMETRY

Fluorescence is a well-established technique for labelling species, particularly in biochemistry. It is well known that the fluorescence emission characteristics of fluorescing species (fluorophors) change with environmental conditions such as temperature, pH, viscosity etc. It is also well known that the fluorescence emission characteristics of fluorophors depend strongly on temperature in two ways:

- i. The fluorescence emission spectrum of the fluorophore changes with temperature;
- ii. The fluorescence lifetime of the fluorophore changes with temperature.

Both phenomena have been used to measure temperature, and there is at least one commercially available thermometer on the market (the Luxtron fluoro-optic thermometer, see

Figure 1) whose operation is based on the dependence of the fluorescence characteristics of a fluorophore on temperature.



Figure 1: The Luxtron I652 two-channel fluoro-optic thermometer, which claims a “0.2 °C accuracy”.

3. FLUORESCENCE LABELLING

The author has used fluorescence in the past for labelling products for anti-counterfeit applications. Fluorescence labelling offers a number of advantages, the most important being that the excitation wavelength is different from the fluorescence wavelength. This means that the fluorescence occurs on a “zero background”, so very low concentrations of the fluorophore are required for labelling, typically a few parts per billion. The author is also aware that one epoxy manufacturer introduces a particular fluorophore into small glass spheres. The spheres are subsequently introduced in very low concentrations in the epoxy products. By monitoring for the presence in the characteristic fluorescence spectrum of the fluorophore which was used for labelling the spheres, the manufacturer can determine whether the epoxy is his own or the epoxy is counterfeit. The absence of the characteristic fluorescence signature indicates a counterfeit epoxy. This labelling can aid in any litigation proceedings in the case of failure of an epoxy bond which was claimed to be his own. The glass spheres which are used to label the epoxy are a few micrometers in diameter.

4. SST MEASUREMENT USING FLUORESCENCE THERMOMETRY

What the author proposes is to label plastic spheres (around 10 μm in diameter, i.e. comparable to the thickness of the sea skin) with a fluorophore. The buoyancy of these microspheres can be arranged so that they just float on the surface of the water, while the bulk volume of the spheres is immersed in the water. This means that because of their small size, the temperature of the spheres will quickly settle to the temperature of the water around them, i.e. the temperature of the top 10 μm film of the water surface, (the sea skin). If the surface of

the sea is now illuminated by the excitation light and the fluorescence characteristics (spectrum or lifetime) are monitored, then the temperature of the spheres (and therefore the temperature of the sea skin) can be estimated. The commercially available fluoro-optic thermometer shown in Figure 1 is a rather simple hand-held device, yet it claims a 0.2 °C measurement “accuracy”. A more sophisticated excitation/interrogation method should be able to improve the uncertainty with which temperature measurements can be made. Ross et al. have used the temperature dependence of the fluorescence of dyes to measure the temperature in micro-fluidics “with a precision down to 0.03 °C” (Ross et al., 2001).

The author is confident that this method will provide a measurement of the SST. What is not currently known is the accuracy with which such a measurement can be made. This requires further effort which is currently not being funded and will depend on the exact details of the method which will be used.

5. ISSUES WHICH MUST BE CONSIDERED

- i. A fluorophore with the correct characteristics will need to be identified. A vast number of fluorophores are commercially available including quantum dots. In demonstrating the measurement of SST using fluorescence thermometry, any fluorophore can be used since any excitation source and any fluorescence detection method can be employed, unlike in the commercially available Luxtron fluorescence thermometer, where the excitation source and detection system must be low cost, have small size, be simple and be robust.
- ii. Safety: While some fluorophores are considered unsafe, there are numerous others which are not (e.g. fluorescein and numerous fluorescence paints are widely available). Furthermore, the fact that the fluorophore will be contained within a solid material such as glass or plastics means that it will not come into contact with the skin. Finally measurements can be done over a limited area in a pool to demonstrate the agreement between measurements made with fluorescence thermometry and radiation thermometry. When the safety of the fluorophore is demonstrated, then measurements can be done anywhere, including the sea.

6. SUMMARY

The main advantage of this method is that it is completely independent from the SST measurement method employed by radiation thermometers, despite measuring the same parameter (the top 10 µm thick layer of the water surface). Agreement between the measurements completed using fluorescence thermometry and using radiation thermometry to measure SST will provide a much more reliable method of confirming the validity of the measurements of radiation thermometry, simply because the two measurement methods are completely independent.

7. REFERENCES

Ross, D., Gaitan, M. and Locascio, L. E., 2001, “Temperature Measurement in Microfluidic Systems Using a Temperature-Dependent Fluorescent Dye”, *Anal. Chem.*, **73**, 4117-4123.