Analysis of Near-surface Temperature Inversion in Diurnal Boundary Layer due to Natural Aerosols

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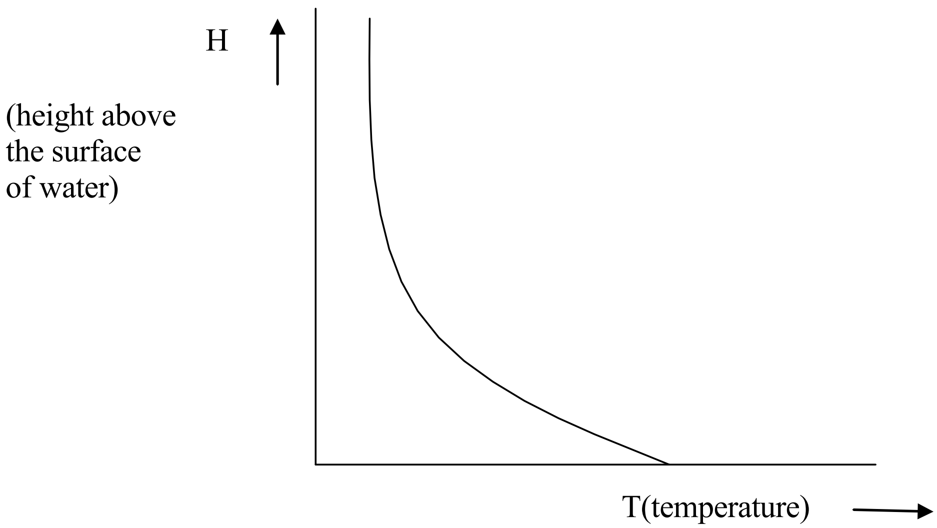
Abstract

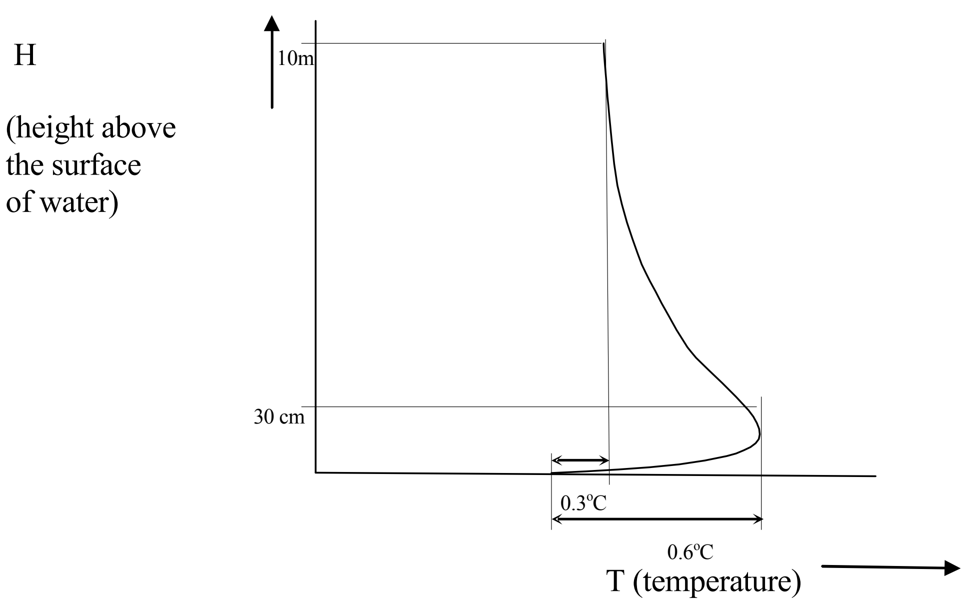
A near surface temperature inversion has been observed in the diurnal sub-cloud layer beneath the mixing layer over the Arabian Sea (Bhat, G. S. (2006), Near-surface temperature inversion over the Arabian Sea due to natural aerosols, *Geophys. Res. Lett.*). The phenomenon has been reproduced in the laboratory and studied in a more controlled manner than what would be possible through field observations. Experiments have been carried out in the lab to analyse the effect of suspended particles on the radiative temperature profile. In order to negate the effect of conduction in the profile, water was chosen as the medium. 45 micron graphite particles were used as the suspension. Results from laboratory experiments presented here show that the near-surface radiative heating is precisely the reason behind the lifted temperature maximum. Observations include the dependence of the LTMaxima on concentration profile of salt particles. It is, in fact, the suspended salt particles that provide the necessary heterogeneity required for the preferential radiative heating causing the temperature inversion. Turbulence in the mixing layer, by determining the distribution of haline particle concentration over the relevant length scales, plays a key role in the phenomenon. Experimental evidence is presented to support this hypothesis.

1. Introduction

The near surface vertical distribution of air temperature in the atmosphere is an important aspect of studies in boundary layer meteorology. Near-surface temperature inversion profile in nocturnal boundary layer a.k.a the Ramdas Paradox has been a celebrated problem. However the same in the diurnal regime has only recently been reported (Bhat, G. S. (2006)). In the summer monsoon he had observed a lifted temperature maximum over the Arabian Sea. His field experiments had a test height was 10m from the surface of water and region of interest was beneath the mixing layer in the sub-cloud region and the lifted temperature was at 30cm from sea level. During day-time the profile is expected to be decreasing upwards from the surface of the water.



However the observed profile was this.



He attributed the reason behind this Lifted Temperature Maximum to the suspended halide particles in air. In this regard we have tried to explore the possibility of achieving similar profiles with water as the medium in the visible range of light. The phenomenon now being reproduced in the laboratory can be studied in a more controlled manner than would be possible through field observations.

Experimental Set-up:

The set-up consists of a 60cm x 60cm x 60 cm glass tank divided into three compartments. The tank is made of 1cm thick glass plates.

The middle compartment is of height 10.5cm and is the test section where particle laden water is taken as the test fluid. The bottom surface of the test section is made of a 6mm thick aluminium sheet whereas the top surface is a 5mm thick sheet of glass. Both these two plates have two holes with diameter 1.5cm through which pipes for circulating water in and out of the bottom section pass through.

The bottom compartment below the aluminium plate is of 23cm height through which water is circulated to maintain a constant bottom surface temperature of the test section. Submersible pumps are used for the circulation of water. Pipes of diameter 1.5cm are connected to the pumps for water circulation.

The top section is above the glass plate acting as the top surface of the test section. Water is circulated in this section to facilitate an environment of uniform constant temperature over the test section. The water inlet to the top section is a pipe of 2cm diameter. This pipe has 20 holes each of 5mm diameter, and tubes of 4cm length are kept protruding out of these holes. The inlet tube is kept along the side of the tank side surface, thus resulting in the formation of 20 water inlets of 5mm diameter, which reduces the fraction of stationary water in the top section. A submersible pump is used as the outlet of water off the top section.

The inner and outer surfaces of the glass tank are insulated with thermo-foam.

Four halogen bulbs are used as the source of radiation. Two of the bulbs are of 125W and the other two are of 500W and all of them are at a height of 1.25m above the top surface of the test section.

T-type (36 gauge) thermocouples are used for temperature measurement. 13 thermocouples are kept inside the test section vertically at heights 0, 1mm, 5mm, 13mm, 18mm, 27mm, 38mm, 47mm, 63mm, 73mm, 85mm, 96mm, 102mm above the bottom aluminium plate. Four thermocouples are used to measure the side wall temperatures of the test section at a height of 5cm. Another two are used to measure the top and bottom temperatures of the glass plate above the test section. The thermocouples are calibrated and found to be agreeing to a temperature by a maximum difference of 0.05K. The data are collected using a Keithley Ethernet-Based DMM/ Data Acquisition System of model 2701.

Graphite particles of size 45 micron are used which were procured from Sigma Aldrich, Bangalore.

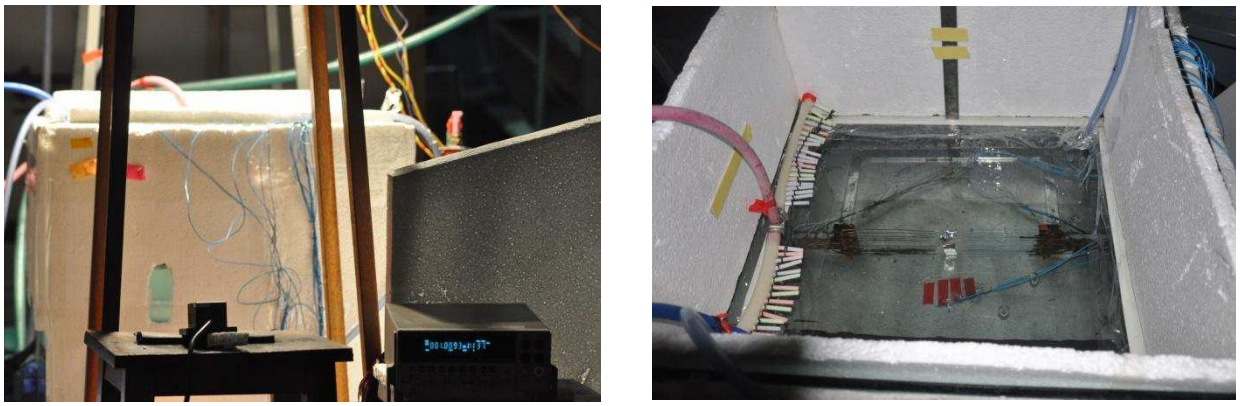
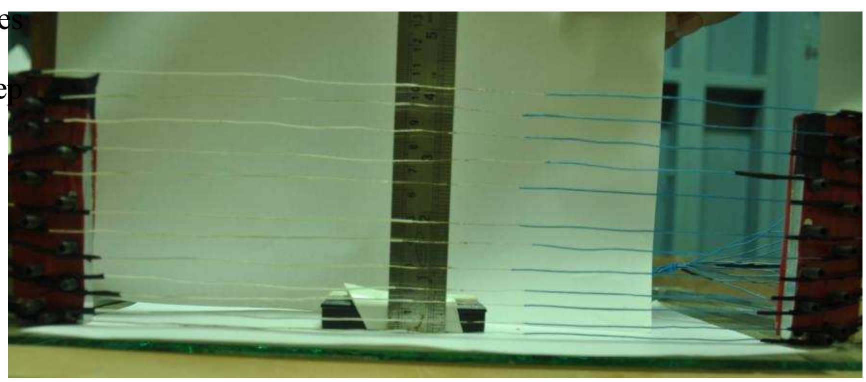


Figure 1: Experimental set up - The above two pictures show the glass tank covered with thermo foam sheet in front and top view respectively. The first picture also shows the Laser source and the data logger.

Figure 2: The thermocouples attached to a frame to keep them vertical.



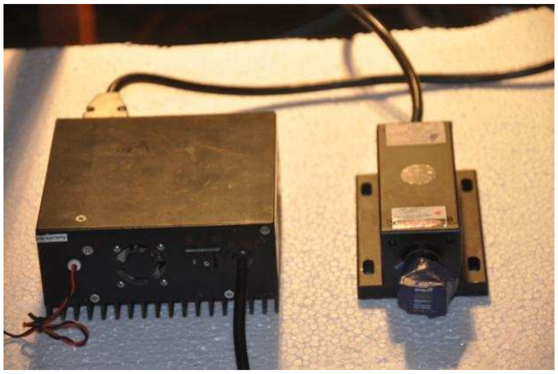


Figure 3: Laser source of 300 mW and 532 nm manufactured by Sanghai Dream Lasers Lasers Technology Co. Ltd.

Figure 4: Keithley Data Acquisition System Model 2701

RESULTS:

The first experiment was done with de-ionized water without any particles. Our incentive was to maintain the top and bottom temperatures near about 1K difference by water circulation. A series of halogen bulbs above were used as the radiative heat source. The water circulating above filtered out the IR radiation for the test section which would primarily heated by the visible and UV rays.

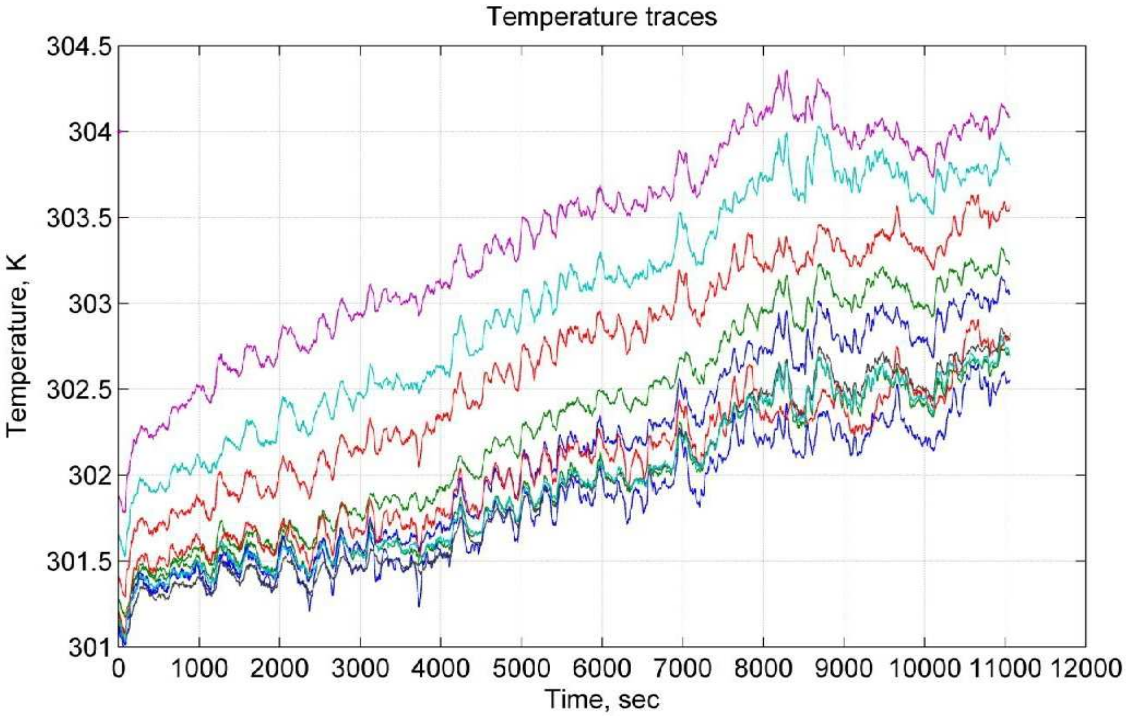


Figure 5: Temperature traces for the thermocouples inside the test-section

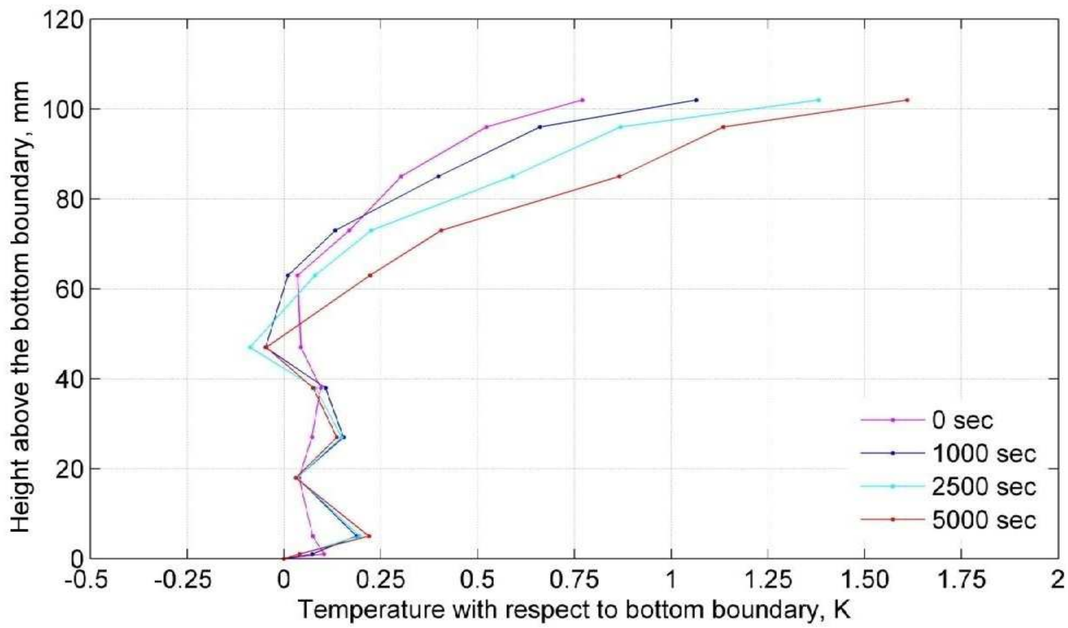


Figure 6: Vertical temperature profile inside the test section using de-ionized water as medium.

The second experiment was done after adding 0.2 gm of 45 micron graphite particles. The particles were given about 12 hours for stratification. The experiment was run for about 3 hours.

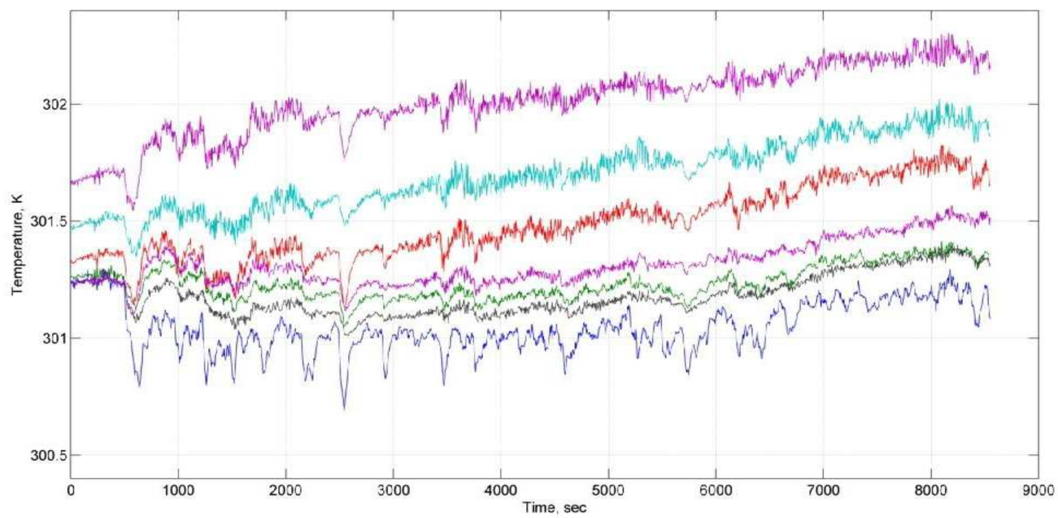


Figure 7: Temperature traces of the thermocouples inside the test section after adding approximately 0.2g of 45 micron graphite particles.

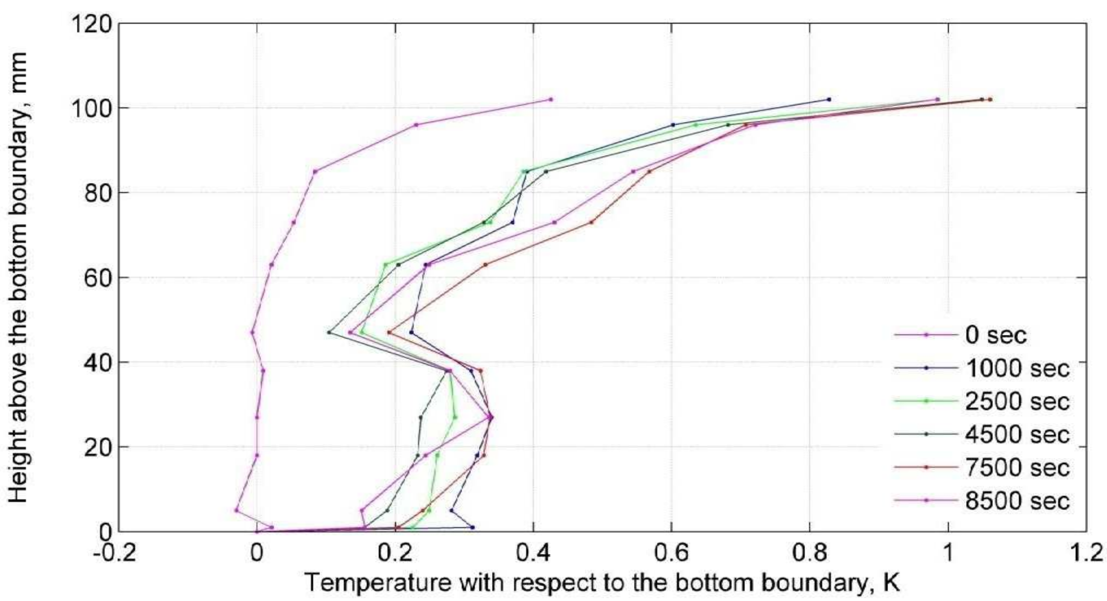


Figure 8: Vertical temperature profile inside the test section after adding approximately 0.2g of 45 micron graphite particles.

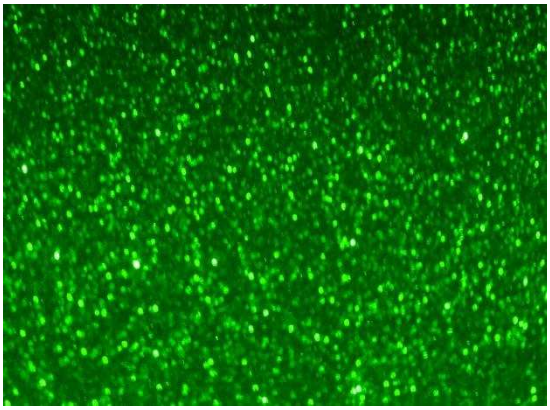


Figure 9: Graphite particles as can be seen after illumination with a 532 nm laser sheet.

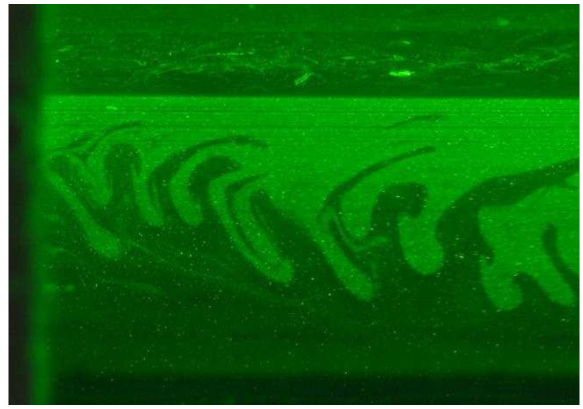


Figure 10: The very light graphite particles form a layer with large particle number density near the upper surface of water in the test section.

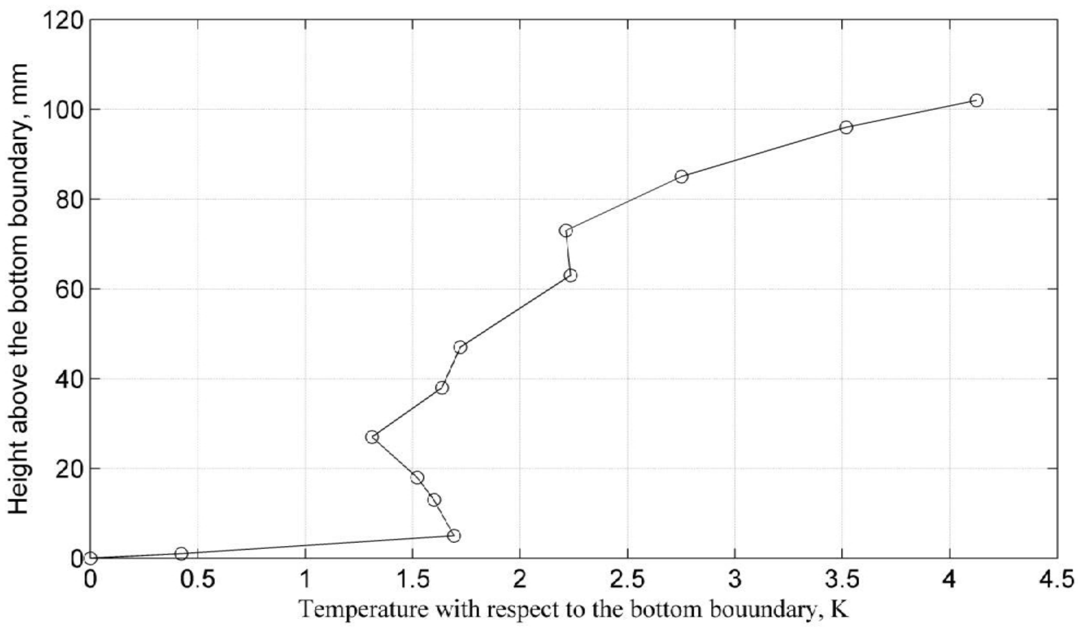


Figure 11: Vertical temperature profile in the test section for 0.4g of particles dispersed in water.

For the experimental run using 0.4g particles, an unstable layer with a temperature difference of about 1K is seen between 5 to 30 cm of height. The Rayleigh number is calculated to be approximately 7000. Convection occurs in this region.

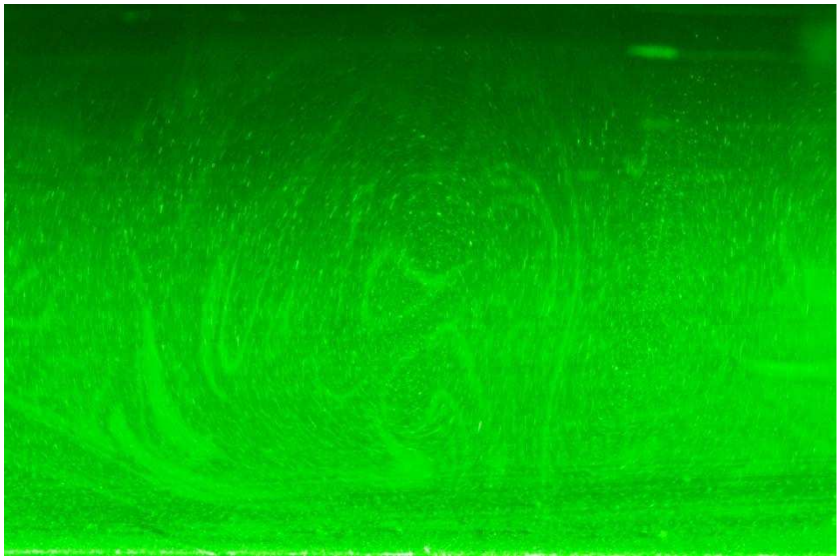


Figure 12: Convection rolls as observed during the experimental run with 0.4g particle dispersed in water.

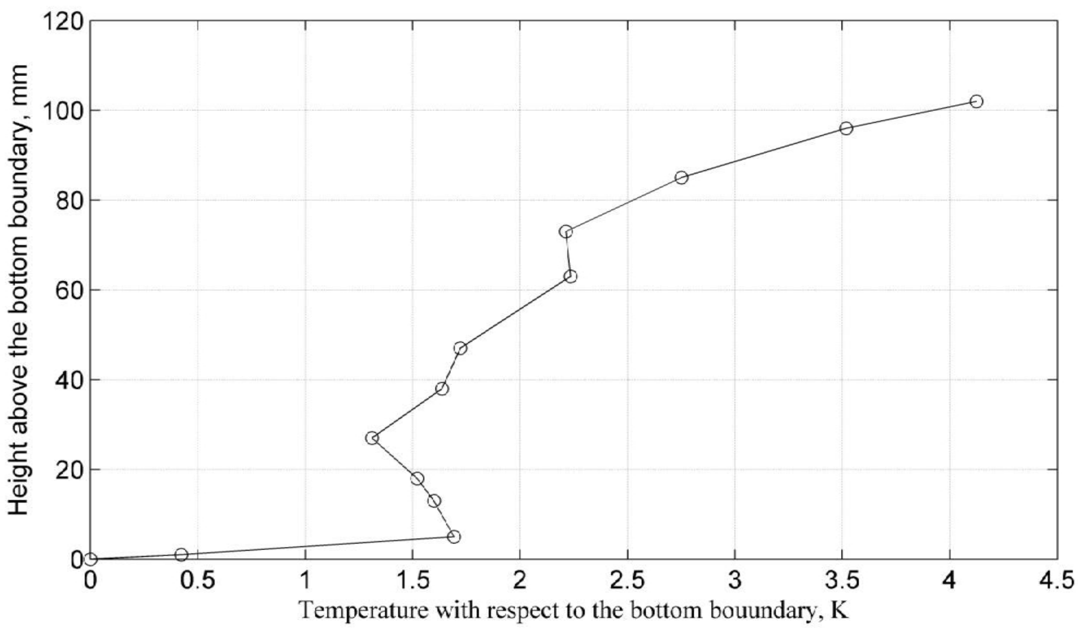


Figure 13: Vertical temperature profile for experimental run with 0.4g particle dispersed in water.

Discussion:

The lifted temperature maxima has been observed as expected. The intensity of maxima is around 0.4K and 1.7K when 0.2g and 0.4g of particles were dispersed in water respectively. 0.2g of 45 micron graphite particles contain number of particles of the order of 10^6. Even the run using de-ionised water showed an intensity of about 0.2K. The de-ionised water contained a small amount of small particles as were observed using the laser sheet.

Thus, as the number of particles increases, the intensity of maxima increases. The fact that the intensity of the maxima has significantly increased due to the addition of particles is testimony to the fact that the concentration of the particles plays a key role in causing the lifted temperature maxima.

The temperature increases monotonically beyond 60mm of height from the bottom boundary. This happens due to two reasons. First, as the experiment is run for more than a couple of hours, conductive heating takes place in this region. For 3 hours of time, heat flows to a distance of approximately 35mm as given by the equation

$$\delta =$$

Second, a persistent layer of particles forms just below the top surface of water as shown in figure 10. These particles absorb radiative heat at a much faster rate than water.

Acknowledgement:

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Reference:

G. S. Bhat, "Near-surface temperature inversion over the Arabian Sea due to natural aerosols", Geophys. Res. Lett., Vol. 33, No. 2, 2006.

J. E. Hutchison, R. F. Richards, "Effcet of Nongray Gas Radiation on Thermal Stability in Carbon Dioxide," *Journal of Thermophysics and Heat Transfer*, Vol. 13, No. 1, 1999.

Gille J., Goody R. M., "Convection in a radiating gas," *Journal of Fluid Mechanics*, 1964.

Goody R. M., "The influence or radiative transfer on cellular convection," *J.Fluid.mech.*, 1956.