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Noninvasive Measurement Of Temperature Field In Natural Covection Of Solidifying Saline Water

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Abstract
Free convection was studied experimentally for aqueous solutions of NaCl and NH_4CL confined in a cubic cavity of 50 mm inner dimension, with two opposite vertical walls kept at constant, but different, temperatures. For various substances the flow pattern and temperature field were carefully studied. The Thermochromic Liquid Crystals (TLC) suspended in the solution, and infrared Termovision was used to noninvasive temperature measurement. It is observed that even for a very low salt concentration, the flow pattern and temperature fields in the cavity changes completely in comparison to pure water. The positives and limits of proposed methods were presented.

Key-Words : Natural convection, Noninvasive measurements, Binary solutions

1. Introduction

The noninvasive temperature measurement is very useful in pipes controlling, where the flow pattern is important. The salt- water solutions during solidification are interesting and difficult to study, because of its changing concentration. During the solidification the salt is forced out from the solid, and the concentration of liquid is growing. This mass transport changes not only the flow pattern, but also the temperature field in cavity. The non-invasive measurement of those temperature fields was the aim of this study.

2.Experimental apparatus and procedure

The temperature fields for pure H_2O were already presented [1,3], experimentally measured and numerically checked. We wanted to observe the two-dimensional temperature field in the cube cavity. For this purpose the flow images of the central vertical cross-section have been collected in the different states of cooling.. The RGB images are taken in each state. Later on they are used to obtain temperature fields [2].

As aforementioned Thermochromic Liquid Crystal (TLC) tracers have been applied to describe both temperature flow fields and particle tracks. The TLC based temperature visualisation is based on the property of some cholesteric and chiral-nematic liquid crystal materials to reflect definite colors at specific temperatures and viewing angle. The color change for the TLC ranges from clear at ambient temperature, through red as temperature increases and then to yellow, green, blue, and finally clear again at the highest temperature. The color-temperature play interval depends on the TLC composition. These color changes are repeatable and reversible as long as the TLCs are not physically or chemically damaged. The response time of TLCs equals about 10ms. It is short enough for typical thermal problems in fluids. The mean diameter of the uncapsulated TLC tracers used in experiments was about 40μm. The temperature measurements are based on a digital color analysis of *RGB* images of the TLCs seeded flow field. For evaluating the temperature the *HSI* representation of the *RGB* color space was used. The incoming *RGB* signals was transformed pixel by pixel into *Hue, Saturation and Intensity*. The color was represented by a “Hue” factor with value from 0 (for “red”) to 152 (for “blue”). Temperature was determined by relating the hue to a temperature calibration function [2]:

$$I = \sqrt{(R^2 + G^2 + B^2} / \sqrt{3}$$

$$S = 225 \cdot (1 - \min(R, G, B) / I$$

$$H = \begin{cases} 63 + ((G' - R') \cdot 63)/(G' + R') \; dla \; B' = 0 \\ 189 + ((B' - G') \cdot 63)/(G' + B') \; dla \; R' = 0 \end{cases}$$

$$R' = R - \min(R, G, B); G' = G - \min(R, G, B);$$
$$B' = B - \min(R, G, B)$$

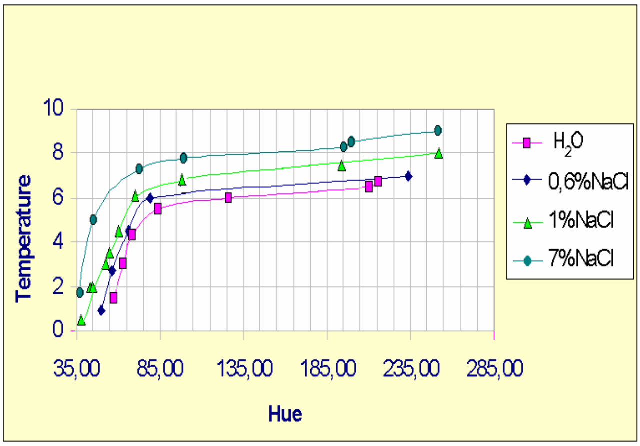

Fig.1. Calibration curves for different NaCl- H_2O solutions with BM/R4C5W/S-40 crystals.

attached antechamber maintains their constant temperature. Four non-isothermal walls of the cavity was made of 9 mm thick Plexiglas.
The temperature of the cooling and heating liquids (and optionally that of the water in the bath surrounding the four non-adiabatic walls) was controlled by thermostats and, optionally by Peltier's elements. The computer-controlled system of three stepping motors allows acquiring images of the several cross-sections fully automatically within several seconds. The computer controls also switch of the halogen lamp. The temperatures was controlled by thermocouples and registered by Molytec.

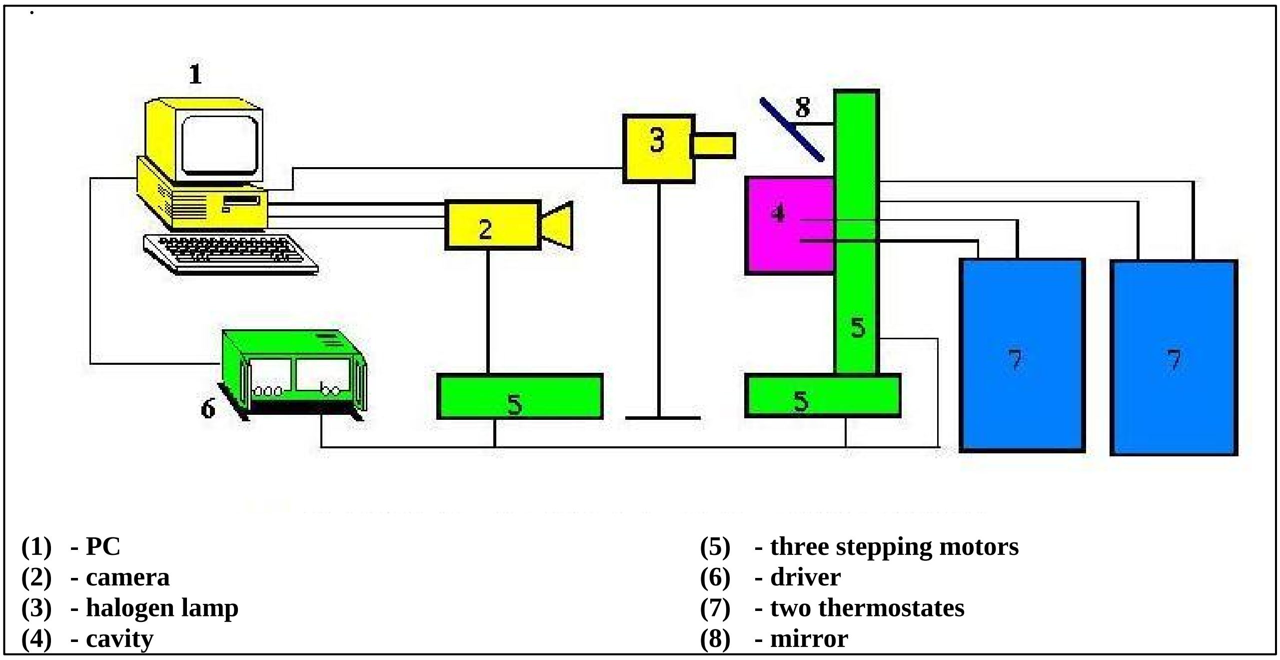

Fig.2 Schematic of the experimental system

Every experimental set-up needs its own calibration because of reflections from the walls and internal cavity elements, and discretisation of images. The calibration curve could be obtained from the images taken for the same fluid, at the same illumination, acquisition and evaluation conditions (Fig.1)
The experimental set-up (Fig.2) consists of a convection box, a halogen tube lamp, the 3CCD color camera and the 32-bit frame grabber (IC-PCI ITI). The flow field was illuminated with a 2mm thin sheet of white light from a specially constructed halogen lamp, and observed in the perpendicular direction. The 24-bit color images of 560x560 pixels have been acquired using a 64MB Pentium 133 computer
The convection cubic box, of 50 mm inner dimension, has two isothermal walls made of a black painted cooper. An anti-freeze coolant flowing through the

In measurement with thermovision the 3CCd camera was relaced by Agema Thermovision 900 LW Scanner, using a Mercury Cadmium Telluride (MCD) sensor refrigerated by liquid nitrogen. Sensivity of the apparatus in real experiments is eq. $0{,}3^0$C. In those experiments the halogen lamp (3) and the mirror (8) were not used.

3. Experimental results

The temperature fields in the NaCl- and NH_4Cl-water solutions in different thermal conditions: T_H and T_C and different concentration was observed. The results are presented for TLC measurement and for pictograms of Thermovision.
Measurement of the temperature fields in 1% and 7% NaCl in H_2O solutions was provided in experimental box surrounded by liquid (fig.3).

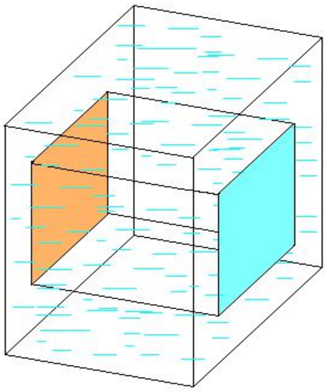

Fig.3. Convection box surrounded by liquid. Isothermal walls colored.

Figures below show, that the color change of the TLC's is depended not only of the external conditions, like light and angle of observation, but also of the concentration of used solution.

The temperature of the front of phase in 1% solution is below, but close to 0°C, and the "red" color is visible inside, but up to zero. (Fig.1) Results of the temperature field measurement in those conditions is shown in Fig.5

In the same conditions for 7% solution the change of phase doesn't created (fig.6). The temperature of solidification is about –4.5°C, but the temperatures inside are higher then the cold wall temperature. The TLC's in 7% solution start working up to 2°C (Fig.1).

The white color describes section, where the TLC didn't work.

In presented results (fig. 5 and 7) we can see, that the temperature measurements with TLC is not very precise in solutions and those experiments need the optical transparence of walls.

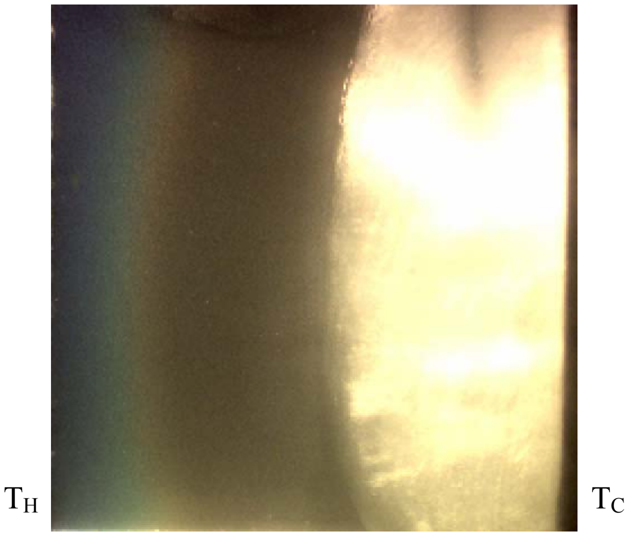

Fig.4 Steady–state free convection of 1% NaCl solution. T_H=5°C, T_C=-5°C. Image of the TLC's

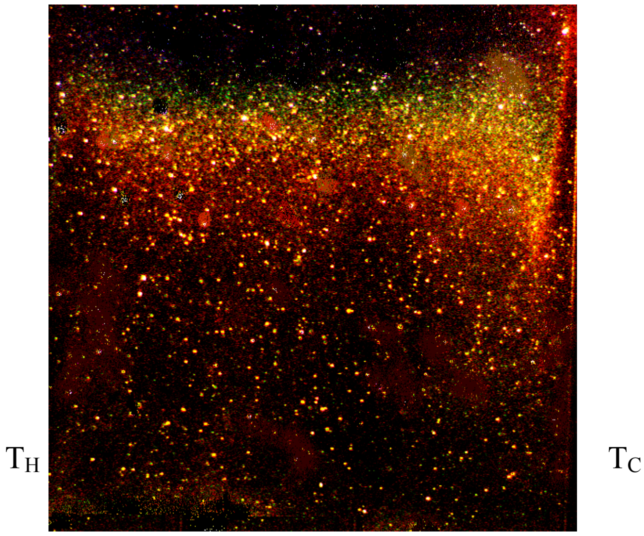

Fig.6 Steady–state free convection of 7% NaCl solution. T_H=5°C, T_C=-5°C. Image of the TLC's

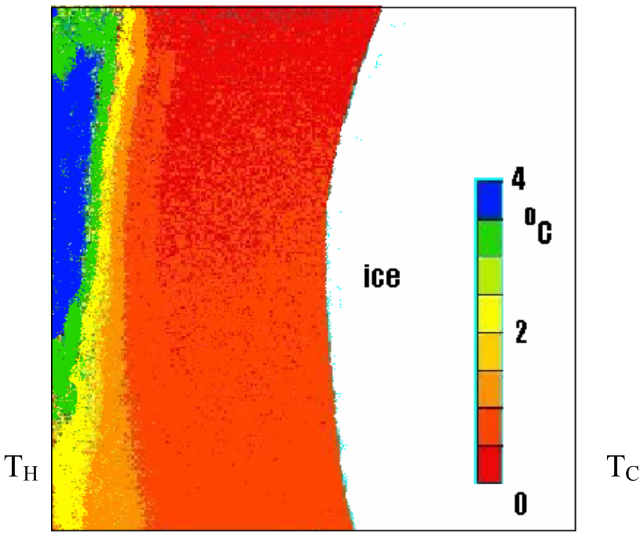

Fig.5 Temperature field in T_H=5°C, T_C=-5°C 1% NaCl solution.

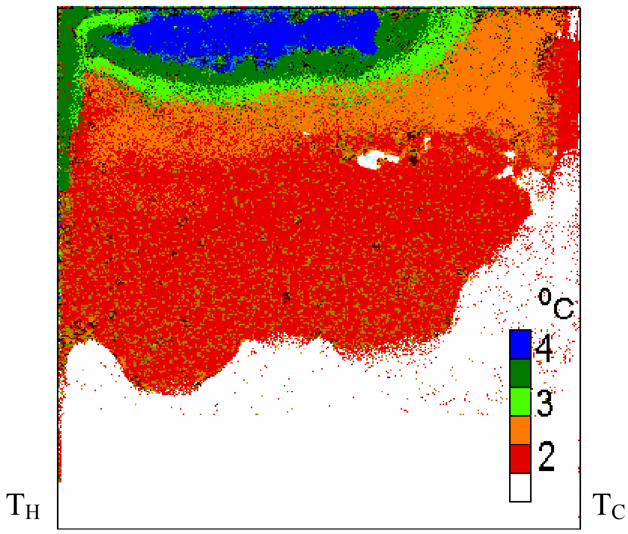

Fig.7 Temperature field in T_H=5°C, T_C=-5°C 1% NaCl solution.

Measurement of temperature fields using Thermovision should be provided in different conditions: That experiment doesn't request optical transparence of walls, but because of its character (measurement of infrared radiation) the answer is the temperature field of external face of wall. The difference between this temperature fields, and internal temperature field of fluid depends of the wall material. Convection box should be surrounded by air (Fig.8)

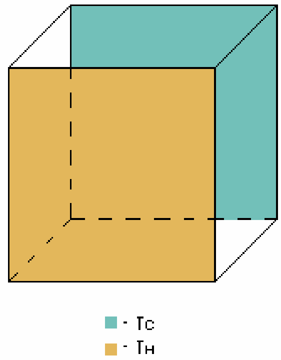

Fig. 8. Convection box surrounded by air Isothermal walls colored.

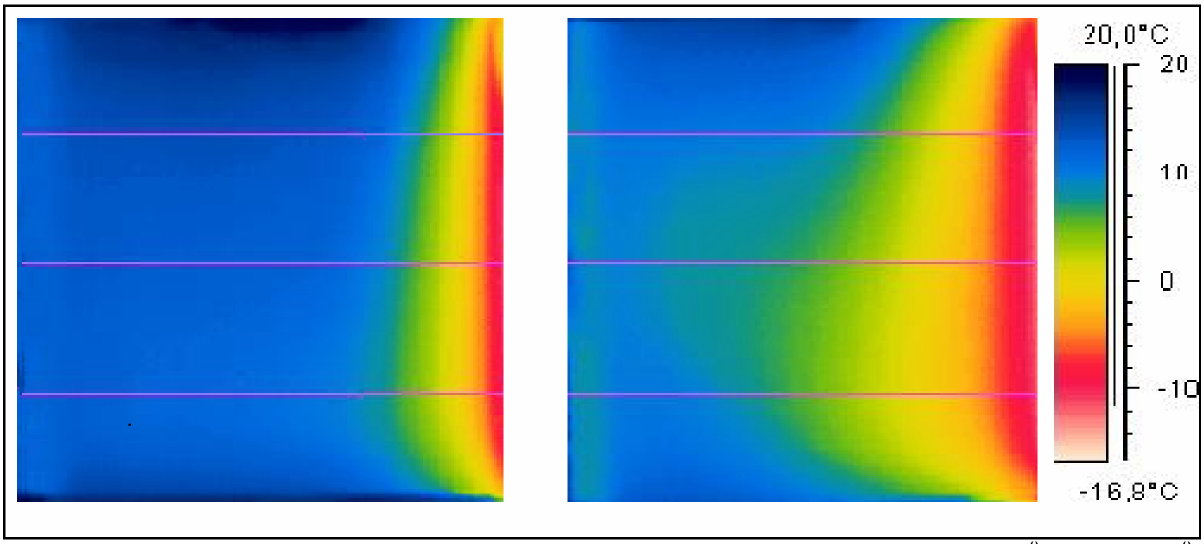

Fig.9. Thermograms of NH_4Cl-water solution after 15 and 60 minutes of freezing. T_H=+9.4^{0}C; T_C=-16,8^{0}C

Fig. 9 presents the results of infrared temperature measurement of NH_4Cl-H_2O solution with concentration of salt 0.6% weight, after 15, and 60 minutes from beginning. The thermal condition in both experiments was: T_H=+9.4^{0}C; T_C=-16,8^{0}C

Fig. 10 presents the comparison between that results and the results of measurement for NaCl-H_2O solution, with the same concentration in the same thermal conditions.

The temperatures was described for 3 levels of box high:

– y=0,5; – y=0,25; – y=0,75.

The levels are shown in Fig.9. by pink lines.

The temperatures in both experiments seem almost identical for every level. The similar differences can be observed for repeated experiments of the same solution

Then we can tell, that the temperature fields measured by Thermovison are the same for both solutions.

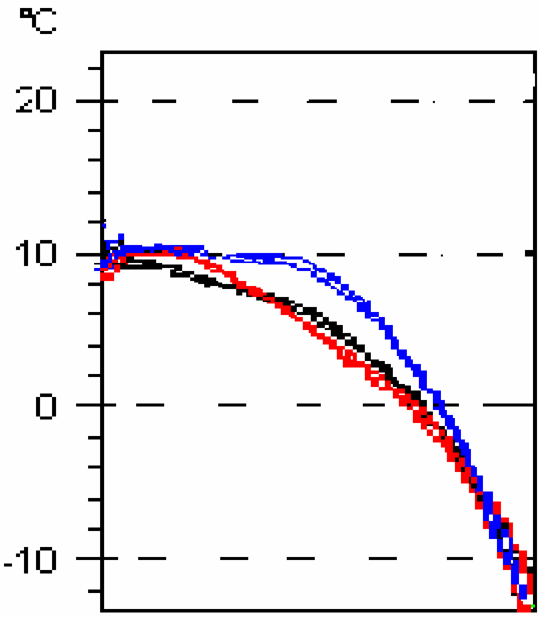

Fig.10 Comparison between temperatures in 0.6% water solutions of NaCl and NH_4Cl in the same thermal conditions.

The temperature field of NaCl solution in condition like at fig.9 in steady-state, but measured by TLC is presented at fig.11.(photo) and fig.12. We can observe the ice position, what was impossible at thermograms.

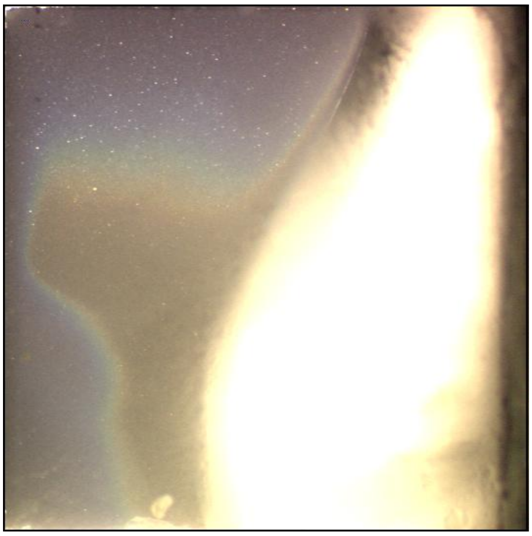

Fig.11 Steady–state free convection of 0.6% NaCl solution. T_H=9.4°C, T_C=-16.8°C. Image of the TLC's

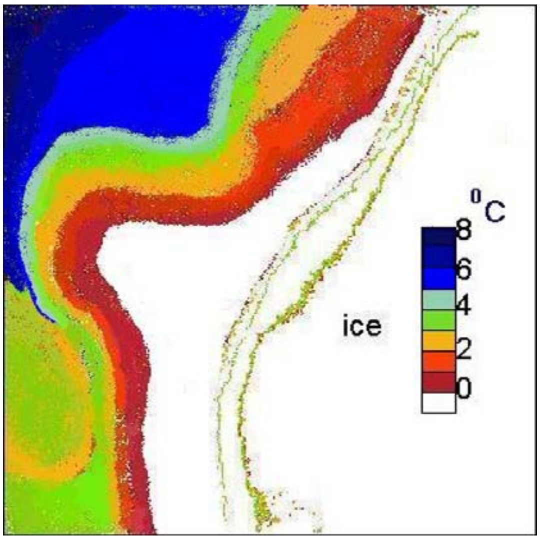

Fig.12 Temperature field in T_H=9.4°C, T_C=-16.8°C. 0.6% NaCl solution.

4 Conclusions

The non invasive temperature measurements was provided for non-concentrate binary solutions.

The Thermochromic Liquid Crystals was used for measure the 2-dimentional temperature field inside the transparent cubic box, where the natural convective flow was observed.

This measurement needs the optical transparence of observed wall, and the results are depended of concentration. Thus, when the solidification appears, and concentration of fluid change, the results could be not correct and more quantitive. The results of temperature measurement in case without concentration are more correct and their accurancy is about 0.5 ^{0}C.

The accuracy of the result should be better in case of simultaneous concentration measurement and correlation between both experiments.

Measurement by Thermovision is not depending of substances, and doesn't request the optical transparence. The result is the temperatures field of the box wall. The results can be similar to the temperatures field inside in case of "temperature transparency" of walls, i.e. metal wall. In presented experiments the plexi-made walls was not transparent for infrared radiation, and the maximum difference between internal and external temperature was 2.1 ^{0}C. That difference could be observed on the presented temperature fields.

The similar temperatures fields of two different solutions are understand, because of very small concentration of salts (0.6%) and the similar temperature of solidification (about -0.5^{0}C.)

The ice front in Thermovision is not visible, but the temperature field can be observed.

Both of those measurement doesn't change the flow inside the convective box, and then can be useful in experiments with natural convection of fluid, if the necessary conditions will be assured.

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