Liquid crystals thermography for technical and biomedical application

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Abstract

The discovery of cyanobiphenyl liquid crystals by Gray et al., the evaluation of their properties at the Royal Signals & Radar Establishment and their commercialisation by BDH (now Merck Ltd) revolutionized liquid crystal (LC) technology and made possible dramatic advances in liquid crystal displays technology over the last decade. Also, the development of LC technique for temperature and temperature gradients measurement over the past ten years, coupled with digital image processing, has opened some new approaches for technical and biomedical thermographic research and may lead to important changes of its application during the next decade.

The main purpose of this paper is to describe the Thermochromic Liquid Crystal (TLC) technique and to report its use to certain technical and biomedical situations, e.g. the study of heat and mass transfer, skin diseases and other medical applications enabled by the new experimental capability. Thermographic methods are fast, reliable and easy for processing and can be adopted in numerous technical problems connected with heat transport. Moreover, they are successfully used as additional non-invasive diagnostic methods especially useful for screening large groups of potential patients. In case of several diseases they are concerned as the main diagnostic methods. In this paper novel applications of thermochromic liquid crystals (TLC), with illustrative examples from our own work, are presented.
1 Introduction

The Termochromic Liquid Crystal (TLC) temperature visualization is based on the property of some cholesteric and chiral-nematic liquid crystal materials to reflect definite colours at specific temperatures and viewing angle. Liquid crystals are highly anisotropic fluids that exist between the boundaries of the solid phase, and the conventional, isotropic liquid phase. The colour change for the TLC ranges from clear at ambient temperature, through red as temperature increases and then to yellow, green, blue and violet before turning colourless (isotropic) again at a higher temperature. They appear colourless above and below the active range. The colour-temperature play interval depends on the TLC composition. It can be selected for bands of about 0.5 to 20 °C, and working temperature of −30 °C to above 120 °C. These colour changes are repeatable and reversible as long as the TLC’s are not physically or chemically damaged. The response time of TLC’s equals about 10 ms.

2 Liquid crystal thermography

Liquid crystals are temperature indicators that modify incident white light and display colour whose wavelength is proportional to temperature. They can be painted on a surface or suspended in the fluid and used to make visible the distribution of temperature. Normally clear, or slightly milky in appearance, liquid crystals change in appearance over a narrow range of temperature called the "colour-play interval" (the temperature interval between first red and last blue reflection), centred around the nominal "event temperature". The displayed colour is red at the low temperature margin of the colour-play interval and blue at the high end. Within the colour-play interval, the colours change smoothly from red to blue, as a function of temperature. Pure liquid crystal materials are thick, viscous liquids, greasy and difficult to deal with. The TLC is also sensitive to mechanical stress. A micro-encapsulation process which encloses small portions of liquid crystal material in polymeric material was introduced to solve problems with the stress sensitivity as well as with the chemical deterioration. For surface temperature measurements application of the unencapsulated material (unsealed liquids) to a clear plastic sheet and sealing it with a black backing coat to form a pre-packaged assembly is used. Commercially available temperature indicating devices using TLC, containing a thin film of the liquid crystal sandwiched between a transparent polyester sheet and a black absorbing background [1, 2].

3 Biomedical application

Requirements concerning thermographic examination are well-known [3,4,5,6]. The minimum area of a testing room have to be 9 square metres. All devices emitting heat should be removed, if possible. Air movements have to be minimised. The preferred temperature of testing room should be 25 to 27 °C,
while humidity should be 50 to 70%. Both those parameters should be carefully controlled during measurement. The effect of sunlight should be minimised.

Figure 1: a) Thermogram of child backbone displacement; b) example of allergic skin test.

Figure 2: Asymmetric thermogram of breasts with breast cancer (dark region).
Figure 3: Visualization of lack of blood circulation caused by Burger disease.

Light sources have to secure scattered light of low intensity to avoid light reflections. Patient should rest of physical activity during 20 minutes before measurement. Skin area studied should be naked at least 15 minutes before test to obtain thermal equilibrium with an environment. Patient's position should be similar to the physiological (normal) one to avoid temperature changes due to enforced changes of blood circulation. Body areas studied should not contact other body areas. Medicines, drugs (alcohol, nicotine and so on) and treatments affecting blood circulation should not be taken, if possible, within 24 hours before measurement. Patient should not drink cold and hot drinks and eat large meals before measurement. Cosmetics can also affect thermal properties of skin. All subsequent measurements have to be done at the same hour of a day. Thermological report should contain all conditions of measurement, including a state of a patient and environment. Patient is allowed to see thermographic images because their colours have positive psychological effect especially in case of children. Following cases have been studied and obtained results are in Fig. 1, 2 and 3.

4 Technical application

In order to demonstrate the feasibility of TLC techniques in practical heat transfer contexts the authors has performed several experiments. The set was carried out to investigate temperature and heat transfer coefficient distributions
on a cooled surface heated by an air flow and disturbed by a number of complex geometrical configurations, namely:

- Square roughness elements and rib-roughened channel,
- Crossed-corrugated and corrugated-undulated elements as used in rotary heat exchangers (regenerators),
- Flat plate heat exchanger element.

Figure 4: True-colour images from liquid crystal thermography for an endwall surface with in-line square ribs (above); Pattern of ten Nusselt number Nu reconstructed by false colour images of the heat transfer surface for Re = 20000 (No. 0: Nu = 79; 9: 99; 8: 113; 7: 123; 6: 136; 5: 147; 4: 160; 3: 175; 2: 185; 1: 209) – (below).
The experimental study was carried out using an open low-speed wind tunnel consisting of entrance section with fan and heater, and then mapping and working sections. Air is drawn through the tunnel using a fan able to give Reynolds number of between 500 and 50,000 in the mapping and working sections. The working air temperature in the rig range between 25°C to 65°C produced by the heater positioned just down stream of the inlet. The major construction material of the wind tunnel is Perspex. Local and mean velocity are measured using conventional Pitot tube and DISA hot-wire velocity probe. The alternative effects of constant wall temperature and constant heat flux boundary conditions are obtained using a water bath, while the temperature is controlled with a thermostat capable of establishing and maintaining temperature to within ±0.01 °C accuracy.

Figure 5: a) False colour image of local Nusselt number contours over a central diamond of the undulated plate of corrugated-undulated geometry (ϕ=70°, Re=2080, H=8.8mm, L=32mm); b) False colour image of local Nusselt number contours: Reynolds no. – 1690; Average Nusselt number – 14.5 Local Nusselt number: red - 6.80, green - 7.82, blue - 11.98, violet - 14.60, khaki - 22.15.

Photographs are taken using a RGB video-camera and true-colour image processing system. The heat transfer coefficient is a defined quantity, calculated from the surface heat flux and the difference between the surface temperature and some agreed reference temperature. This is usually the far field temperature, the mixed mean temperature or the adiabatic surface temperature. Liquid crystals can be used to determine the distribution of the surface temperature, and if the surface heat flux can be found, this allows evaluation of the heat transfer coefficient or the Nusselt number. The alternative effects of constant wall temperature and constant heat flux boundary conditions are obtained using a water bath. Photographs are taken using a RGB video-camera and a true-colour image processing technique. Usually several isotherms (each corresponding to a different heat flux) are taken by RGB video-camera to record the local Nusselt.
contours under an oblique Reynolds number. The location of each isotherm and colour (adjusted to each Nusselt number) are digitised following a projection of the false colour image on a digitising image respectively. Figure 4 shows a photograph of the colour distribution of the liquid crystal layer around square section column, image of the computer display after segmentation processing (Hue: 45-55) and false colour image processing respectively on bottom [7]. Also, Figure 5a shows a false colour image of local Nusselt number contours over a central diamond of the corrugated-undulated heat exchanger surfaces [8]. The cross corrugated and corrugated-undulated surfaces are frequently employed to improve heat transfer coefficient for high heat flux applications. Improvements in their flow and thermal characteristics does not require any demonstrations and would substantially reduce fuel and production costs. The measuring technique comprising the use of LC flexible sheets and true-colour processing may also be used for a great variety of applications and should be of considerable use in improving the design of all types of compact heat exchanger. Experimental procedure cover full-field flow patterns in classic heat exchanger elements (flat plate with fine-tubes in-line, staggered and with vortex generators) describing local heat transfer coefficient and Nusselt number on the surfaces [9]. Example of such results is presented in Figure 5b.

5 Conclusions

Thermographic examination can be used in case of diagnostics and monitoring of different diseases. Those methods are especially useful for children because they are non-invasive, fast, reliable and visually attractive. TLC can be used especially in small medical centres, as well as by home doctors. There is also a possibility to use TLC for remote diagnostics (radio or phone description of symptoms).

The measuring technique comprising the use of TLC flexible sheets and true-colour image processing may also be used for a great variety of technical applications and should be of considerable use in improving the design of all types of compact heat exchanger. The computer aided analysis of colour images of micro-encapsulated TLC is an important investigative method of two-dimensional surface temperature measurement.

References

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