OPTICAL DIAGNOSIS SYSTEMS FOR MEASURING THERMOFLUIDDYNAMICALS PHENOMENA IN LIQUID BIOSYSTEMS UNDER ULTRA HIGH PRESSURE

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Summary In modern bioprocess engineering, novel visualization systems for investigating thermofluiddynamical, particularly, phase transition phenomena occurring when liquid systems are pressurized up to 10000 bars, are already presented. Of crucial importance is the observation made for the first time that phase transition causes a substantial convective transport which has been totally ignored in literature till now.

INTRODUCTION

Pressure is a fundamental thermodynamic quantity, comparable to temperature or chemical potential. Thus, the result of application of sufficiently high pressures in bioprocesses proves to be extremely manifold. This reveals pressure as basic tool for fundamental research, for specific biostructure creation and bioprocess design. As a consequence of this, research in the field of high pressure treatment of biomaterials has become recently to an extremely promising and, therefore, worldwide very dynamically developing discipline. Most progress has been achieved in food and biosciences but other disciplines such as medicine have also recognized the high potential of high pressure treatment meanwhile.
In most of the papers in literature the description of biophysical and chemical effects under high pressure occurs assuming validity of thermodynamics for homogeneous matter at rest. It could be shown experimentally and theoretically that this postulation does not hold [1]. In fact, compression is always connected to a forced convection. Furthermore, compression under practical (non-isotherm) conditions generates thermal diffusion and, thus, natural convection in liquid biomaterials. Altogether, it must be stated that the pressurization processes are always heterogeneous even in the case of homogeneous matter available.
Excluding certain biochemical reactions, the inner time scale of running processes during pressurization must be expected to be substantially longer than the sound velocity, which is responsible for the transmission of pressure. Therefore, pressure treatment can be considered as instantaneous but not as homogeneous [1]. The present contribution deals with novel methods suitable for visualizing heterogeneities of the velocity and pressure fields. Particularly, the adaptation of these methods for measuring pressure induced phase transition and corresponding results are presented.

EXPERIMENTAL METHODS

For visualization of velocity and temperature fields microencapsulated thermochromic liquid crystals are used while they can reflect selectively light as a function of temperature. Furthermore, in [2] it was shown for the first time that the wave length of the reflected light also depends on the pressure. Finally, the liquid crystals used are also well suitable as tracer. Thus, they allow determining the temperature distribution by illuminating the liquid crystals with white light and analyzing the reflected light (color or wavelength). Additionally, this facilitate the determination of the velocity field via Particle Image Velocimetry (PIV).
The main experimental setup consists of a tempered high pressure optical cell having a volume of 2 ml, which is equipped with sapphire windows of 6 mm optical width. This high pressure cell is designed to bear pressures up to 700 MPa. This system is illuminated by a sheet of white light from a xenon lamp. The field is recorded by a fixed 3-chip RGB (Red-Green-Blue) CCD camera which is located at a right angle to the incident light sheet. This reflected light is first expressed as HUE values and then related to temperature and pressure by help of digital post-processing. Performing experiments in a wide range of pressure and temperature with different types of liquid crystals have shown that they can be used in a wide temperature range and at pressures at least up to 700 MPa. Thus, High Pressure Particle Image Thermography (HP-DPIT) and High Pressure Particle Image Velocimetry (HP-DPIV) have been developed.

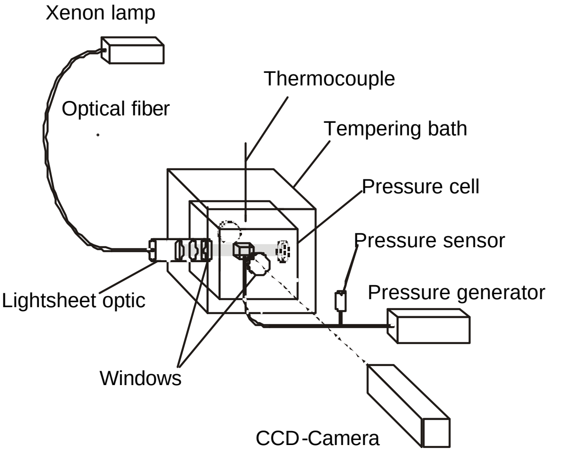

Figure 1: Experimental setup

The liquid crystal particles (having 10-15 µm diameter and 1 g/ml density) used in this study are encapsulated in a polymeric material for protection (from Hallcrest Ltd, BM/R-30C2W/S40).The particles are disposed for tracing the fluid motion in the substance. Visualizing temperature and velocity fields in liquids necessitates only a low particle concentration of about 10^{-2} to 10^{-3} volume percent. Experimentally, significant difficulties are caused by finding the proper liquid crystals in the region of phase transition. In general, it is possible to have liquid crystal solutions at every start temperature and bandwidth (the temperature where liquid crystals start to reflect and the range in which they change the reflected colour, respectively). But, low temperatures decrease the stability of crystals and therefore it is not possible to produce narrow bandwidths.

RESULTS

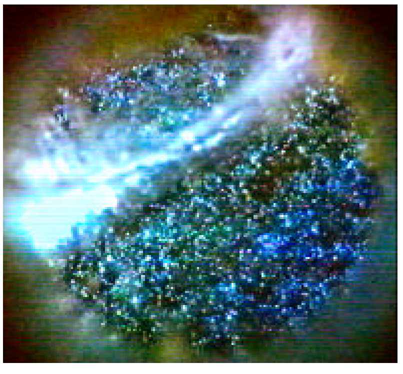

Figure 2: Phase transition of Ice I under high pressure (150 MPa)

Figure 2 and 3 illustrates typical results obtained for the temperature and velocity field in water during pressure induced phase transition to the Ice I conformation [3]. For this process the cell is first cooled down to 263 K and then pressurized to 120 MPa. Then the temperature of the temper bath is set to a temperature around 278 K. In Figure 2 the diffuse streak corresponds to the transition front whereby the rigid phase is placed in the upper part. The blue color corresponds to the higher temperature which decreases with increasing wave length. Thus, red indicate the smallest temperature whereby the detectable temperature difference between blue and red is 1.3 K. This demonstrates the excellent temperature resolution of HP-DPIT. Figure 2 also clearly demonstrates the heterogeneity of temperature distribution in the liquid phase. Most remarkable is the "cold spot " [1] located in the upper right part. In this context it must be taken into consideration that temperature strongly influences biophysical and –chemical processes. Furthermore, the effect of high pressure on microorganisms is strong function of temperature, too.

The existence of the cold spot mentioned is not only a result of thermal diffusion but mainly of convective transport. Figure 3 illustrates convection during melting of ice. This process starts by melting of ice near the wall region where temperature is maximal. In the presence of liquid ice detaches from the inner wall of the cell. Ice I moves up because of its density is lower than that of water. Movement of the ice block forms two counter rotating vortices in the water layer below it. These vortices have accelerative effect on heat convection: the liquid from near wall region is carried near to the solid-liquid surface and phase transition develops. In PIV image solid body motion can be differentiated with the area located in the upper part of the figure. In the lower fluid part, substantial convection is observed. This is contradictory to the pure diffusive effect of a system in rest assumed in literature. Thus, results for biophysical and –chemical as well as microbiological effects obtained yet have to be checked taking into consideration the coupled momentum and energy transfer found in experiments. Furthermore, the design of high pressure chamber for practical applications of high pressure on biomaterials must include the occurring convective transport processes.

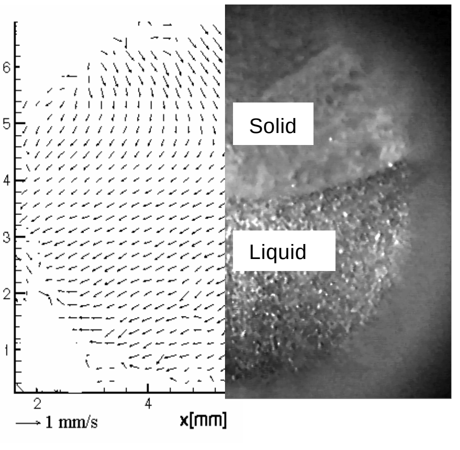

Figure 3: Convective processes during melting of Ice I

CONCLUSIONS

HP-DPIT and HP-DPIV, originally developed for diagnosing temperature and velocity fields in pure one-phase liquids under high pressure, have been further adapted to a method for High Pressure Digital Phase Transition Detection (HP-DPTD). The latter has been shown to be suitable for detecting the transition front as well as the temperature and velocity distribution in its neighborhood. The results found show conclusively that neither the assumption of homogeneity nor of pure diffusive transport in a resting liquid holds. As biosystems are very sensible against mechanical and thermal heterogeneities results published yet are worth to be checked carefully.

References

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