Response of Superheated Emulsions to heavy ions

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Abstract
The response of superheated emulsion to heavy ion has been investigated at the heavy ion medical accelerator facility (HIMAC), Chiba, Japan. The response has been observed by counting the nucleation rate by varying the operating temperature of the emulsion. The present study is important in order to explain the nucleation in superheated emulsion by heavy ion.

1. INTRODUCTION

The response of the superheated emulsions to heavy ions was investigated at the Heavy Ion Medical Accelerator Facility (HIMAC), Chiba, Japan. The superheated emulsions used in the present work consists of drops of the superheated liquid, R114 [$C_2Cl_2F_4$, b.p. 3.77°C] suspended in a firm polymer matrix. The emulsions were irradiated by ^{40}Ar (500MeV/u), ^{20}Ne (230MeV/u). The response was observed by counting the nucleation rate and by varying the operating temperature of the emulsions. The present work studies the nature of the response of the superheated emulsions to heavy ions of different energies by varying the operating temperature of the emulsions and measures the threshold temperature of nucleation. The results obtained from the experiments were also compared with the estimations.

2. PRESENT WORK

It is known that there is a minimum energy required for nucleation to occur in superheated liquid, the so called critical energy. The critical energy decreases with increases in the operating temperature and by varying the operating temperature of the emulsions, ions of different energies can be detected. The critical energy for nucleation obtained from reversible thermodynamics can be expressed as

$$W = \frac{16\,\pi\,\gamma^3(T)}{3\,\{P_v(T) - P_l\}^2} \qquad (1)$$

where $\gamma(T)$ is the surface tension at temperature T, $P_v(T)$ is the vapour pressure of the liquid at temperature T, and P_l is the liquid pressure [1]. The critical energy (W) is related to the critical LET of ions in the sensitive liquid by the following equation

$$\frac{W}{k\,R_c} = \left(\overline{\frac{dE}{dx}}\right)_{L_{eff},c} \qquad (2)$$

Where $\left(\overline{\frac{dE}{dx}}\right)_{L_{eff},c}$ is the critical LET and $\left(\overline{\frac{dE}{dx}}\right)_{L_{eff}}$ is the track averaged LET over L_{eff} with $L_{eff} = 2R_c$ and '*k*' is the nucleation parameter [2-5].

The response of the superheated emulsions to a uniform beam incident normally to the emulsions is given by

$$\frac{1}{I_B\,N_o}\left(\frac{dN}{dt}\right)_{t=o} = s_d \qquad (3)$$

When the operating temperature (T) is at or above the threshold temperature, equation (3) holds, and when T is below the threshold temperature, $\frac{1}{I_B\,N_o}\left(\frac{dN}{dt}\right)_{t=o} = 0$. Therefore the ideal case is that the response should be zero below the threshold and at or above threshold it should be a constant (s_d).

The superheated emulsions used in the experiments were about 8 cm long and 1.5 cm in diameter. The interest of the present work is to observe the response of the emulsions by the higher energy part of the heavy ions of lower LET in the emulsions. The reported work with heavy ions studied the threshold LET by irradiating the emulsions with the axis parallel to the beam and by measuring the path length of the ions in the emulsions [6]. In the present experiments, the detector was irradiated vertically, so that the maximum path length of the ions in the emulsions is about 1.5 cm, which eliminates the Bragg peak of the ions and the threshold temperature of nucleation could be measured by increasing the operating temperature above the room temperature. The temperature was changed from room temperature, 25°C, to 80°C by the temperature controller (SDC21Yamatake Honeywell, Japan) with an accuracy of ± 0.1 °C. The nucleation was observed by counting the number of nucleated drops with

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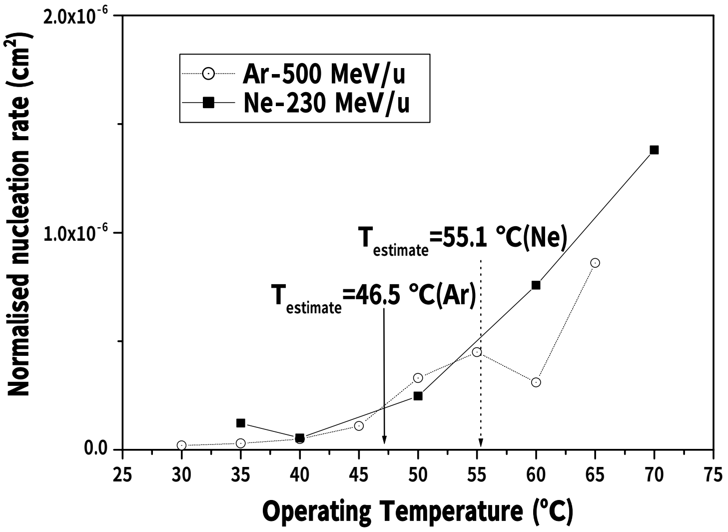

Figure 1: Observed response of the emulsions for Ar and Ne ions with the theoretically estimated threshold temperatures (46.5, 55.1℃)

an acoustic transducer, preamplifier, pulse shaping circuit, and the multi-channel analyzer [7].

3. RESULTS

The experimentally observed variation in the normalized initial nucleation rate $\left[\frac{1}{N_o I_B}\left(\frac{dN}{dt}\right)_{t=0}\right]$ in the presence of Ar and Ne ions of different energies is shown in Figure-1. The response of the emulsions shows a gradual increase with temperature near the threshold. Figure-1 shows that at low temperatures the response is very low and almost flat. The response above this value has been taken as the true response for the ion with a specific energy. The origin of this flat part at lower temperature is supposed to be due to scattered ions of different energies at the experimental site during the irradiation. The threshold temperature has been evaluated as the midpoint between the temperatures at the flat part of the response and the response at the next immediate higher experimental temperature.

Before entering into the emulsions, the ions pass through 6 m of air, 1 mm of Al, and 1 mm of glass. The ion energies in the emulsions were estimated using TRIM code by considering the energy loss in air, Al, and glass.

The estimation of the threshold temperature was made by relating $\frac{W}{kR_c}$ to the LET of the ions in R114 with 'k' (=0.11) as a constant nucleation parameter employing equation (1). The threshold temperatures obtained from the estimation are also shown in Figure-1.

4. DISCUSSION

The response of the emulsions with rising temperature shows a gradual increase near the threshold. There is a reasonable agreement between the estimated threshold temperatures and the experimental results. According to the calculation, the response of the emulsions should increase sharply at the threshold, but the experimental results show that the response increases gradually near the threshold. Though the incident heavy ions are mono-chromatic, there is scattering of the ions by the material (such as Al, Glass) surrounding the emulsions, and this produces the ions of lower energies incident on the emulsions. There is also a distribution of the size of the drops. These various factors affect the response of the emulsions and prevent the appearance of the expected sharp cut off at the threshold temperature. The present study is important in order to explain the nucleation in superheated emulsions by heavy ion.

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