R&D on a large single volume detector for dark matter search experiment

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Introduction

It is well known that a liquid can be raised to a metastable state without vaporization, where it is at a temperature higher than its boiling point. This metastable state of the liquid is known as the superheated state. It has already been observed that the micrometer sized superheated droplets of perfluorocarbons in an emulsion can be vaporized by exposing it to the energetic particles [1]. The mechanism of radiation induced nucleation has been described by Seitz's thermal spike theory, according to which the energy deposition by the ionizing particles produces highly localized hot regions that produce microbubbles larger than a critical size, which expand and finally vaporize the metastable liquid. The superheated liquid is used in the dark matter search experiments [2], due to its property of being sensitive to the highly ionizing radiations, yet virtually insensitive to the majority of the background events produced by the gamma rays, beta rays, cosmic muons etc. The PICASSO, COUPP and SIMPLE are the leading groups working on the dark matter search experiments using superheated liquids. In these experiments, it has been observed that the neutron and alpha particles produce the majority of the background event. Though the background neutrons can be reduced substantially by proper shielding, but the radioactive contaminations present in the emulsion itself produce the alpha particles which cause the background. The alpha induced events in the detector have to be reduced for a better experimental data for the dark mater searches. The alpha particles have a very small attenuation length in the detector medium and the alpha induced bubble nucleation occurs near the surface of the droplet. Thus the detector containing large number of micron sized smaller droplets has a larger total interfacial area compared to a detector with a single droplet of same active volume. The objective of this work is to make a prototype single droplet module with a relatively smaller surface area with less alpha activity which is suitable for the dark matter search experiment with superheated liquids.

Fig. 1 The pressure chamber for the detector fabrication.

Detector R & D

In this work, we have used three refrigerant liquids such as the R12 (CCl_2F_2; b.p. -29.8°C), R134A ($C_2H_2F_4$; b.p. -26.6°C) and R114 ($C_2Cl_2F_4$; b.p. 3.7°C) as the sensitive liquid and the aquasonic gel and Triton-100 as the supporting matrix. For the detector fabrication, a perspex pressure chamber (Fig. 1) was used which was designed and fabricated at the Saha Institute of Nuclear Physics. The superheated liquid is normally unstable due to the presence of the heterogeneous nucleation sites such as the gas pockets, air bubbles etc. To reduce the heterogeneous nucleations the active liquid is transferred in a degassed medium.

It was observed that in the aquasonic gel medium the droplets of size of few millimeters can be produced. When we transferred more active liquid it was observed that due to the density mismatch between the refrigerants and the gel, the R12 and R134A floats above the gel and vaporizes quickly when the pressure was reduced below the saturation vapour pressure of the active liquid. For R114, it was observed that the transferred liquid sinks in the gel, since R114 is heavier than the gel. As a result of being in direct contact with the perspex surface a large number of heterogeneous nucleations were observed from the perspex surface.

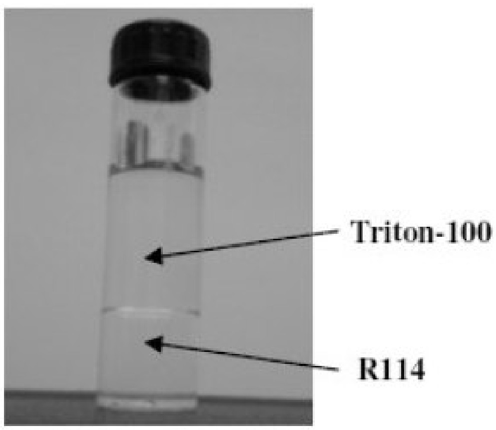

Fig. 2 The superheated R114 liquid at the bottom with the surfactant at the top

To produce a stable detector the heterogeneous nucleations from the container walls has to be reduced as much as possible. With the execution of next R & D, it was found that to deactivate the surface nucleation sites, a surface wetting agent like surfactant is the most suitable one. We used Triton-100 for detector fabrication. In this method first Triton-100 was taken in a glass vial and then it was degassed. After that the glass vial was put in a pressure chamber and kept under 60 Psi pressure for a few minutes. Then about 11ml of R114 was transferred inside the surfactant. R114 is heavier than Triton-100 and it forms a layer at the bottom of the vial (Fig.2). After releasing the pressure, at room temperature (about 25^{o}C) the stability of the detector was examined. Here the liquid was at a reduced degree of superheat (S_T) of 0.21 [$S_T = (T - T_b)/(0.9T_c - T_b)$, where T is the ambient temperature; T_b and T_c are the boiling point and critical temperature respectively. All temperatures are in Kelvin]. In total 10 hours of observation only one nucleation event was noticed in the detector. In the present R & D work, this method of detector fabrication for a large volume superheated liquid based detector is found to be most effective.

This method was also repeated with R134A liquid. Here about 10ml of R134A was transferred in the vial. After releasing the pressure at 25^{o}C (S_T = 0.57 which is much higher than that for R114 at 25^{o}C) only three nucleation events were observed and the active liquid was stable up to about 15 minutes at a high degree of superheat, about 51^{o}C above its boiling point.

Conclusion

From this study it is observed that a detector containing one or two millimeter sized superheated liquid droplets in an aquasonic gel is stable up to a few hours at room temperature. In other case, if the volume of the active liquid transferred in the gel is increased, instead of droplets a single layer of the active liquid is formed. These detectors are prone to heterogeneous nucleations from the container surface and thus unstable. By deactivating the surface nucleation sites, if the active liquid is transferred in the surfactant, the detector shows a much better stability that is suitable for the long term practical use of such detector to dark matter search experiment. By choosing a less viscous surfactant, repeated detector operation can also be achieved.

Acknowledgments

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References

[1] S. C. Roy, R. E. Apfel and Y. C. Lo, Nucl. Instrum. and Meth. A **255**, 199 (1987).
[2] S. Archambault et al., PICASSO collaboration, Phys. Lett. B **682,** 185 (2009).