Design Considerataions for a Laboratory Condensation Chamber to Investigate Issues of IFE Liquid Walls

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The objective of this presentation is to report on the status of the facility for the study of flibe vapor condensation at UCLA. The effectiveness of the electro-thermal plasma source to simulate IFE chamber prototypical conditions has been previously tested. Preliminary results of flibe vapor generation in an expansion chamber with bare, transparent walls have been used to model the behavior of the plasma source and guide the design of new components aimed at the investigation of the condensation process. The complexity of the design of the condensation chamber is presented with a discussion on its operational characteristics. Suitable diagnostics to quantify condensation rates in the highly varying pressure and density regimes have been identified.

1. Introduction

Liquid walls represent the most effective solution to the problem of the absorption of neutron and x-rays pulsed wall loads that are typical of Inertial Fusion Energy systems. The advantage of a flowing liquid surface is evident: the surface constantly renews itself and neutron and x-ray energy deposition and damages accumulate only in the short residence period and not through the reactor lifetime. A flowing liquid blanket would also naturally carry out the heat recovery and tritium extraction function without the need of other structural materials, therefore reducing activation and simplifying the design. The choice of material is limited by the necessary presence of lithium for tritium breeding. The molten salt flibe, composed of two moles of lithium fluoride (LiF) and one mole of beryllium fluoride (BeF2), combines many attractive properties for IFE systems, among which a low vapor pressure [1,2]. This is a necessary condition to ensure that the chamber environment can be efficiently maintained at the vacuum conditions required for drivers propagation, yet not sufficient. The x-rays mean free path in the liquid flibe is extremely short, and the energy associated with the x-ray flux is deposited in the first few millimeters of liquid. The volumetric heat density is sufficient to vaporize the liquid and partially dissociate the molecules, creating a cloud of superheated, partially ionized vapor that rapidly expands into the chamber. Recombination, cooling and condensation of this cloud are crucial issues for the feasibility of high repetition IFE systems [1,3]. The Fusion Sciences Technology Group at UCLA started in 1999 a project to investigate chamber clearing rates by addressing the issues of flibe recombination and

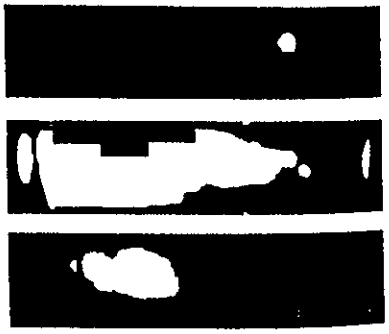

Fig.1 Flibe plasma generation

condensation under IFE conditions. The design, construction and characterization of an experimental facility for the generation of flibe plasma has been described elsewhere [4]. The visible radiation emitted during a flibe discharge in a transparent chamber recorder with a CCD camera is shown in Fig.1. This paper reports on the design of the chamber for the study of vapor clearing rates.

2. Design considerations for the condensation chamber

The effort here presented is aimed at achieving in the experimental facility conditions that are relevant to IFE chambers by a careful design of the condensation chamber. The 1-D code ODIN has been used to extrapolate plasma parameters from the experimental data [4]. For this study the most relevant of them is the initial volumetric density of the superheated vapor. Numerical analysis based on the HYLIFE-II design showed that the initial peak of vapor density generated from x-ray ablation of the liquid surface is approximately 1×10^{18} #/cm^3 [5]. The variables that most affect the vapor density in the laboratory experiments are the volume of the test chamber and the energy of the discharge (that determines how much plasma is produced). A parametric study of the vapor density as a function of the discharge current intensity peak (that determines the overall discharge energy) for chamber volumes of 5, 10 and 15 liters is performed. To maximize the ratio of condensation surface area to volume the compact chamber of 5 liter volume is chosen. The parametric study shows that a discharge with a 90 kA current peak is needed to produce the desired density. Analysis of the Pulse Forming Network is performed to assess its feasibility. The current and voltage data collected in the plasma source are used to evaluate the transient plasma resistance, and the results extrapolated to high energy discharges. The analysis shows that the capacitor banks have to be charged to -13 kV, using only about 60% of the maximum capability of the facility.

The design is aimed to create a simple cylindrical geometry to benchmark the numerical code under development. A ratio of 3:1 is chosen for the 5 liter chamber, resulting in a cylinder of 5'' diameter and about 15'' length (Fig.3). The area for condensation is 0.14 m^2, but the volume to liquid surface ratio can be easily varied for scaling purposes by arranging the configuration of the internal wall. In the IFE chamber, the vapor cloud expands in contact with flibe liquid surfaces that form the protective pocket. To preserve these conditions, the chamber first wall is formed by a uniform film of liquid flibe. The scarce availability of flibe (about 1 liter) does not allow a design based on a free flow of liquid to cover the wall. The film is formed by flowing liquid between the structural wall and a screen (Fig.4). Flibe is introduced in the chamber at the top from two external reservoirs and slowly flows downward by gravity forces and pressure differences controlled with mechanical

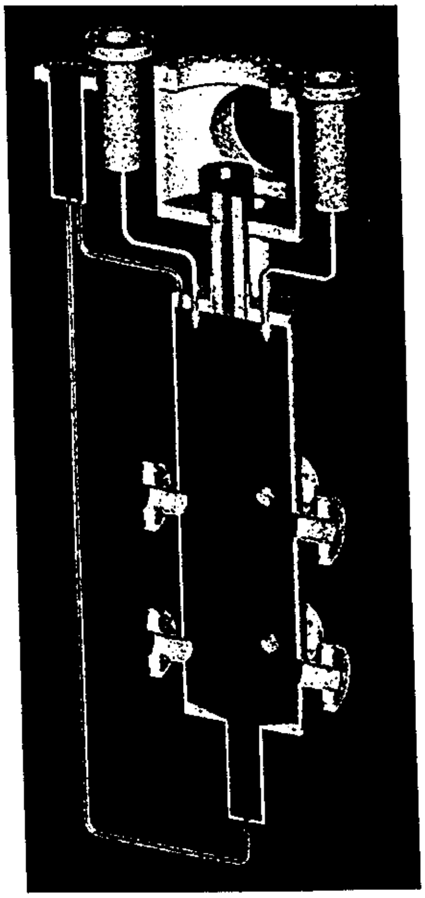
Fig.3 Condensation chamber

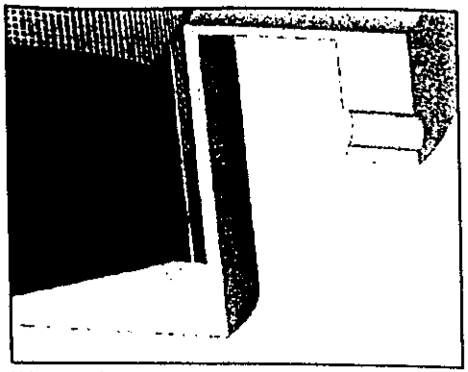

Fig.4 Liquid wall detail

valves. The liquid seeps through the meshes of the screen creating the wet wall. The mesh size of the screen is varied in the vertical direction to form a uniform liquid layer. Smaller mesh sizes balance the effect of thickening of the liquid wall due to gravity effect. Surface areas not wetted by flibe (top plate) are maintained at the same temperature of the liquid. A pumping port is necessary to remove residual gases in the heating phase and ensure clean and repeatable initial conditions. It is located on the upper plate, and is closed with a shutter during the test. Flibe collects at the bottom of the chamber and is then transferred back in the reservoirs by pressurizing the chamber volume with argon. Nickel wires are inserted in the reservoirs to measure the liquid level during transfer operations. Each wire is supplied with a voltage potential. Since flibe is a weak electrical conductor, a current will be detected when the liquid level reaches the tip of the wire. All the surfaces in contact with liquid flibe are made of Nickel 200 to minimize corrosion due to the formation of HF. The structural wall and the plasma source anode are the vacuum boundary of the system. The chamber and the reservoirs are heated with Inconel-based electrical band heaters to maintain the flibe at 550 C. The chamber top lid and the plasma source temperature are independently controlled. The chamber is already configured for a second set of experiments, where cooling flibe droplets are injected from the top of the chamber using auxiliary pressurized reservoirs. The design of the droplet generating nozzles has to be scaled with HYLIFE-II conditions, and is not discussed in this paper even if experimental testing of various methods of flibe droplet generation and size control has started.

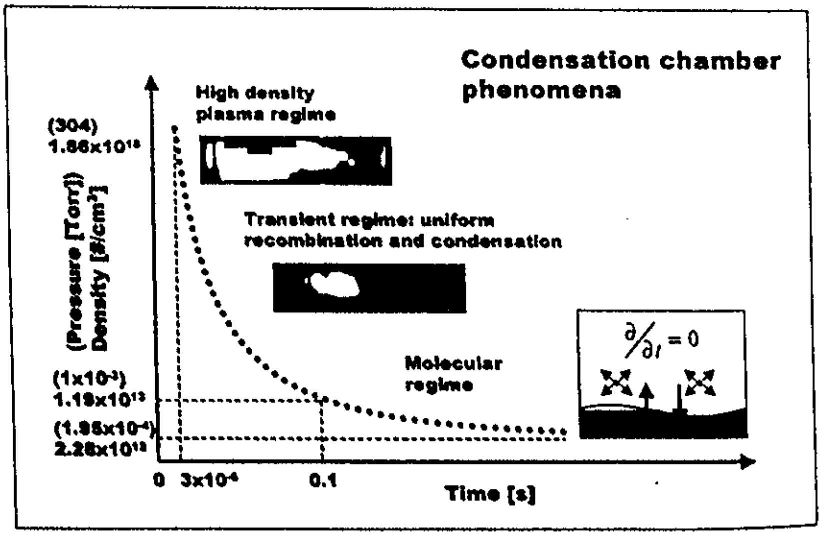

Fig.5 Illustration of condensation chamber phenomena

The scheme in Fig.5 illustrates the highly varying pressure and density regimes developing during each test. First the high density, 1-3 eV partially ionized vapor is injected in the chamber with IFE prototypical density. The initial pressure of the plasma is nearly atmospheric, and the cloud emits intense radiation in the visible spectrum. Then the plasma recombines into superheated vapor, cools down and condenses in contact with the walls. In Fig.5 the marked intermediate value of 1 mTorr refers to the upper limit at which the ion beam driver can propagate [6]. The value of 0.1s has been estimated numerically [5], and its experimental verification is the main goal of the project here described. Ultimately the pressure in the chamber should drop back to the steady-state value in equilibrium with the liquid surface, even if the presence of impurities will inhibit a complete recovery of the initial conditions without clearing the residual gases. The variety of pressure regimes coupled with the high operational temperature and the corrosive nature of liquid flibe impose severe restrictions on suitable diagnostics. Two fast response, solid state pressure transducers will be mounted through thermally isolate pipes at the top of the chamber. A shutter is needed to isolate them from the chamber volume during steady-state heating, to avoid flibe condensation in the tubes. The shutter opens during the test. The transducers are based on a piezoresistive sensor for the 10-760 Torr range and a pirani sensor in the vacuum regime. The effect of the high temperature, corrosive environment on the sensors is a concern, as well as the effect of the presence of the cold areas of the tubes inlet on the condensation process. Non intrusive, optical diagnostics appear to be the best solution, aside from their complication and expensiveness. The chamber is designed with two sets of optical ports. The ports are heated and covered with a shutter to avoid condensation on the window during the steady-state heating phase. During the test, the shutter opens and the window in contact with the external environment will act as a condensation sink. This effect is assumed negligible due to the short duration of the process. The radiation emitted by the high-density plasma upon injection is channeled to a SPEX 1702 0.75m spectrometer. Following the pressure broadening reduction of the spectral lines allows a time-resolved estimate of the vapor pressure in the high-density phase. This effect will become hard to resolve as the pressure drops, and laser-based methods might have to be used in the intermediate to molecular regime [7]. The three ports configuration showed in Fig.5 allow the use of laser absorption methods through the facing windows or laser fluorescence and Raman scattering through the 90° windows. The facing windows will also be used for laser direct scattering methods to measure cooling droplet size. The method has already been tested, and will be used before the experiments to characterize the droplet spray pattern.

3. Summary

Design considerations for a laboratory chamber to study flibe vapor condensation with conditions relevant to IFE systems have been presented. The objective was to discuss the complexity of the technical issues involved with the laboratory simulation of the IFE liquid pocket based on the HYLIFE-II design, and to present the solution adopted for the UCLA facility.

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