DESCRIPTION OF A FACILITY FOR VAPOR CLEARING RATES STUDIES OF IFE REACTORS FLIBE LIQUID CHAMBERS

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ABSTRACT

The design and operating characteristics of the ALICE (Advanced Liquid Ionized Condensation Experiment) facility at UCLA are here presented. The goal of this vapor condensation experiment is to rapidly generate an IFE prototypical post-shot vapor density in a control volume using characteristic liquid chamber material (flibe, Li_2BeF_4), and investigate the condensation rates for the proposed schemes. This experimental goal is achieved by: 1) a pulsed electrothermal plasma source that simulates the pellet explosion for rapid vapor generation and 2) an expansion chamber that represents the IFE liquid chamber. This paper reports also on the construction and operation of a furnace for flibe casting. Melting and handling procedures connected with the use of flibe are also discussed. The first flibe liner has been inserted in the plasma source. Results from the first low energy experiments are showed.

I. INTRODUCTION

In the framework of the IFE liquid chamber protection scheme R&D at UCLA, a facility is constructed to investigate vapor condensation and clearing rates for IFE liquid wall chamber concepts. This facility is designed to produce a high density partially ionized vapor cloud of flibe to simulate vapor generation by x-ray ablation from an IFE target. The generated vapor is driven into the expansion chamber by the pressure difference, and simulates the phenomena occurring in the IFE chamber. The plasma jet first undergoes abrupt expansion, generating alternate expansion and compression waves reflecting on the chamber walls. When the hydrodynamics phenomena extinguish, a uniform vapor pressure is reached and bulk condensation starts. Later, liquid jets and droplet spray will be introduced in the chamber to simulate the interaction of the vapor with the undisturbed liquid wall and the effect on enhancing condensation. A picture of the facility is shown in Fig. 1 and its operating capability is listed in Table 1.

Since the completion of the facility assembly in February 1999, shots were performed using different polycarbonate liners to characterize the plasma gun and pulse forming network performance. It has been found that Lexan ($C_{16}H_{14}O_3$) shows a better resistance to cracking and fracturing under the thermo-mechanical load. As the goal was to better understand the plasma characteristics and obtain operating experience, the voltage has been limited to 10 kV for safety. Also, only single capacitors have been used in each shot in order to test them independently. As a result, we achieved shots with maximum discharge energy of 2.5 kJ. The results confirmed the pulsed nature of the plasma source, and are in good agreement with data from other thermoelectric sources.[1,2]

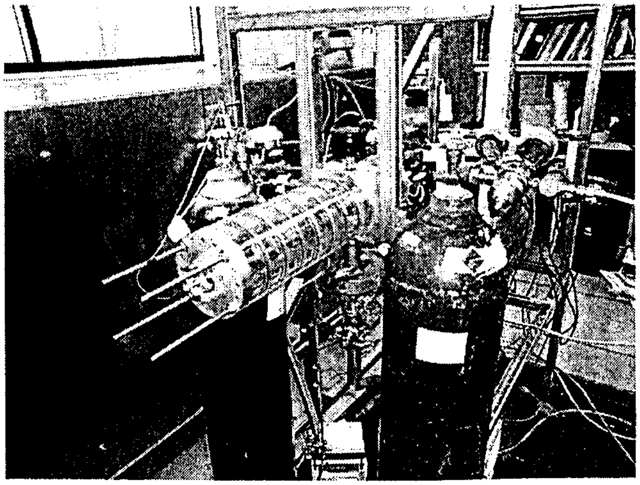

Fig.1 The ALICE facility at UCLA.

ALICE OPERATIONAL CAPABILITY	
Max. discharge voltage	22 kV
Expected max. current	500 kA
Discharge period	100 μs
Max. energy storage	154 kJ

Table 1 ALICE operational capability.

In this paper we first give a general description of the vapor condensation experiment (a detailed discussion of the facility design and first phase of operation can be found in a previous paper).[3] Than we describe a new improved design of the triggered spark gap that allows a better control of the discharge by accurately controlling the voltage breakdown. Also, we present the construction and operation of the flibe melting facility, and discuss the results of the first casting experiments. Results of the first shots using a flibe liner inside the plasma source are also briefly presented.

II. FACILITY DESCRIPTION

The laboratory facility ALICE (Advanced Liquid Ionized Condensation Experiments) consists of four independent modules: the pulse forming network, the plasma source, the condensation chamber and the data acquisition system. The pulse forming network is a network of electric components designed to store up to 145 kJ energy necessary to produce the plasma jet and to deliver it to the source in a single pulse of around 100 μs duration under safe operational conditions. The plasma source, schematically showed in Fig.2, is designed to confine the discharge inside a hollow cylinder (liner) made of the material to be ablated.

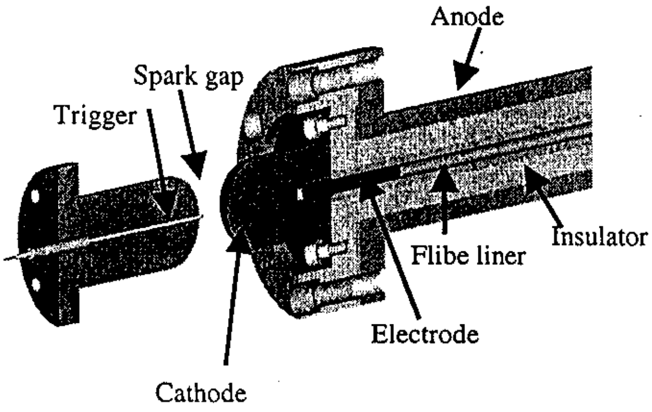

Fig.2 Plasma source schematic.

The condensation chamber presently used is aimed to characterize ALICE plasma source capability in terms of generated vapor characteristics and to set guidelines for the design of the next phase. It has been constructed by connecting a series of transparent plastic cylindrical modules to maximize flexibility and to allow direct observation of the discharge products. Its overall volume is about 3 liters. The design of next phase condensation chamber has started. To reproduce IFE chamber conditions it is necessary to preserve the area ratios of bulk liquid, droplets and stainless steel structural surfaces. To obtain this the inner surface of the chamber will be coated with a flowing liquid flibe film. The total area will be scaled with the debris energy (about 30% of fusion yield). The data acquisition system records the electrical parameters of the discharge and the pressure history. A Rogowski coil from Pearson Electronics measures the current pulse, with a +1%, -0% of initial pulse response accuracy. A 1:1000 high voltage probe from Tektronix measures the voltage drop. A 2 μs raising time piezoelectric transducer measures the transient pressure signal during discharge, while a capacitance manometer measures the slower pressure drop that tends to restore the chamber base pressure. A residual gas analyzer detects the remaining non-condensed gas compositions near the end of the condensation period.

A. The Triggered Spark Gap

The previous design of the spark gap did not allow a complete characterization of the trigger event in terms of electrodes position and trigger intensity, and therefore it was difficult to restore the same conditions after each shot. Also, it proved to be inadequate to sustain the mechanical forces acting on the plasma source as a consequence of pressure build-up and plasma jet expansion in the chamber. In the new design of the spark gap the third electrode that carries the trigger signal is positioned inside an insulated bore in the cathode and kept flush with its surface. The trigger wire tip can be replaced with a screw mechanism if being ablated during discharge. The gap between anode and cathode can be accurately controlled and measured with an analog reader (Fig.3).

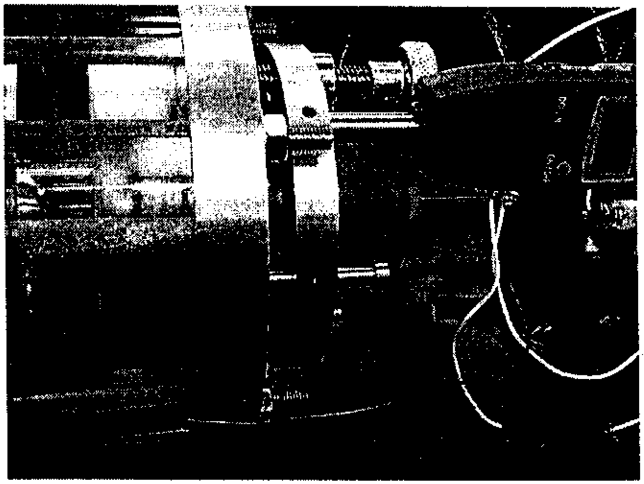

Fig. 3 Triggered spark gap.

The breakdown voltage of a dielectric (for a fixed gas composition and electrode geometry) is a complex function of its pressure.[4] To allow characterization of the voltage breakdown that initiates the discharge and to avoid oxidation of the electrodes, anode and cathode have been inserted inside a pressure controlled chamber. The chamber is filled with pure Nitrogen at the desired pressure. The new design proved to be very effective during the last series of flibe shots. The optimal configuration was found to be a Nitrogen pressure of 76 Torr with a 10 mm gap between the electrodes for the low energy shots performed.

B. Plasma Characteristics

Under the ideal plasma assumption, the resistivity of the plasma during discharge can be numerically modeled. The analysis of the current signal with the aid of the numerical code ODIN allows the extrapolation of other plasma parameters useful for the characterization of the condensation process. Plasma parameters are estimated using the 1-D time dependent code ODIN, a numerical tool developed to extrapolate physical parameters of plasma jets produced in the electrothermal source SIRENS.[5,1,8] This 1-dimensional code models the energy transport, particle transport, plasma resistivity, plasma viscosity and equation of state. The geometry configuration of the source, material properties, and time dependent current signal during the discharge are the necessary input to the code. The source is divided into a specific number of cells and each cell is considered to be in local thermodynamic equilibrium (LTE), with the plasma modeled as a viscous fluid. The viscous drag forces are varied according to the Reynolds number of each cell, and the model varies from laminar to turbulent accordingly. The plasma parameters are assumed to be constant across the cross section of the capillary. The ablated material in the source is assumed to be totally dissociated into the constituent atoms. The ionized gas is assumed to be ideal plasma (correction for weakly non-ideal plasma will be incorporated in future calculations), and the Spitzer model is applied to evaluate the arc resistivity. With this assumptions only the ionization energy of each species present in the liner is necessary to evaluate plasma properties. For flibe calculations ionization energies for F, Li and Be have been introduced. An example of ODIN calculation is showed in Fig.4. Predicted temperature (eV) and ionization state of the plasma are plotted as a function of discharge time for a reference 45 kJ shot and a peak discharge current of 180 kA.

III. FLIBE CASTING

Molten flibe (2 LiF, 1 BeF_2) has been chosen as liquid wall material and primary loop coolant in IFE chamber designs because of its low induced activation, low viscosity and high temperature stability and because it is relatively inert in air and water. However, the use of the prototypical material flibe presents technical challenges for handling and safe operations not only because of its high melting temperature of 465 °C but also because of the beryllium particulate involved in the experiment (in its different composite forms). Furthermore, flibe has a tendency to corrode most structural materials at temperatures above 500 °C due to the reaction potential between HF and the container constituent metals ($M+2HF = MF_2+H_2$), with the possible exception of nickel-based alloys.[7]

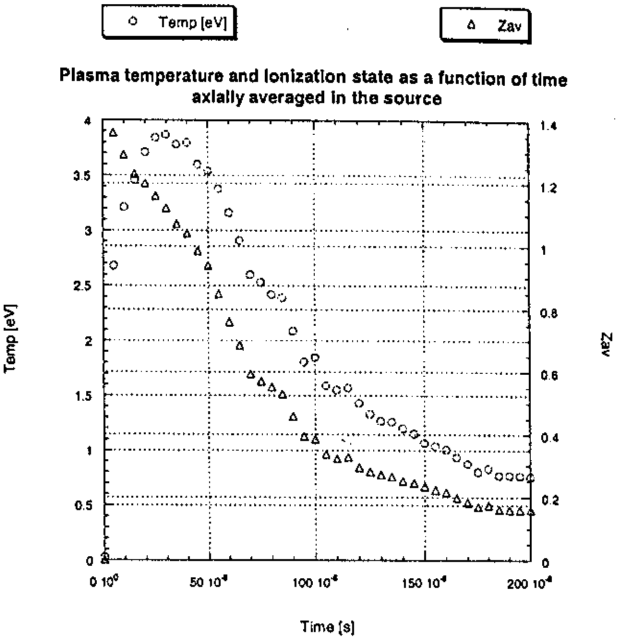

Fig.4 Example of plasma parameters calculations: temperature and ionization state.

Flibe has to be inserted in the plasma gun at room temperature (therefore in its solid crystalline form) in the shape of the cylindrical liner described before. The dimension of the inner radius of the liner is dictated by functional requirements of the plasma gun. Furthermore, comparison between Lexan and flibe shots can be done only for the same liner geometry. For this reasons flibe has to be cast into the desired shape before inserting it in the gun. A furnace has been built as part of the ALICE facility to fulfill this task Fig.5.

Because of the health hazard of Be particles and the corrosive properties of flibe, the design and operation of the furnace present many technical challenges. Solid flibe is inserted at first in a graphite funnel that is connected to a vertical graphite (or quartz) tube. A graphite rod is than centered inside the tube to obtain the desired annular shape of empty volume. Graphite and quartz have been chosen because they showed good interface properties during melting and re-solidification, allowing the extraction of the solid liner from the casting container (the process is facilitated by the negative expansion of flibe while cooling). After melting, flibe flows into the empty volume in the tube driven by gravity force. To allow direct observation of the melting process the chamber upper wall is a Pyrex slab and aligned holes have been placed in the funnel lid and in the reflecting shield. Since the plasma gun design allows to insert liners with different outer diameters, we did not extract the flibe liner from the outside graphite tube to avoid cracking. The presence of the graphite outer shell has no impact on plasma formation in the gun, since the only physical mechanism involved is the ablation of the first few millimeters of the liner inner surface. Chemical analysis on the samples have yet to be performed, but the darkening of the surface of the cast material with respect to the original rock salt might be due to oxidation because of the high water vapor content inside the furnace.

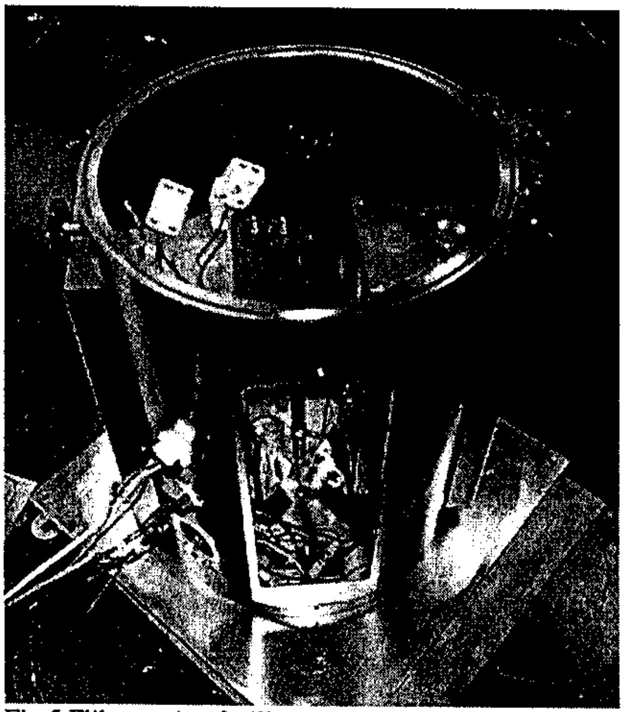

Fig.5 Flibe casting facility.

For the safety handling of solid Flibe before and after casting the furnace has been assembled inside a beryllium safe glove box that was already available in our laboratory at UCLA. To minimize the presence of water vapor during melting and the heat transferred to the furnace structure the furnace enclosure is pumped and maintained in the 100 mTorr range. To minimize weight and corrosion problems, the structure has been made of aluminum and than nickel-plated. Inside the vacuum chamber we used a square furnace assembly composed of two ceramic radiative heating elements facing two metal reflectors and closed at the top and bottom by nickel shields. This design ensures a precise control of the furnace temperature and good temperature uniformity in the volume enclosed in the radiative area.

An RGA (residual gas analyzer) is connected to the chamber to help identify the vapor species that may exist inside the casting chamber. Unfortunately, during the first casting experiments we experienced repeated arching inside the chamber when the tension supplied to the heaters hit its peak value. This vaporized material (mainly Teflon and other wire insulating plastic) created a rich background of hydrocarbon gas pollutants. It also made it impossible for the pump to lower the water vapor peak. As a result, the flibe may have been partially oxidized, and the RGA readings are not very significant because the background noise is as high as the expected traces from flibe vapors. The most likely species expected to be in the flibe vapor are HF, LiF, BeF_2, with some fraction of Li_2BeF_4, Li_2F_2 and $LiBeF_3$. A reference value for the highest partial pressure (LiF) is 1.95E-04 at 550°C [6]. The presence of the water vapor peak allowed to sample gases only through a pressure valve, so all it can be inferred from the scans is the rising with temperature of the peak corresponding to LiF (atomic mass 26). We are currently undertaken the necessary upgrades to achieve cleaner conditions in the furnace.

IV. FIRST EXPERIMENTAL RESULTS OF FLIBE VAPOR GENERATION

The first flibe liner has been inserted in the plasma gun and the characterization of the generated vapor started. At this moment only low energy shots have been performed, with discharge current peaks below 3kA. The reason for this is that at this energy range shots can be repeated without degradation of the liner electrical and mechanical characteristics. This is necessary to characterize the behavior of the discharge using flibe liner and to minimize the quantity of material used in the process, given the low amount of flibe salt currently available to us (30 g received from Oak Ridge National Laboratory). Analysis of the results with the numerical code ODIN will allow a first extrapolation of the generated vapor parameters. An example of current rise and voltage drop during a discharge is shown in Fig.6.

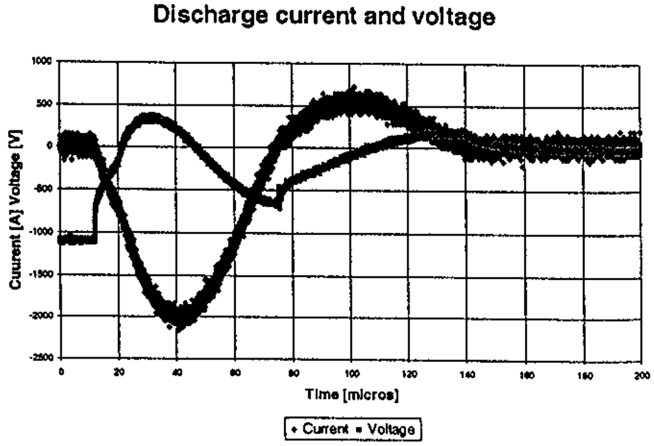

Fig.6 Example of current and voltage data during a low energy shot with flibe.

The series of flibe shots has successfully proven the possibility of using it in the plasma source, and the similarity of the discharge parameters with the other materials previously tested. It has nevertheless shown the necessity of upgrading the data acquisition system to better understand and evaluate early vapor condensation using pressure (and maybe temperature) history data. The piezoelectric transducers need to be electrically isolated from the chamber volume to avid the initial apparent voltage drop due to the presence of negative ions in the chamber. Fig.7 shows a pressure history recorded during a flibe shot.

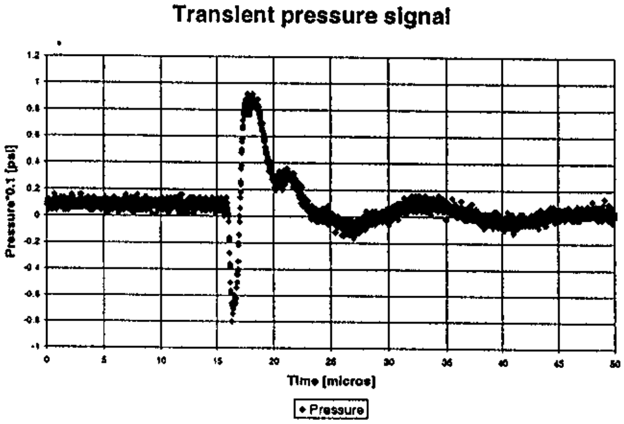

Fig.7 Example of pressure history data of a flibe shot.

V. SUMMARY

A facility that enables the study and evaluation of vapor clearing for IFE chambers with liquid walls is described in this paper. The facility includes two major parts fulfilling two different functional requirements: an electrothermal plasma source to simulate IFE explosion and consequent chamber pressure built-up and vapor formation, and a vapor condensation chamber to simulate vapor clearing processes and phenomena. The first experimental results confirm the possibility of simulating IFE processes with ALICE. It also provides design data in order to complete the design of the second condensation chamber and data acquisition system to analyze the condensation process.

With the new spark gap design, the characterization of the plasma source is completed. The intensity and time behavior of the discharge have been analyzed as a function of the energy stored, using at first non-toxic carbon plastic Lexan as material to be vaporized and than introducing flibe liners in the plasma source. The construction and operation of the flibe casting facility to produce the flibe liners has also been described. Given the low amount of raw material available, flibe shots have been limited to a non-destructive, low energy range. Data from flibe shots have been compared with the more extensive collection of Lexan shots. The data acquisition system has also been also tested. Pressure data from the coupled piezoelectric transducer and capacitance manometer transducer are analyzed to first characterize flibe condensation in the absence of any condensation enhancing techniques.

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