Progress in Research on IFE Chambers and Targets

October 2003 – September 2004

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• One proposed idea to protect the first wall from fusion debris and to assist in the removal of thermal energy in an inertial fusion energy reactor is to use liquid sheets of molten salt.

• A shock tube is used to experimentally study a flat liquid layer subjected to a shock wave. The shock wave accelerates the liquid layer down the shock tube where it is imaged in the test section. The pressure history is recorded as well as images and volume fraction of the shocked water layer.

A water layer is placed on a 0.94 µm Mylar membrane at the interface section 0.46 m above the test section. A Mach 2.12 planar shock wave accelerates a 12.8 mm thick water layer downwards into the test section where the shocked liquid layer is imaged with a flash X-ray onto a conversion screen and recorded with a CCD camera as shown in the schematic below. In the figures on the right, X-ray images which have been converted to water volume fraction at different times after the shock acceleration are shown on the left and the average along the middle region are shown on the right. The shocked layer stretches significantly to about 18 times of its original thickness within about 3.3 ms and contains a maximum volume fraction of about 23%.

**Publications and Presentations**


Thick-Liquid Protection — Georgia Institute of Technology  
S.G. Durbin, M. Yoda, S.I. Abdel-Khalik

- Quantified influence of fine screens on initial conditions and surface ripple fluctuations, see Figures 1 and 2
  - Uniform flow at nozzle exit for all flow conditioner configurations
  - Second screen decreases streamwise velocity fluctuations but not surface ripple
  - Central disturbance observed in transverse velocity fluctuations and free-surface fluctuations for conditioning with no screen
- Quantified impact of boundary layer (BL) cutting on surface ripple and turbulent breakup, see Figures 3 and 4
  - BL cutting improves surface smoothness and reduces turbulent breakup
  - Optimum configuration: Flow conditioning with one screen and 1% of total mass flowrate cut from each face
    - Meets proposed target injection upper limit of $N = 6 \times 10^{21}$
    - Surface ripple well below proposed HYLIFE-II limit of 0.07δ

Publications and Presentations
Progress in IFE Technology: October 2003-September 2004 (Cont’d.)

REDOX Control in Molten Flibe (2 LiF:1 BeF2) – INEEL/ANL-W
D. Petti, R. Anderl, M. Simpson, P. Sharpe, G. Smolik and Japanese collaborators on JUPITER-II: Task 1-1-A

- Experimental system has been developed to establish and control fluorine potentials in molten Flibe with controlled HF inputs.
- Analytical methods (QMS and an automated titration system) have been developed to measure HF concentrations in the outlet gas.
- REDOX control, i.e., HF removal, has been demonstrated by the insertion of Be metal sample in Flibe at 530°C.
- Test series completed with variables: Be exposure time, HF concentration (~1000 & 2000 ppmv), and H2/HF ratio.
- Models have been developed to predict transients in HF concentration during and after Be metal insertion.
- Future goals are to study lower HF concentrations (10 ppmv) and establish Be solubility limit in molten Flibe.

Publications and Presentations

Figure 1. REDOX test system.
Figure 2. Measurements of HF concentrations in the outlet gas during and after Be insertion.
Figure 3. HF model predictions (black) and HF measured concentrations (pink) for Test 10 with 1000 ppmv HF input.
Progress in IFE Technology: October 2003-September 2004 (Cont’d.)

Thick-Liquid Protection, Chamber Dynamics, and Power Conversion—University of California at Berkeley

P.F. Peterson, C.S. Debonnel, G.T. Fukuda, P.M. Bardet, J. Freeman, and the thermal hydraulics team

• UC Berkeley has designed and tested a new scaled large-vortex; the device proved to be a substantial improvement over last year’s vortex.

• A light mineral oil allowing molten salt scaled experiments with little distortion has been identified. Laser visualization of a scaled beam line vortex suggests that a 1-kHz surface renewal rate, which could allow accommodation of a 2-MW/m² heat flux.

• The Vacuum Hydraulics Experiment is being upgraded for higher fidelity simulations of liquid jet disruptions.

• Flibe and flinabe vapor pressures are being measured at relevant temperatures. Preliminary results for pure BeF₂ agree well with published values.

• The pre-conceptual design of a molten coolant gas cycle with 54% thermal efficiency and a compact turbine building has been completed.

Publications and presentations


Progress in IFE Technology: October 2003-September 2004 (Cont’d.)


• The Berkeley gas dynamics code TSUNAMI has been further validated through LLNL’s Condensation Debris Experiment, which offers many similarities with IFE chambers. TSUNAMI predictions and experimental results agree well qualitatively and quantitatively (Fig.1).

• Effort toward a new heavy-ion point design is pursued and innovative target chambers are being explored. The RPD chamber was modified to accommodate the assisted-pinch beam propagation scheme; TSUNAMI was employed to model gas transport and control in the target chamber and the beam lines (Fig.2). The novel large vortex chamber is being investigated as well (Fig.3).

• The next version of TSUNAMI, “Visual Tsunami” is being developed.

Publications and presentations


Progress in IFE Technology: October 2003-September 2004 (Cont’d.)

IFE Chamber Dynamics Modeling and Experiments—University of California, San Diego (http://aries.ucsd.edu/IFE)

- Research on EUV lithography began in our large new lab on February 2004 (Figure 1):
  - EUV spectroscopy added to our diagnostic capabilities (Jen-Optik transmission grating spectrometer, energy monitor).
  - Modeling capabilities and personnel added for rad-hydro and atomic physics (Hyades, Helios, Cretin, Hullac)
- Experiments and modeling studies of underdense Sn and Ti, including CH (plastic foam) and SiO₂ (aerogel) carriers are currently underway (Figure 2).
- Experimental improvements are under investigation:
  - SBS cell for temporal pulse compression
  - density interferometry (Nomarski or Mach-Zehnder)
  - high-field electromagnets for magnetic diversion studies.
- New research on non-LTE plasmas and XUV emissions was started in September 2004 in collaboration with LLNL. The goal is a quantitative understanding of non-LTE plasmas:
  - Address problems in which temperature cannot be uniquely related to the energy.
  - Address long-standing problems modeling radiation from low-density plasmas.

Figure 1. Larger lab with new EUV spectroscopy diagnostic capabilities

Figure 2. Experiments and modeling studies of underdense Sn using EUV spectroscopy and new modeling capabilities

Figure 3. Research on non LTE plasmas will include benchmarking of our modeling capabilities with well-characterized spectroscopic data
Vapor dynamics and condensation studies – University of California, Los Angeles
M. Abdou, A. Ying, N. Morley, P. Calderoni, M. Ni, T. Sketchley

- Super-heated flibe vapor cooling and condensation was measured experimentally in conditions scaled with HYLIFE-II parameters
- Pressure curves follow an exponential decay with time constant $t = 6.58 \text{ ms}$ with chamber walls at 500°C
- Although presence of residual H$_2$ in the flibe pool (from HF purification) did not allow complete recovery of initial equilibrium conditions, the results suggest that for pure flibe vapor the total condensation period is below 60 ms - compatible with the desired 6 Hz rep rate of HYLIFE-II

SEM and EDX analysis of deposited flibe suggest that condensation is locally inhibited on surfaces oriented perpendicular to the vapor velocity in the initial expansion phase ($< 1$ ms) that is characterized by high kinetic energy and a highly directional expansion. A possible explanation is that the center of those surfaces are flow stagnation points and the vapor temperature could locally remain above the critical temperature (T$_c = 4500$ K for flibe), therefore inhibiting the formation of a liquid phase. After the initial expansion phase the vapor has uniform vapor velocity and lower temperature resulting in the observed deposition of micron-sized droplets on all surfaces.

A novel diagnostic for time-resolved spectroscopic lithium and beryllium vapors density measurements was developed and calibrated for lithium vapors. The vapor is excited in a controlled glow discharge in coaxial cylindrical geometry. Light emission is collected by a fiber optic lens and transferred to a compact spectrometer for analysis. A Langmuir probe is used to estimate emitting vapor temperature and density. Measured vapor parameters are correlated to emitted line intensity for real time characterization of condensation process.

Publications and presentations:
[1] P. Calderoni, A. Ying, T. Sketchley and M.A. Abdou “Vapor Condensation Study for HIF Liquid Chambers” presented at 15th HIF, June 2004 and accepted for publication on Nuclear Instruments and Methods in Physics Research - Section A
[3] P. Calderoni “Experimental and numerical study of transient condensation of lithium and beryllium fluoride excited vapors for IFE systems” presented at IAEA RCM, 4-7 November 2003, IAEA Headquarters, Vienna
Progress in IFE Technology: October 2003-September 2004 (Cont’d.)

Integration, Systems Studies, Safety & Environment and Driver-Chamber Interface — Lawrence Livermore National Laboratory


- Completed neutronics analyses for various liquid breeder options for use in Heavy-Ion Fusion chambers. Results show reduction of the DPA rate compared to dry-wall chambers, which allows accelerated damage testing with currently available fission-based neutron sources (see Figure 1).

- Performed activation analyses for various candidate steels for the HYLIFE-II chamber. Waste options assessment shows ODS ferritic steel as the most promising structural material option for the HYLIFE-II concept, given its low activation performance and potential for high temperature operation.

- Cross-section uncertainty analysis applied to HYLIFE-II chamber material. It has been found that only the effect of Nb and W induces a significant uncertainty in the overall low-activation performance of these steels.

- Completed system analysis of modular solenoid option for heavy ion driver and contributed to analyses of thick-liquid vortex chamber that could be used with solenoid-based driver.

- Performed safety assessment of Be use in IFE from chemical and radiological toxicity perspectives. Segregation of inventories and additional confinement are essential to minimize potential beryllium exposures.

Publications and Presentations


