Wetted Foam Liquid Fuel ICF Experiments

Can wetted foam liquid fuel ICF experiments be useful for exploring the transition from “hydro-like” to “kinetic-like” behaviors at the time of shock convergence?

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The hot spot formation processes in DT ice layer and DT liquid layer ICF capsules are quite different.

The baseline DT ice layer ICF ignition capsule design requires a hot spot convergence ratio > 30 with a hot spot that is dynamically formed from DT mass originally residing in a very thin layer at the inner DT ice surface.

DT liquid layer capsules can have the hot spot formed from mass originating within a spherical volume of DT vapor and can have significant flexibility in hot spot convergence ratio (CR) and in the range of 12 to 25 via the adjustment of the initial cryogenic capsule temperature and, hence, DT (or DD) vapor density.

Simulations indicate that backing off on hot spot CR is an excellent way to reduce capsule instability growth and to improve robustness to low-mode x-ray flux asymmetries.

There are a number of additional motivations for developing a wetted foam liquid fuel layer platform, including potential hot spot diagnostic applications.

A liquid DT layer (wetted into CH foam) allows for a higher vapor density compared to a DT ice layer. This provides flexibility in hot spot CR.

hot spot CR = 34
S. W. Haan et al., Phys. Plasmas 18 051001 (2011)

hot spot CR depends upon vapor density (14 < CR < 25)
As the capsule implodes, the hot spot specific energy is gained at a larger radius in liquid DT layer capsules.

Variations on the Si-doped CH NIC ignition capsule:

Comparison of ice and liquid layer capsules

- black = 0.3 mg/cm³
- red = 1.0 mg/cm³
- green = 1.5 mg/cm³
- blue = 2.0 mg/cm³
Shock flash TN burn rate is higher and compression burn rate is lower with liquid layers as compared to ice layers.

Variations on the Si-doped CH NIC ignition capsule:
- Black = 0.3 mg/cm$^3$
- Red = 1.0 mg/cm$^3$
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Variations on the full-scale wetted foam HDC capsule:
- Black = 0.3 mg/cm$^3$
- Red = 1.0 mg/cm$^3$
- Green = 2.0 mg/cm$^3$
- Blue = 3.0 mg/cm$^3$
Significant TN burn occurs with less convergence with liquid layers as compared to ice layers.

Variations on the Si-doped CH NIC ignition capsule

Variations on the full-scale wetted foam HDC capsule

Significant TN burn occurs with less convergence with liquid layers as compared to ice layers.
Hydrocodes matched measured yields in exploding pusher implosions at Knudsen numbers ($N_K$) comparable to the wetted foam design, suggesting kinetic effects may be minimal.
We are developing a new NIF experimental platform that employs wetted foam liquid fuel layer ICF capsules.

**The liquid layer platform builds upon some recent innovations.**

### CH foam-lined HDC capsules

- **HDC ablator**
  - DT liquid + CH foam
  - $0.22 \text{ g/cm}^3 + 0.035 \text{ g/cm}^3$

- **DT vapor**
  - $0.6$ to $4.0 \text{ mg/cm}^3$
  - $T_{\text{cryo}} \sim 20$ to $26 \text{ °K}$

### Near-Vacuum Hohlraums

- **HDC capsule in a NIF near-vacuum hohlraum**
  - He, $0.032 \text{ mg/cm}^3$
  - Dimensions: $5.75 \text{ mm}$, $10.13 \text{ mm}$, $3.375 \text{ mm}$

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Initial experiments will use sub-scale HDC capsules with liquid D2 or DT layers fielded in a NIF “575 near vacuum hohlraum” (575 NVH).

HDC capsule in a NIF near-vacuum hohlraum

HDC sub-scale capsule with liquid DT wetted CH foam

DT liquid + CH foam
0.22 g/cm³ + 0.035 g/cm³

DT vapor
0.6 to 4.0 mg/cm³
T_{cryo} ~ 20 to 26 °K

He, 0.032 mg/cm³

Liquid D2 layer
We will use DT liquid layer capsules in a NIF sub-scale campaign to explore the relationship between convergence ratio and robustness of hot spot formation.

HDC sub-scale capsule with liquid DT wetted CH foam

907 µm
844 µm
794 µm

HDC ablator
DT liquid + CH foam
0.22 g/cm³ + 0.035 g/cm³

DT vapor
0.6 to 4.0 mg/cm³
$T_{\text{cryo}} \sim 20$ to 26 °K

DT liquid layer ICF capsules can provide flexibility in hot spot convergence ratio via the adjustment of the initial vapor density.

Simulations of 3-shock sub-scale wf capsules

Initial vapor density (mg/cm³) vs. hot spot convergence ratio
An initial goal will be to measure hot spot size, neutron yield, $T_{\text{ion}}$, and burn width to infer hot spot pressure for liquid layer implosions.

Our hypothesis is that hot spot formation will be robust and 1D-like for a relatively low convergence ratio hot spot in which hot spot is created largely from the vapor, but will deviate from 1D-like behavior as vapor pressure is reduced and hot spot convergence ratio is increased.
When we discover a CR threshold with 1D-like behavior, we will advance from sub-scale to full-scale NIF experiments.

1D performance will depend upon initial vapor density and resulting hot spot CR.
Status of the wetted foam experimental plan:

An HDC capsule with a CH foam layer was assembled into a Au 575NVH, was wetted with liquid D2, and was successfully shot in NIF experiment N160320-002.

The first wetted foam implosion was successfully shot on NIF using a liquid D2 layer, with CR ~ 14.

The first liquid DT layer experiment is scheduled for April 21, also with CR ~ 14.

A demonstration of changing convergence via vapor density is scheduled for June 26.
We will use sub-scale HDC capsules with wetted CH foam layers to implode capsules with vapor densities in the range of 0.6 to 4.0 mg/cm$^3$ and predicted hot spot CR’s in the range of 12 to 25.

The HDC sub-scale capsules with liquid DT layers will be fielded in NIF “575 near vacuum hohlraums” (575 NVH).

Our hypothesis is that hot spot formation will be robust and 1D-like for a relatively low convergence ratio hot spot in which hot spot is created largely from the vapor, but will deviate from 1D-like behavior as vapor pressure is reduced and hot spot convergence ratio is increased.

A goal of the sub-scale experiments is to measure hot spot size, neutron yield, $T_{ion}$, and burn width to infer hot spot pressure for liquid layer implosions and determine a CR limit at which burn truncation occurs due to 3D effects.

The wetted foam liquid fuel layer platform would then be used for hot spot diagnostic applications to understand and repair departures from 1D-like behavior as CR is gradually increased.
Can wetted foam liquid fuel ICF experiments be useful for exploring the transition from “hydro-like” to “kinetic-like” behaviors at the time of shock convergence?

• Rosenberg and Petrasso have pointed out that the shock convergence phase of the wetted foam design can be in a much more “hydrodynamic-like” regime than other ignition-relevant implosions.

• As the capsule implodes, the hot spot specific energy is gained at a larger radius in liquid DT layer capsules as compared to DT ice layer capsules.

• Shock flash TN burn rate is higher and compression burn rate is lower with liquid layers as compared to ice layers.

• Significant TN burn occurs with less convergence with liquid layers as compared to ice layers.

• Regardless of the Knudsen number at shock convergence, the vast majority of TN yield occurs during the compression phase, when the Knudsen number is low. Is it possible that inaccurately-modeled conditions at shock flash in the DT ice layer design can ultimately have a harmful impact at compression?