Flying Metal Pipe for Target Transport in IFE Reactor (Revised)

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0. Introduction

The residual vapor of the liquid metal in IFE reactor chamber causes

1) drag force to the target
2) deviation of the orbit of the target.
3) heat transport to the target

Black body radiation from the chamber wall causes

4) heat transport to the target
Flying Metal Pipe for Target Transport in IFE Reactor

Outline of presentation
1) Parameters of pipe, target and reactor
2) Dynamics
3) Deviation of the orbit of the target
4) Heat transport to the target
5) Heat transport to the pipe
6) Summary
1. Parameters of pipe, target and reactor

Pipe

Inner radius: 0.50cm  Outer radius: 0.55cm
Length: 200cm  Initial temperature: 300K
Material: Li (LiPb)
Mass: 17.6g (297g)
Injection speed: 20m/s
Injection point: top of the reactor (0, 0, 3), 3m from center

Target

Radius: 0.2cm  Mass: 5mg
Injection speed: 100m/s  Initial temperature: 17K
Injection point: top of the reactor (0, 0, 6), 6m from center
Energy of Neutron 113MJ (=0.5 \times 10^{20} \times 14.1\text{MeV})
Energy of X-ray and Plasma 37MJ

Reactor

Inner radius: 300cm
Operation temperature: 800K
Li wetted wall
Gas number density $10^{21} \text{ m}^{-3} (=1.1\text{Pa} = 0.08\text{torr})$
2. Dynamics

Target 100 m/s

Metal Pipe

Wall

$T = 0 \text{ sec}$

$T = 0.0677 \text{ sec}$

1. Pipe is injected

2. Target is injected

$T = 0.0977 \text{ sec}$

$T = 0.1229 \text{ sec}$

3. Target in

4. Target out

$T = 0.1275 \text{ sec}$

$T = 0.3670 \text{ sec}$

5. Shot

6. Melt starts

Li pool
Other causes of deviation of the orbit

Thermal expansion of structural material

\[ T=\text{low} \quad \text{T=high} \]

100 \( \mu \text{m/K} \)

Coliolis force

20 \( \mu \text{m} \) at the center

Micro vibration of structural material

? \( \mu \text{m} \)

Micro vibration of earth

? \( \mu \text{m} \)
4. Heat transport to the target

4-1 Radiation heat from reactor chamber wall
Assumption: Black body radiation

Radiation from wall \( \sigma T_w^4 = 2.3226 \) W/cm\(^2\)
Radiation from pipe \( \sigma T_p^4 = 0.0459 \) W/cm\(^2\)
Radiation from target \( \sigma T_t^4 = 4.7 \times 10^{-7} \) W/cm\(^2\)
Without pipe \( \sigma (T_w^4 - T_t^4) \times 0.0299 \)
With pipe \( \sigma (T_p^4 - T_t^4) \times 0.0252 + \sigma (T_w^4 - T_t^4) \times 0.0047 \)

<table>
<thead>
<tr>
<th></th>
<th>without pipe ((t_1=0.0299))</th>
<th>using pipe ((t_2=0.0047))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q(_\text{rad})</td>
<td>0.0694 J/cm(^2)</td>
<td>0.0120 J/cm(^2)</td>
</tr>
</tbody>
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Radiation heat is reduced as \((t_2/t_1)\)

4-2 Convection heat from gas
Assumption: Cryo-pump effect (no gas) in the pipe

In the pipe \( Q_{\text{conv}} = 0 \)
Out of the pipe \( 1.428 \) W/cm\(^2\)
\( Q_{\text{conv}} = NC_m M(\Delta H_t + \Delta H_v + C_s \Delta T_{452-17} + C_L \Delta T_{800-452})/6 \)
Without pipe \( 1.428 \times 0.0299 \)
With pipe \( 0 \times 0.0252 + 1.428 \times 0.0047 \)

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<td>Q(_\text{conv})</td>
<td>0.0427 J/cm(^2)</td>
<td>0.0067 J/cm(^2)</td>
</tr>
</tbody>
</table>

Heat from residual gas is reduced as \((t_2/t_1)\)
5. Heat transport to the pipe

5-1 Neutron heating of the pipe by microexplosion

\[ dT(0) = 47.6 \, \text{C} \quad dT(200) = 1.16 \, \text{C} \]

37 cm from target 237 cm from target

Total neutron heating = 448 J
(Calculated by ANISN-JR and GICX-40)

5-2 Plasma and X-ray heating by microexplosion

\[ 37 \text{MJ} \times \left( \frac{\pi \times 0.5^2}{4 \times 37^2} \right) - \left( \frac{\pi \times 0.5^2}{4 \times 237^2} \right) \]
\[ = 1648 \, \text{J} \]

5-3 Convection heating

\[ 1.171 \, \text{W/cm}^2 \times 0.2750 \, \text{sec} \times 691.150 \, \text{cm}^2 \]
\[ = 223 \, \text{J} \]

5-4 Radiation heating

\[ 2.3226 \, \text{W/cm}^2 \times 0.2750 \, \text{sec} \times 691.150 \, \text{cm}^2 \]
\[ = 441 \, \text{J} \]

Total heating and average temperature increase

Total: 2760 J
Maximum temperature increase \( \Delta T \): 80 K
Pipe is still **SOLID** after microexplosion
6. Summary

Flying metal pipe is proposed. The metal pipe is composed of material identical to liquid metal used in the IFE reactor such as Li. The pipe is injected into the IFE reactor chamber. Subsequently IFE target is injected and it goes into the metal pipe, goes out from other side and arrives at the center of IFE reactor chamber.

Principal results obtained in this study are following,

(1) Heat transport to the target is reduced
(2) Drag force to the target is reduced
(3) Deviation of the orbit of the target is reduced

These results relaxes the operation condition of

- target injection speed (low V possible),
- residual gas density (high N possible),
- operation reactor temperature (high T possible)

Variation A
The method presented here is applicable in the case of other type of flying pipe made of LiPb, Flibe etc.

Variation B
Cryogenic (77K) flying metal pipe
- Xe (161K:Solidification, 164K:Boiling)
Cryogenic pump effect occurs