Mixed Liquid Divertor Concepts

Dick Majeski

PPPL

ALPS Meeting
Argonne National Lab
8-9 May 2000

Introduction

- Most discussions on the use of liquid lithium as a PFC center on thin film in/thin film out.
  - "Mixing" generally is seen to be desirable *only while the film is exposed to high heat flux.*
  - Is it also desirable to mix the hot surface liquid with cooler bulk liquid after exposure, and recirculate the fluid internal to the tokamak?
- At first glance, this appears to be a bad idea. Total specific heat increases by $V_{bulk}/V_{surface}$. Therefore:
  - Replacement time for the liquid reduced by ($V_{surface}/V_{bulk}$).
  - *BUT* - volume pumped goes up by $V_{bulk}/V_{surface}$.
  - Pumping requirements are unchanged.
  - Total in-vessel inventory increases.
  - Not much of a win!
- However, this conclusion is based on the assumption that the temperature of the lithium inventory can only rise by 200^{o} C, for either the surface fluid OR the bulk liquid.
- Can this constraint be relaxed?
  - One possibility: internal cooling.

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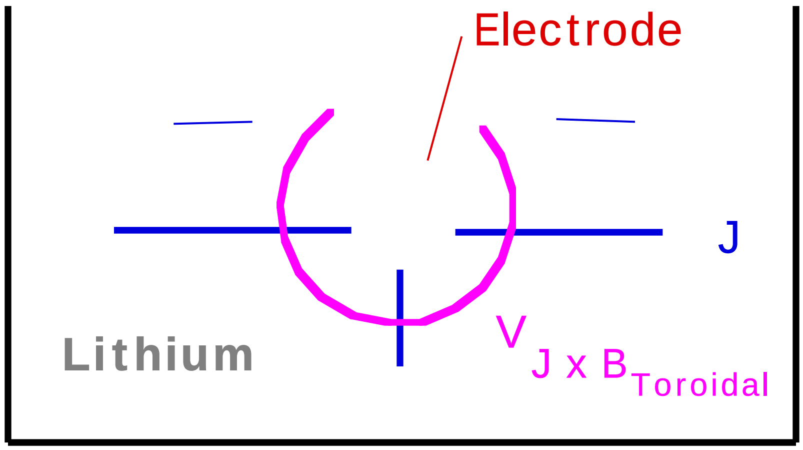
Introduction

- Another possibility - must the inlet material be liquid?
- Consider solid lithium pellets delivered to a bulk liquid reservoir.
  - 0.84 MJ/kg required to heat liquid lithium from 200 to 400^o C.
    - » Heat of fusion is 103 cal/g.
  - 1.2 MJ/kg required to melt lithium pellets delivered at 20^o C.
  - Volume of circulating lithium would therefore be reduced by 60% if lithium were delivered as a solid.
  - Downside: How do you deliver the pellets?
  - Small pellets would reduce MHD drag.
- Neglect delivery issue for now.
- Is a mixed liquid lithium divertor feasible?

A concept for a mixed liquid lithium divertor target.

- J x B flows can be used to circulate lithium in a divertor “pool”.
  - E.g. Spencer Pitcher’s concept for a mixed liquid metal divertor for C-mod:



- But - at the surface, where ideally mixing should be most rapid, J || surface. J x $B_{toroidal}$ is vertical.
  - Flow drive is “indirect” (drag,   P), especially above the electrode.
- Desirable to have the fastest flow at the surface, not in the bulk liquid.

AC drive for liquid metals

- On possible way to preferentially drive surface currents is to use the skin effect.
  - Liquid lithium: $\rho_e \sim 25 \times 10^{-6}\ \Omega$-cm.
  - Skin depth is $\delta = 25.2/f^{1/2}$. About 3 cm at 60 Hz.
- For flow in the major radial direction, consider a toroidal AC current in the surface of the liquid lithium divertor target.
  - J x $B_{vertical}$ will drive an oscillating flow along R.
  - How fast can we oscillate the fluid?
- Can express the acceleration a as:

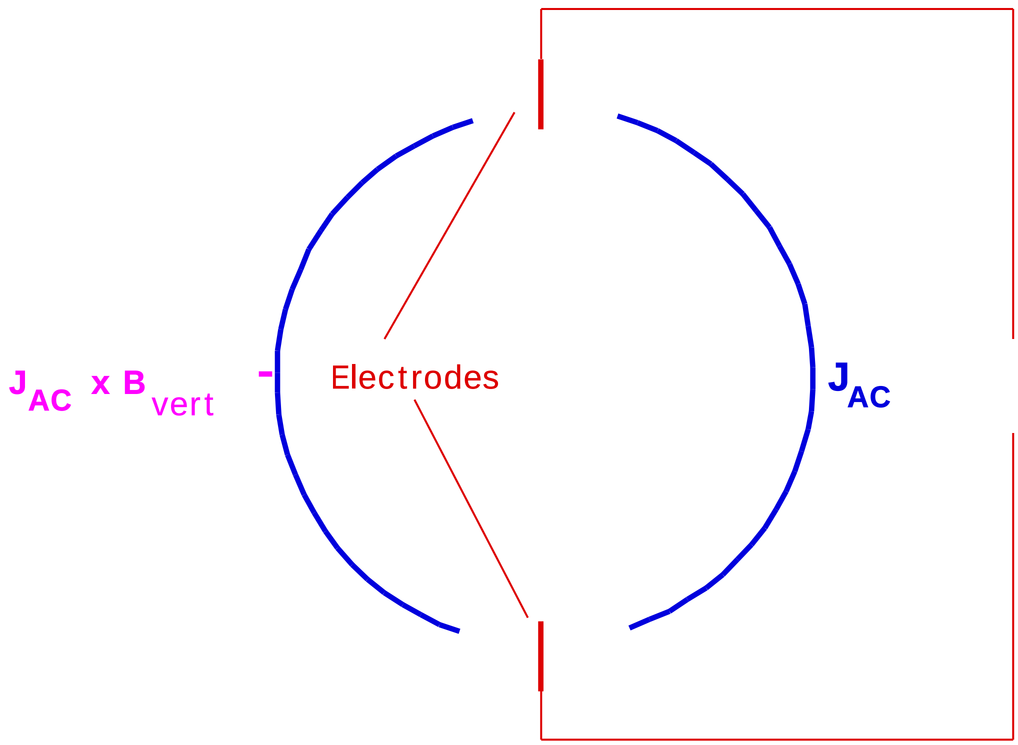
$$a = \frac{B_{vert}}{\rho_m \rho_e} E$$

Where ρ_m is the mass density, and E = (V/L) is just the applied electric field.

- Approximating the vertical field as 0.1 x toroidal field, for a 5T tokamak we find a= 4×10^3 (E) m/sec^2, (E in V/m).
  - a= 4×10^4 m/sec^2 for a 10V/m field. Certainly non-negligible.
- Only the surface fluid is driven. No force on the bulk fluid.

AC drive for liquid metals

- If we consider a sinusoidal applied field, then the peak velocity of the fluid is 106 m/sec.
  - Fluid displacement is 0.28 m.
- Fluid will be swept with no “dead spot” as long as the divertor width is <2x peak displacement.
  - A 50 cm wide divertor pool is allowable.
- For a 5m major radius divertor target, 50 cm wide:
  - Applied voltage is ± 78V.
  - RMS current driven is 220 kA.
  - 12.8 MW required << P_{div}.



AC drive for liquid metals

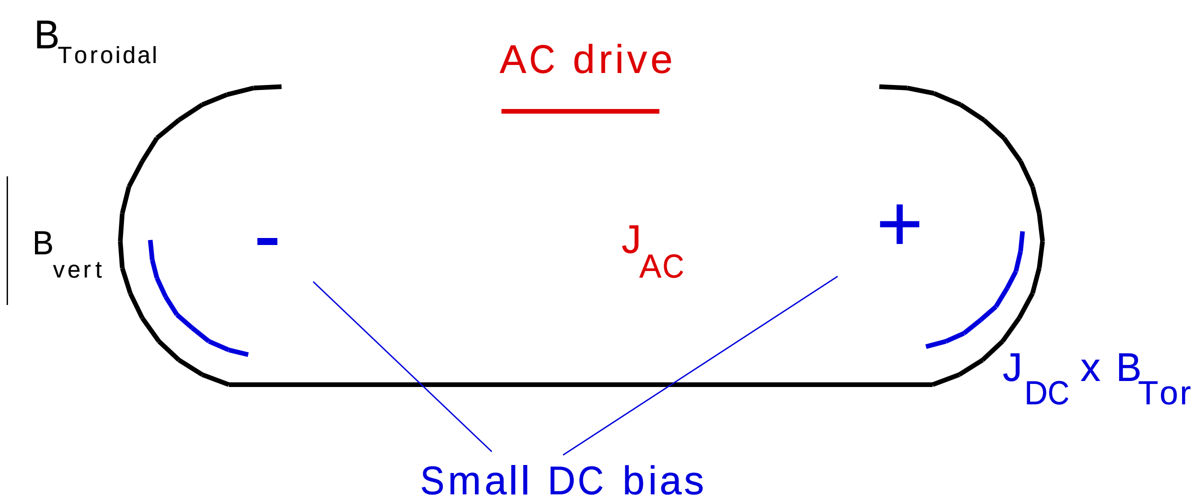
- Power handling. Borrow an expression for the temperature rise from L. Zakharov:

$$\Delta T = 2q_{wall}\sqrt{\frac{t_{transit}}{\pi\kappa\rho_m C_p}}$$

where κ = 47 W/m°K, C_p=4200 J/kg°K.

- For a 200 °C surface temperature rise during the time the fluid is swept from the center of the divertor target to the edge (3.3 msec), allowable heat flux is 31 MW/m^2.
  – Narrower divertor channel would permit 50 MW/m^2.
- Finally, consider adding a small DC bias to drive circulation.

May also use the DC bias to pump fluid out of the divertor system



Summary

- "Mixing" liquid lithium divertor targets may have advantages in some cases.
  - Consider for example delivery of solid lithium to the in-vessel reservoir.
- AC currents could in principle drive very rapid oscillatory surface flows in liquid lithium.
- "Swept" fluid may handle very high divertor heat loads.
- Rapid sweeping would facilitate helium pumping providing the residence time of helium ash in the fluid was ~ 1 msec.
- But:
  - Accelerations can be huge. Mixing of the surface fluid may be very effective indeed.
  - Wave excitation - field may penetrate.
  - Vibration.
    - May be mitigated by multi-phase operation.
- Consider looking at AC drive experimentally.