3/27 Lecture - Tritium Management

1) Side-stream
2) Units
3) Solubility in flibe
4) JUPITER II Paper

1) Side-stream

Concentration in flibe: $C_T = (1.5)\,10^{-5}\ g/m^3$

$\Downarrow$

Tritium inventory in flibe: $M_T = (1.5)\,10^{-3}\ g$ ①

Tritium generation rate: $Q_T = 95\ g/yr = (3)\,10^{-6}\ g/s$ ②

① + ② ⇒ Tritium residence time: $\tau_T = \frac{M_T}{Q_T} = \boxed{500\ sec.}$

vs.

flibe inventory: $M_{flibe} = 100\ m^3$ ③

flibe flow-rate: $\dot{Q}_{flibe} = 2\ m^3/s = 3700\ kg/s$ ④

③ & ④ ⇒ $\tau_{flibe} = \frac{M_{flibe}}{\dot{Q}_{flibe}} = \boxed{50\ sec.}$

Q: can we strip out tritium with a 5% side-stream?

in this case $\tau_T / \tau_{flibe} = 10 \Rightarrow$ tritium stripping can be achieved with a $1/10$ side-stream.

explanation:

let $x =$ side-stream fraction of primary coolant flow

$$x = \frac{\dot{Q}_{strip}}{\dot{Q}_{flibe}}$$

stripping condition : $Q_T \leq x \, \dot{Q}_{flibe} \, c_T$

$$c_T = \frac{M_T}{M_{flibe}} \Rightarrow \quad x \geq \frac{Q_T}{M_T} \cdot \frac{M_{flibe}}{\dot{Q}_{flibe}} \Rightarrow$$

$$\Rightarrow \boxed{x \geq \frac{\tau_{flibe}}{\tau_T}} \Rightarrow x \geq \frac{1}{10} \text{ in this case.}$$

2) units

30,000 Ci / mol T

15,000 Ci / mol T_2

$\boxed{9600 \quad \text{Ci} / g\ T_2}$

$\approx 10^4$ Ci / g T_2

$t_{1/2} = 12\,\text{yr} = (3.9)10^8\,\text{s}$

$\lambda = \frac{\ln 2}{t_{1/2}} = (1.8)10^{-9}\ 1/\text{s}$

$\text{activity (Ci)} = \lambda \underset{\#\ \text{atoms}}{\underset{\uparrow}{N}} =$

$PV = nRT$

$(101{,}000)\,V = 1\ R\,(273 + 25)$

$= (8.3)\,\frac{J}{K\text{-mol}} \cdot 298$

1 mol STP = 45 m^3 $\Rightarrow$ 1g T_2 = 7.5 m^3 STP

0°C, 1 atm

1g T = 0.33 mol = $(6.02)10^{23}\,(0.33)$ atoms

$(1.8)10^{-9}\,(6.02)10^{23}\,(0.33) = (3.15)10^{14}$ Bq

1 Ci = $(3.7)10^{10}$ Bq $\Rightarrow$ 1g T_2 = 9600 Ci

3 g/mol T

6 g/mol T_2

$100\ g/yr = 10^6\ Ci/yr = 2{,}600\ Ci/day = 0.03\ Ci/s$

$1\ yr = 365\ days = (3.16)\,10^7\ sec.$

$1\ day = (8.64)\,10^4\ sec.$

$$100\ g/yr = \frac{(100)\,10^4\ Ci}{(3)\,10^7\ sec} \approx 0{,}03\ Ci/sec$$

3) Mass Transport in the Salt

$D_{pebble} = 3cm$

$A_{pebbles} \approx 2000\,m^2$

$Q_T = (3)\,10^{-6}\,g/s$

$q_T'' = (1.5)\,10^{-9}\,g/m^2\text{-}s$

Why $C_T = 10^{-5}\,g/m^3$?

for a pebble bed

Prandtl $\quad Pr = \frac{\nu}{\alpha}$ thermal diffusivity

$Nu = 2 + 1.1\,Re^{0.62}\,Pr^{0.33}$ heat transfer

Nusselt

$Sh = 2 + 1.1\,Re^{0.62}\,Sc^{0.33}$ mass transfer

Sherwood

Schmidt $\quad Sc = \frac{\mu}{\rho D} = \frac{\nu}{D}$

$Sh = \frac{h_{mass}}{D/L}$

mass diffusivity $\quad [D] = m^2/s$

T in flibe: $\quad D = (3.83)\,10^{-9}\,m^2/s$ faster mass transport!

flibe $\quad \alpha = (2.30)\,10^{-7}\,m^2/s$

$Sc \approx 900 \qquad Pr \approx 15$

$Sh \approx 500 \qquad Nu \approx 100$

$h_{mass} \approx (6.35)\,10^{-5}\,m/s \Rightarrow C_T = \frac{(1.5)\,10^{-9}\,g/m^2 s}{(6.35)\,10^{-5}\,m/s} = \boxed{(2)\,10^{-5}\,g/m^3}$

$D/L = \frac{(3.83)\,10^{-9}}{0.03} = (1.27)\,10^{-7}\,m/s$

$q_T'' = h_{mass}\,(C_T - \underbrace{C_{Tsurf}}_{\text{assume } 0}) = h_{mass}\,C_T \Rightarrow C_T = \frac{q_T''}{h_{mass}}$

Tritium diffusion through flibe Fukada (2005)

Ref 2–6 : Diff & Perm.

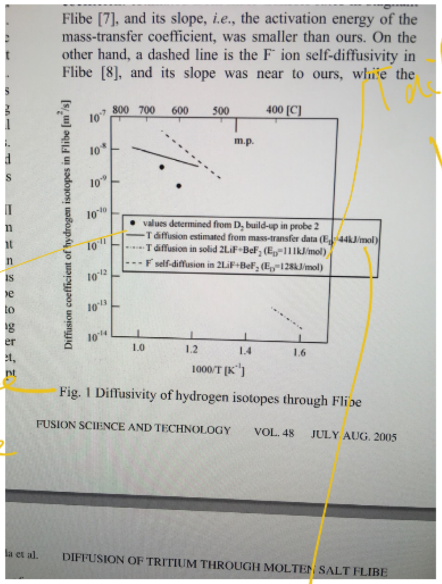
Ref 7: stagnant flibe

Ref 9: eqn 1.

$$D = \frac{K_B T}{6\pi \mu r_a}$$

Stokes-Einstein Eqn.

- HF treated flibe
- dual-cylinder probe
- D_2 downstream vs time vs upstream vs. time



Flibe [7], and its slope, *i.e.*, the activation energy of the mass-transfer coefficient, was smaller than ours. On the other hand, a dashed line is the F⁻ ion self-diffusivity in Flibe [8], and its slope was near to ours, while the

- ● values determined from D_2 build-up in probe 2
- —— T diffusion estimated from mass-transfer data (E_D=44kJ/mol)
- -·-·- T diffusion in solid $2LiF+BeF_2$ (E_D=111kJ/mol)
- - - - F⁻ self-diffusion in $2LiF+BeF_2$ (E_D=128kJ/mol)

Fig. 1 Diffusivity of hydrogen isotopes through Flibe

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a et al. DIFFUSION OF TRITIUM THROUGH MOLTEN SALT FLIBE

T diffuse low temp

h_{mass} in stagnant flibe

Ref 7.

μ = visc.

r_a = molec diam. of diffusive species

T = temp.

$$\frac{K_B}{6\pi} = \text{const} = \frac{(1.4)\,10^{-23}}{6\pi}\ J/K = (7.4)\,10^{-25}\ J/K$$

$\mu_{flibe} \approx 0.01$ Pa-s ; $r_a \approx 10\,Å = 10^{-9}\,m$ & $D \approx \frac{10^{-24}}{\underbrace{(0.01)}_{10^{-2}}10^{-9}} \approx \boxed{10^{-13}}$

10^{-11}

vs

10^{-9}

$r_a = 10^{-5}\,m = 10\,\mu m$

Slope = activation energy = $\left(\frac{K_B}{6\pi\mu r_a}\right)$

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Ref 5

Tritium behavior in flibe depends on

1 chemical species → Ref 5

Ref 6-10

Ref 11, 12, 15 } → 2 diffusivity of T^+

3 solubility

Ref 13, 14

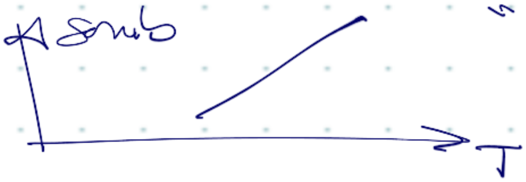
H_2 gas purge $\xrightarrow[\text{exchange}]{\text{isotope}}$ HT → enhanced permeation through metal walls

D_2, H_2 solubility $\approx \frac{1}{100}$ of HF, DF solub. @600°C

Reactive gases

"Chemical Solubit"

Inert gases



"Physical Solub'lt"

"Voids" or "holes" in structure of the molten salt

$$-RT \ln\left(\frac{C_d}{C_g}\right) = KA\gamma$$

total surf. area of holes

$$KA = 18.08\, r^2$$

r = atomic radius (Å)

Jupiter II Paper

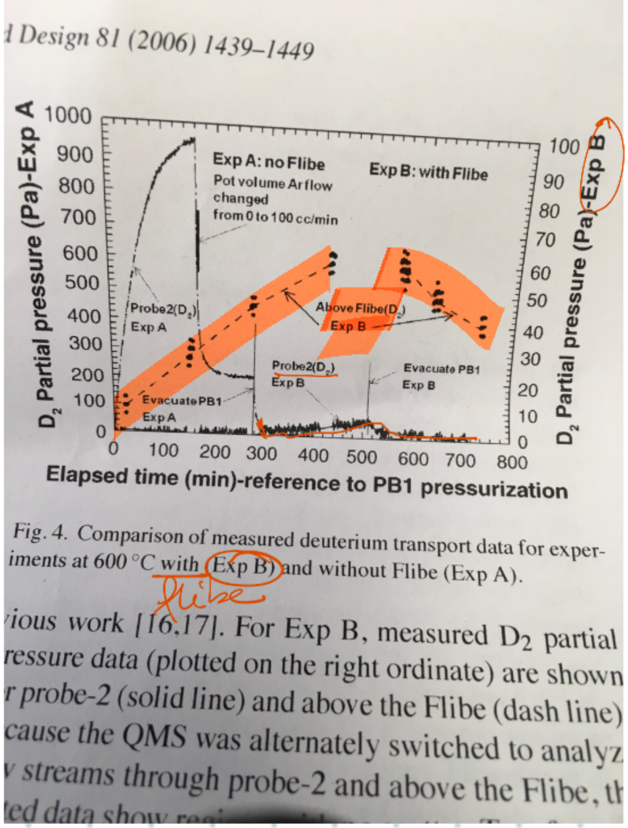


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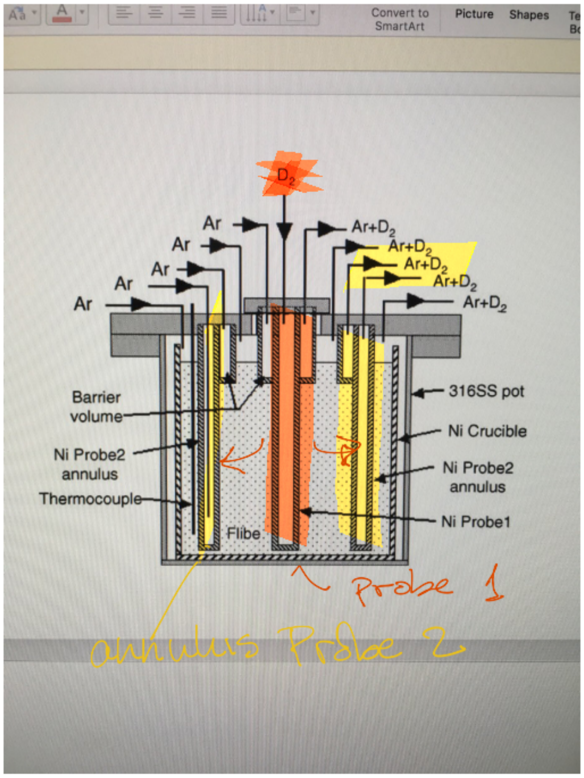
Fig. 4. Comparison of measured deuterium transport data for experiments at 600 °C with (Exp B) and without Flibe (Exp A).

flibe

ious work [16,17]. For Exp B, measured D_2 partial ressure data (plotted on the right ordinate) are shown r probe-2 (solid line) and above the Flibe (dash line) cause the QMS was alternately switched to analyz v streams through probe-2 and above the Flibe, th ted data show re



1) Flibe-diffussion is rate-limiting, not Ni-permeation

2) Cover-gas D_2 shows that salt-loading with D_2 is happening while Probe 1 is filled w/ 90,000 Pa of D_2, then discharges once Probe1 is flushed (i.e. source of D_2 is removed).

@ 700 °C

$$K_c = (4)10^{-3} \Rightarrow \quad K_H = \frac{K_c}{RT} = (4)10^{-3}$$

$R = 8.3$ J/K-mol

$T = 973$ K

$$\Rightarrow K_H = \frac{(4)10^{-3}}{8076 \text{ J/mol}}$$

$$\Rightarrow \boxed{K_H \approx (5)10^{-7} \text{ mol/m}^3\text{-Pa}}$$

$1\text{ m}^3 = 1000\text{ L}$

$$\approx \frac{5(10)^{-7} \text{ mol}}{10^3 \text{ L} \cdot 10^{-5} \text{ atm}} = (5)10^{-5} \text{ mol/L-atm}$$

$$C_T = (1.5)10^{-5} \text{ g/m}^3 = (0.25)10^{-5} \text{ mol } T_2/\text{m}^3$$

$$P_{T_2} = \frac{C_T}{K_H} = \frac{(0.25)10^{-5} \text{ mol/m}^3}{(5)10^{-7} \text{ mol/m}^3\text{-Pa}} = \boxed{5 \text{ Pa}}$$