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FROM:

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Summary

An introductory study has been made to estimate the amount of CuSO_4 catalyst needed in the HRR to internally recombine the radiolytic gases produced. Design criteria for the study are:

Power	=	500 Mw
Core volume	=	12,000 liters (10 ft core vessel)
Total volume of fuel loop	=	36,000 liters
Fuel concentration	$\approx$	2 gms U-235/liter
Temperature rise across core	=	50°C

Minimum copper requirements for 100% internal recombination and for 80% internal recombination are given below for three operating temperature and pressure ranges in the HRR.

Temperature Range	Pressure, psia	Cu ⁺⁺ Conc. g-mols/liter	
		80% recombination	100% recombination
200-250°C	1000	0.09	0.11
225-275°C	1440	0.016	0.019
250-300°C	2000	0.0035	0.0043

Calculation of Cu⁺⁺ Concentration

To make an accurate analysis of internal recombination using CuSO_4 catalyst, the average residence time of the fuel must be known for the core vessel, heat exchanger, and in the piping and other components around the high pressure loop. To find these values the fuel circulation rate and the volumes of the core, heat exchangers, piping and other components of the high pressure loop must be known. At the present stage of the HRR design these quantities are not at all fixed, but are in a fluid state.

In the studies on the internal recombination in the HRT [1] an accurate analysis was made taking into account the temperature variation in the core vessel and in the heat exchanger. It was found that if the average temperature was used along with the saturation value for dissolved D_2 at the core exit (outlet temperature) a reasonably accurate value would be obtained for the minimum copper concentration required for 100% internal recombination by assuming the steady state equation.

$$\frac{dy}{dt} = v - k_{Cu} x y = 0 \quad (1)$$

Solving equation (1) for x

$$x = \frac{v}{k_{Cu} y} \quad (2)$$

where x = Copper conc. g mols Cu^{++} /liter
 v = gas production rate, moles D_2 /mol sol'n-sec.
 y = D_2 conc. in fuel sol'n, mol fraction.
 k_{Cu} = recombination rate constant.

The recombination rate constant is given by [1]

$$k_{Cu} = ae^{-\frac{b}{T}} \quad (3)$$

where $a = 2.37 \times 10^{10}$
 $b = 12,200$

The k_{Cu} = liters g-mol Cu^{++} -sec.

Some values for k_{Cu} are

Temperature, °C	k_{Cu} , liters/g-mol Cu^{++} -sec
225 ($\approx 437^\circ F$)	0.544
250 ($\approx 482^\circ F$)	1.754
275 ($\approx 527^\circ F$)	5.082

[1] Aven, R. E. and Lawrence, M. C., "Calculation of Effects of Copper Catalyst in the HRT", CF 56-4-4.

The HRR will probably operate somewhere in the temperature range 200°C to 300°C. Three temperature ranges were considered:

1. 200°C to 250°C; Probable total pressure = 1000 psia
2. 225°C to 275°C; Probable total pressure = 1440 psia
3. 250°C to 300°C; Probable total pressure = 2000 psia

The concentration of D_2 in the fuel solution, y , is given by Henry's Law

$$y = \frac{P_{D_2}}{K_{D_2}} \quad (4)$$

where P_{D_2} = partial pressure of deuterium in the gas phase when the associated liquid phase is saturated with deuterium.

K_{D_2} = Henry's Law constant for deuterium.

The pressure tending to hold the deuterium in solution can be estimated from (assuming 2/3 pressure due to D_2 and 1/3 due to O_2)

$$P_{D_2} = \frac{2}{3}(P_T - P_{D_2O}) \quad (5)$$

P_T = total operating pressure

P_{D_2O} = vapor pressure at the temperature of the fuel solution at the core exit [Steam Tables].

Some values for the partial pressure, Henry's Law coefficients and saturation concentration of deuterium are given in Table I.

The gas production rate is found from [2]

$$v' = 3.5 \times 10^3 P_c \text{ cc } D_2(\text{STP})/\text{sec.} \quad (6)$$

where P_c = Core power, Mw

[2] Aven, R. E. and Haubenreich, P. N., "Radiolytic Gas Generation Rates in the HRT", CF 55-8-77.

Therefore for the HRR

$$v' = (3.5 \times 10^3) 500 = 1.75 \times 10^6 \text{ cc D}_2(\text{STP})/\text{sec} \approx 0.172 \text{ lb mols D}_2/\text{sec}$$

If the fuel solution is assumed to be all D₂O (essentially true) then

$$\text{No. of lb-moles solution} = \frac{(36000) (800 \text{ gms D}_2\text{O/liter @ 250}^\circ\text{C})}{(453.6) (20)} = 3490$$

The average deuterium production rate in the HRR is then

$$v = \frac{0.172}{3490} = 4.93 \times 10^{-5} \frac{\text{moles D}_2}{\text{mol sol'n-sec}}$$

The minimum copper concentration for 100% internal recombination can be found from equation (2). If 20% of the radiolytic gas is letdown to a low pressure system, the approximate copper concentrations required are found by assuming that the curves of % D₂ recombined versus Cu⁺⁺ concentration are of the same form as the HRT curves [1]. Values for Cu⁺⁺ concentrations are given in Table I.

TABLE I

Copper and Deuterium Concentration in the HRR

Temp. Range °C	Core Exit Temp. °C	P _T psia	P _{D2} psi	K _{D2} mol fract/psi	y _{D2} (Sat.)	Cu ⁺⁺ Conc. g-mols/liter Recombination	
						100%	80%
200-250	250	1000	280	3.40 x 10 ⁵	0.00083	0.11	0.09
225-275	275	1440	385	2.63 x 10 ⁵	0.00146	.019	0.016
250-300	300	2000	500	2.20 x 10 ⁵	0.00227	.0043	0.0035

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