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SUBJECT: Predicted Vapor Pressures in the HRT

TO: S. E. Beall

FROM: E. H. Gift

SUMMARY

Radiolytic gas concentration in the HRT as a function of operating power and temperature have been calculated for the conditions of Run 18. The partial pressure of the radiolytic gas was estimated for the various conditions. The maximum total vapor pressure (the maximum summation of the radiolytic gas partial pressure, excess oxygen partial pressure, and D_2O vapor pressure) was found to exist at the core and blanket outlets for all average temperatures greater than $250^{\circ}C$. Below $240^{\circ}C$ at some recombination rate constants and power levels, the maximum pressure will be highest at the heat exchanger exit.

In the calculations the transfer of radiolytic gas between the core and blanket systems was neglected. The simplification is equivalent to saying that the radiolytic gas transfer between the systems is equal. The results of the calculations show that this is nearly true when 60% of the total power is generated in the core. The effect of pump-up in each system was included.

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PREDICTED VAPOR PRESSURES IN THE HRT

Introduction

The prediction of both maximum radiolytic gas pressure and the maximum total vapor pressure in the HRT system is important. The predictions can be used to help specify and set the operating conditions for the system and also to help in the analyses of some experimental data. These predictions can be of special importance when both the core and the blanket are generating power at two different average temperatures.

A major difficulty in prediction of the radiolytic gas concentration is the proper choice of a radiolytic gas recombination rate constant. In this report two recombination rate constants are used which should adequately bracket the actual rate constant. This use of two probable rate constants should also show the relative importance of the radiolytic gas recombination rate constant on the total vapor pressure as a function of temperature.

Method of Calculation:

The radiolytic gas recombination and production rates in the HRT can be expressed as:

$$\frac{dC}{dt} = v - kxC$$

where, C = Deuterium concentration, $\frac{\text{mols } D_2}{\text{mol soln}}$

t = Time, sec

v = Deuterium production rate, $\frac{\text{mol } D_2}{\text{mol soln-sec}}$

k = Recombination rate constant, $\frac{\text{liters}}{\text{mol-sec}}$

x = Copper concentration, mols/liter.

Based on the following assumptions, the deuterium concentration at any point in the system can be calculated.

1. Deuterium is produced only in the core and blanket proper. (The deuterium produced external to the core and blanket is less than 2% of the total.)
Thus,

$$v = 3.466 \frac{P_{avg}}{V \rho_{avg}} \quad (1)$$

where, P_{avg} = Average power generated in core or blanket vessel, Mw

ρ_{avg} = Average density in core or blanket vessel, g/liter

V = Volume of core or blanket vessel, liters .

2. Fuel feed occurs immediately on leaving either core or blanket vessels.
3. The average recombination rate constant for the core vessel, the blanket vessel and the heat exchangers can be adequately represented by a log mean average of the constant at the inlet and outlet conditions.

With these assumptions the deuterium concentration at either the core or blanket exit is:

$$C_c = \frac{v}{k_{avg} x} \left(1 - e^{-k_{avg} x t_1} \right) \left[1 + \frac{\left(\frac{Q}{Q+q} \right) e^{-k_{avg} x t_1}}{\frac{k_1 x (t_h - t_1)}{e^{k_1 x (t_h - t_1)}} \frac{k_{avg} x (t_e - t_h)}{e^{k_{avg} x (t_e - t_h)}} \frac{k_2 x (t_f - t_e)}{e^{k_2 x (t_f - t_e)}} - \left(\frac{Q}{Q+q} \right) e^{-k_{avg} x t_1}} \right] \quad (2)$$

Similarly at the core or blanket inlet the deuterium concentration is:

$$C_o = \frac{\frac{Q}{Q+q} \frac{v}{k_{avg} x} \left(1 - e^{-k_{avg} x t_1} \right)}{\frac{k_1 x (t_h - t_1)}{e^{k_1 x (t_h - t_1)}} \frac{k_{avg} x (t_e - t_h)}{e^{k_{avg} x (t_e - t_h)}} \frac{k_2 x (t_f - t_e)}{e^{k_2 x (t_f - t_e)}} - \left(\frac{Q}{Q+q} \right) e^{-k_{avg} x t_1}} \quad (3)$$

- where,
- C_c = Deuterium concentration at the core or blanket exit,
 $\frac{\text{mols } D_2}{\text{mol soln}}$
- C_o = Deuterium concentration at the core or blanket inlet,
 $\frac{\text{mols } D_2}{\text{mol soln}}$
- v = Deuterium generation rate, $\frac{\text{mol } D_2}{\text{mol soln-sec}}$
- x = Copper concentration, g mols/liter at 4°C
- Q = Flow rate, lb/min (1879 for blanket, 3262 for core)
- q = Pump-up rate, lb/min (6 for blanket, 10 for core)
- t_1 = Transit time of core or blanket vessel, sec
- $t_h - t_1$ = Flow time from core or blanket to heat exchanger, sec
- $t_e - t_h$ = Transit time of heat exchanger, sec
- $t_f - t_e$ = Flow time from heat exchanger to core or blanket inlet, sec
- k_1 = Recombination rate constant at core or blanket exit,
 mols/liter-sec
- k_2 = Recombination rate constant at core or blanket inlet,
 mols/liter-sec
- k_{avg} = Log mean rate constant, mols/liter-sec

Since the absolute value of the recombination rate constant is not known with a high degree of accuracy, equations (2) and (3) were solved using:

1. In pile loop D_2O recombination data. These data seem to represent the lowest consistent values of the rate constant. The rate constant as given by these data is:¹

$$k = 3.061 \times 10^8 e^{-10506/T} \quad (\text{g mols/liter-sec}) \quad (4)$$

where, T = fuel temperature, $^\circ\text{K}$.

2. HRT data from run 14.² Although this data is quite scattered it can be represented adequately by a rate constant of value 1.4 times¹ the in pile loop data. Thus:

$$k = 4.286 \times 10^8 e^{-10506/T} \text{ (g moles/liter-sec) .} \quad (5)$$

If McDuffie's data³ were evaluated using the gas solubility data of BMI-1067⁴, the rate constant would be slightly lower than that described by equation (5), but somewhat greater than that described by equation (4). Thus it seems that actual recombination rate constants will be bracketed by use of both equations (4) and (5).

The summation of vapor pressures for a particular position and temperature can be represented by the following equation:

$$P_T = P_{D_2O} + P_{O_2} + c \left(H_{D_2} + \frac{H_{O_2}}{2} \right) \quad (6)$$

where, P_{D_2O} = The vapor pressure of D_2O at the solution temperature

P_{O_2} = The partial pressure corresponding to approximately 500 ppm of added oxygen.

H_{D_2} = Henry's Law constant for deuterium in uranyl sulfate, psi/mol-fraction.

H_{O_2} = Henry's Law constant for oxygen in uranyl sulfate, psi/mol-fraction.

For the evaluation of equations (4) and (5) the copper concentrations are those indicated thus far by HRT run 18 for which the mol ratio of uranium to copper has been 2.017 for the core and 2.156 for the blanket.⁵ The enrichment has been 86.3% U^{235} . The critical concentration data used are those having a blanket to core uranium concentration ratio of 0.32.⁶

The results of these calculations for conditions at the core and blanket outlet are presented in the following set of graphs. Figures 1 and 2 show the radiolytic gas partial pressure and the total vapor pressure, respectively, at the core outlet using equation (5) for the rate constant. Figures 3 and 4 show the similar core data using equation (4) for the rate constant.

Figures 5, 6, 7, and 8 present the corresponding data for the blanket. It can be seen from Figures 2 and 4 and Figures 6 and 8 that at average core or blanket temperatures greater than 260°C, the total vapor pressure is not greatly changed by the change of rate constant.

The relationship between the summation of vapor pressures at the core or blanket inlet and outlet can be seen in Table I.

From the table it can be seen that at the average temperature of 250°C, the summation of the vapor pressures at the core or blanket outlet is always greater than at the inlet. At the average temperature of 240°C, the summation of vapor pressures at the core or blanket outlet is much closer to that at the inlet than the 250°C data and that for one case, that of core conditions and k of equation (4), the summation of vapor pressures is actually greater at the inlet than at the outlet.

Thus it seems quite likely that for average core or blanket temperatures lower than 240°C the maximum summation of vapor pressure will actually occur on the cold, or core and blanket vessel inlet, side of the system.

This phenomenon is a result of the fact that in this temperature range as the temperature drops the partial pressure exerted by the dissolved gas increases, due to the decrease in gas solubility, more than the water vapor pressure is decreased. The sum of the two pressures can thus be greater at the heat exchanger exit than at the heat exchanger inlet. As a result, for some temperature and power conditions bubbles may appear in the circulating pump suction even when there is no evidence of bubbles being removed by the gas separator.

Table I

Comparison of Inlet Total Vapor Pressure of Core ~~Blanket~~
to the Outlet Total Vapor Pressure

Reactor Power (Mw)	For k of Eq. (4)		For k of Eq. (5)	
	Total Outlet Vapor Pressure (psia)	Total Inlet Vapor Pressure (psia)	Total Outlet Vapor Pressure (psia)	Total Inlet Vapor Pressure (psia)

For Core Average Temperature of 240°C:

0.5	985	1032	903	870
1.0	1491	1464	1180	1135
1.5	1898	1908	1444	1408
2.0	2293	2372	1703	1695

For Core Average Temperature of 250°C:

0.5	975	1002	903	907
1.0	1241	1182	1101	1032
1.5	1497	1442	1292	1211
2.0	1742	1704	1475	1393

For Blanket Average Temperature of 240°C:

0.25	809	783	759	732
0.5	987	951	892	849
1.0	1334	1304	1149	1094
1.5	1654	1677	1388	1354

For Blanket Average Temperature of 250°C:

0.25	827	796	795	764
0.50	950	896	889	831
1.0	1185	1106	1068	972
1.5	1406	1320	1237	1117

Figure (1)

Figure (2)

Figure (3)

11.

TOTAL VAPOR PRESSURE IN THE HET AS A FUNCTION OF CORE AVERAGE
TEMPERATURE AND CORE AVERAGE POWER

(Calculations made using in pile
loop recombination data)

Core
Average
Power, Mw.

Core
Outlet,
Total
Vapor
Pressure,
psia.

2.0
1.5
1.0
0.5

10^3

Temperature, °C.

Figure (11)

13.

MAXIMUM TOTAL VAPOR PRESSURE IN THE HWT BLANKET AS A FUNCTION
OF BLANKET AVERAGE TEMPERATURE AND BLANKET AVERAGE POWER

(Calculations made for 1.4 times
in pile loop recombination
data)

Figure (6)

RADIOLYTIC GAS PRESSURE IN THE HRT BLANKET AS A FUNCTION OF BLANKET

Figure (7)

Figure (8)

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