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SUBJECT: Mixing of HRT Core and Blanket Systems Through External Connections

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SUMMARY

Adequate mixing (80 lb/min or higher) of the core and blanket high pressure systems can be accomplished either by interconnecting the chemical plant process lines or by connecting the sample access holes of the core and pressure vessels. The cross connection of the chemical plant process lines would probably be the easiest to install and control, but if the stagnant space in the blanket corrosion sample port requires purging, it is recommended that a connection between the access holes be made.

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Introduction

Attempts are being made to operate the HRT with the existing core vessel using the mixing provided through the present hole (the self-induced opening in the core vessel). Using this method of operation, apparent transfer rate of fluid from the core to the blanket systems is about 3-1/2 to 4 lbs/min.¹ If higher mixing rates are desired to provide faster mixing and/or more uniform mixtures between the core and blanket systems², other connections between the two systems will be required.

One of the methods of providing greater mixing between the core and blanket systems is the interconnection of the chemical processing lines. To facilitate this, a connection would be required from Line 167 to Line 267 and one from Line 267 to Line 166. The driving force for flow through these connections is then the pressure drop across the core and blanket heat exchangers. As far as can be determined this connection can be made without an inordinate amount of effort.

A second method of providing adequate mixing for operation of the HRT as a single region reactor is by connecting the core vessel and blanket vessel corrosion sample access flanges. Flow in this case would be from blanket to core through the proposed connection and from core to blanket through the hole in the core vessel wall. The additional line will be relatively easy to install since it could be made up on a jig out of the reactor cell. Also it would provide a purge for the blanket access tube.

Procedure and Results

Pressure Drops in the HRT High Pressure System:

In order to calculate the flow through the proposed connections, the pressures in the various parts of the core and blanket systems must first be determined.

Using the blanket mockup, Parsly³ was able to measure the blanket inlet loss (caused by the nozzles, a 90° elbow and a short run of pipe) and the overall blanket loss (minus the 90° elbow). Head loss to the pressurizer leg is calculated assuming that flow from the shroud at the top of the blanket vessel is axial only, and the measured inlet loss is corrected for the 90° elbow. In the mockup, the top portion of the shroud is blocked off, but some earlier data are available in which the shroud was open as in the HRT. With these corrections, the following table represents the best estimates of the various losses through the pressure vessel.

Table I
Blanket Losses

Flow Rate gpm	Nozzle Inlet Loss, ft	Vorticity Loss, ft	Shroud to Pressurizer Loss, ft	Total Loss ft
400	10.9	11.1	4.0	26.0
350	9.3	8.3	3.1	20.7
300	6.9	6.8	2.3	16.0
250	5.1	5.1	1.6	11.8
200	3.6	3.7	1.0	8.3

There are some data available giving pressure drops through a mockup core vessel^{4,5}. Two major differences exist between the HRT core vessel and the mockup: (1) the mockup has a more squared exit than the HRT core vessel, and (2) the exit line on the mockup is a 3 in. Sch. 40 pipe rather than 3-1/2 in. ID pipe as on the HRT core vessel. Thus the available data must be corrected before it is applicable to the HRT.

Since the break in the core vessel appears to be at the intersection of the 30° and 90° cones, the screen loss to this point is estimated. The energy balance from one screen to another in a diffusing system is:

$$\frac{V_1^2}{2g_c} + p_1 = \frac{V_2^2}{2g_c} + p_2 + \frac{kV_2^2}{2g_c} + \epsilon \frac{(V_1^2 - V_2^2)}{2g_c} \quad (1)$$

where: k = screen constant^{6,7,8}

ϵ = 1 - efficiency of the expansion

Using this method of calculating the screen losses and correcting for the outlet shape and diameter of the mockup, very good agreement is obtained between the calculated and the experimental values. These results are shown below for the cases with and without the corrosion specimen sample holder in the core vessel.

Table II
HRT Core Losses Without the Corrosion Sample Holder

Flow Rate gpm	Inlet Loss to Hole ft	Loss from Hole through Sphere Exit ft	Friction Loss to Pressurizer Leg ft	Total Loss ft
400	1.12	3.04	1.12	5.28
350	0.86	2.30	0.86	4.02
300	0.63	1.71	0.63	2.97
250	0.44	1.18	0.44	2.06
200	0.28	0.76	0.28	1.32

Table III

HRT Core Losses with the Corrosion Sample Holder

Flow Rate gpm	Inlet Loss to Hole ft	Loss from Hole through Sphere Exit ft	Friction Loss to Pressurizer Leg ft	Total Loss ft
400	1.12	7.81	3.22	12.15
350	0.86	5.95	2.47	9.28
300	0.63	4.39	1.81	6.83
250	0.44	3.05	1.26	4.75
200	0.28	1.96	0.81	3.05

The equivalent length of straight pipe between the connection of the pressurizer leg with the main piping and the heat exchangers is approximately 27.5 ft for both systems as determined from the layout drawings. In each system the gas separator lies within this section. Pressure drops across this section and across the heat exchanger for various flow rates are shown in Table IV below.

Table IV

Head Losses Across HRT Gas Separator, Heat Exchanger
and High Pressure Piping

Flow Rate	Piping and Gas Separator Loss ft(10)	Heat Exchanger Loss ft(9)
400	13.73	47
350	10.60	37
250	5.53	20

A simplified sketch of the HRT high pressure system is shown in Figure 1. Included are estimates of pressures existing within the system for a blanket flow rate of 250 gpm and a core flow rate of 400 gpm with and without an opening between the fuel and blanket systems in the core vessel. A similar sketch with a blanket flow rate of 350 gpm and a core flow rate of 400 gpm is shown in Figure 2.

Comparison of Calculated and Measured Pressure Losses:

To check the calculated results, differential pressures were measured between the core and the blanket pressurizers. During these tests, the blanket pressurizer was completely filled with D₂O. Readings were made on the differential pressure recorder PdR-250A using measuring element PdE-250B and on the differential pressure indicator PdI-250 using measuring element PdE-250A for the following cases:

1. Fuel circulating pump on, blanket circulating pump on
2. Fuel circulating pump on, blanket circulating pump off
3. Fuel circulating pump off, blanket circulating pump on
4. Fuel circulating pump off, blanket circulating pump off

Using information calculated previously¹¹, the core flow is estimated to be 428 gpm and that in the blanket to be 238 gpm. Assuming the pressure drop across the hole in the core vessel making corrections for the change in momentum of the fluid at the outlet tee of the two vessels, the measured results compare with the calculated results as shown in Table V.

Table V

Head Loss from the Core Vessel Hole to the Pressurizer Leg

	Core, ft (without corrosion sample)	Blanket, ft (230A pump)
Calculated	4.8	6.3
Measured	9.0	5.2

It can be seen that the results compare favorably within the experimental error.

Insertion of the corrosion sample holder into the core will increase the head loss here and will decrease the flow rate to 412 gpm when using the 400A pump. Changing from a 230A pump to a 400A pump in the blanket will increase the pressure drop and increase the flowrate to 345 gpm. Calculated corrections added to the calculated and measured results of Table V are shown in Table VI.

Table VI

Head Loss from the Core Vessel Hole to the Pressurizer Leg
for New Conditions

	Core, ft (with corrosion sample)	Blanket, ft (400A Pump)
Calculated	11.7	11.7
Measured*	15.9	10.9

* Calculated corrections made to measured results in Table V.

Interconnection of the Chemical Processing Lines:

Knowing the pressure drops in the core and blanket high pressure systems, the flow through the lines cross connecting the chemical processing lines may then be computed. To connect Lines 167 and 266 will require 25.5 ft 1/2 in. Sch. 80 straight pipe, 2 - 90° elbows, 2 tees, and two - 6 in. radius 90° bends. (For pressure drop purposes this full connection is equivalent to 36.9 ft of straight pipe). To connect Lines 267 and 166 will require 26.3 ft 1/2 in. Sch. 80 pipe, 3 - 90° elbows, 2 tees, and two - 6 in. radius 90° bends. (This full connection is equivalent to 39.2 ft of straight pipe).

The following equations are used for calculation of the expected flows:

$$\Delta H = \frac{4 f V^2 L_e}{2 g_c D} \quad (2)$$

$$f = \frac{0.046}{\left(\frac{\rho D V}{\mu}\right)^{0.2}} \quad (3)$$

$$w = \rho \frac{\pi}{4} D^2 V \quad (4)$$

where ΔH is the head difference across the line.

Substituting Equations (3) and (4) into Equation (2) and solving for the mass flow rates gives:

$$w = \frac{\rho \frac{\pi}{4} (\Delta H g_c)^{0.556} D^{2.667} \left(\frac{\rho}{\mu}\right)^{0.111}}{(0.092 L_e)^{0.556}} \quad (5)$$

Assuming that the fuel solution has the same physical properties as D_2O , a total pressure of 1500 psia and an average temperature of 270°C in the transfer lines the constants are:

$$\rho = 53.04 \text{ lb/ft}^3$$

$$\mu = 0.764 \times 10^{-4} \text{ lb/sec ft}$$

$$D = 0.0455 \text{ ft}$$

$$L_1 = 36.9 \text{ ft (For flow from core to blanket)}$$

$$L_2 = 39.2 \text{ ft (For flow from blanket to core)}$$

Substituting these values into Equation (5)

$$w_1 = 0.1684 \Delta H_1^{0.556} \equiv \text{Mass flow rate from core to blanket.} \quad (6)$$

where ΔH_1 = Total pressure at core heat exchanger entrance minus total pressure at blanket heat exchanger exit, ft

$$w_2 = 0.1628 \Delta H_2^{0.556} \equiv \text{Mass flow rate from blanket to core} \quad (7)$$

where ΔH_2 = Total pressure at blanket heat exchanger entrance minus total pressure at core heat exchanger exit

The amount of mass transfer from one system to the other by these lines may be calculated by these equations as a function of the difference between the core and blanket pressurizer pressures for any desired core and blanket flow rates. The results of these calculations are shown in Figures 3 and 4 for a core flow rate of 400 gpm and blanket flow rates of 250 gpm and 350 gpm respectively.

Access Holes Connection:

The proposed line connecting the corrosion sample access holes will be a 1 in. Sch. 80 pipe. Flow resistances in this flow line are assumed to be due to the following:

- a) Entrance from blanket to access port.
- b) Length of access port.
- c) Tee from port to connecting line.
- d) Actual length of 1 in. Sch. 80 pipe.
- e) 3 elbows
- f) Exit from connecting line to core access port.
- g) Core corrosion holder annular space and slots.
- h) Exit from access port to core main stream.

The equivalent length of 1 in. Sch. 80 pipe for flow calculations is 36.1 ft for flow from the blanket to the core and 39.3 ft for flow from the core to the blanket.

To predict the flows, the following equation is used

$$w^2 = \frac{(3600)^2 2 g_c \rho^2 D^5 \Delta H}{6.49 f L_e} \quad (8)$$

where ΔH is the difference in head between the entrance of the blanket access hole and the cross at the outlet of the core vessel (Line 100). Results obtained by using this equation are shown in Figure 5.

The predicted head differences across the connecting line are shown in Table VII. In calculating these differences, it is assumed that the blanket head loss from the hole in the core vessel to shroud is 80% of the total vorticity loss. With these differences and the results based on Equation (8) (Figure 5), the expected flow rates through the connecting line are found. These results are also shown in Table VII.

Table VII

Flow Through Line Connecting Corrosion Sample Access Holes
(400 A Circulating Pump in Core System)

	<u>Solution</u> <u>Core</u>	<u>Flow Rate</u> <u>Blanket</u>	<u>Head</u> <u>Differences</u>	<u>Flow Through</u> <u>Connection</u>	
230A pump in blanket:					
Corrosion Sample in Core	412 gpm	238 gpm	7.8 ft	20.6 gpm	153 lb/min
Corrosion Sample not in Core	428	238	0.8	5.9	44
400A pump in blanket:					
Corrosion Sample in Core	412	345	5.2	16.6	123
Corrosion Sample not in Core	428	345	-1.8*	- 8.7*	-64*

* Pressure higher on core end of connection and therefore flow is from the core to the blanket.

For these calculations, it is assumed that there will be flow of solution of equal magnitude but of opposite direction through the core vessel hole. Also, it is assumed that the pressure drop across this hole is negligible. Therefore, there would be no net transfer of fluid from one system to the other.

Discussion

More rapid mixing between the core and the blanket systems than the present rate of 3-1/2 to 4 lb/min of fluid can be obtained by interconnecting the chemical processing lines or by connecting the two corrosion sample access holes.

If the chemical processing lines are interconnected, it should be observed for nearly all cases that the flow from the blanket to the core through one of these lines is not equal to that from the core to the blanket through the other line. But since only very small pressure differences are required for large flows through the hole in the core vessel, it is expected that the volumes in each system can be maintained constant by transfer through this hole. The differential pressure requirements of the pressurizers would not be changed appreciably over the situation without mixing through the proposed lines. Thus the addition of the mixing lines should present no further operational difficulties in controlling the liquid levels and pressures in the pressurizers.

Connecting the corrosion sample access holes, the flow through the connecting line is from the blanket to the core, and there is equal flow from the core to the blanket through the hole in the core vessel. From Table VII, it can be seen that if the core corrosion sample holder is not in place, an orifice or a similar constriction may be required to get the required flows through the connecting lines. This is due to a smaller pressure drop in the core outlet without the corrosion sample holder. Assuming the pressures at the hole for both the core and the blanket to be equal for the latter case, the driving force across the connection will be much less and the flow will be much lower or even reversed.

This connection will also provide a purge for the stagnant volume in the blanket access hole and it can be made by connecting only two flanges at the top of the pressure vessel.

Conclusions

Either the cross connection of the chemical processing lines or the connection of the corrosion sample access holes will provide adequate mixing for the single region operation of the HRT. The cross connection of the chemical process lines would probably be the easiest to install and control. But if the stagnant space in the blanket corrosion sample access hole requires purging, it is recommended that a connection between the sample access holes be made.

Nomenclature

D	Inside diameter, ft
f	Fanning friction factor
g_c	Constant, $32.17 \frac{\text{lb}_m \text{ ft}}{\text{lb}_f \text{ sec}^2}$
ΔH	Head difference, ft of fluid
k	Screen constant
L_e	Equivalent length of pipe, ft
V	Fluid velocity, ft/sec
w	Mass flow rate, lb_m/sec
ϵ	ϵ - (efficiency of expansion)
ρ	Density, lb_m/ft^3
μ	Viscosity, $\frac{\text{lb}_m}{\text{sec ft}}$

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Legend:

P = Pressurizer pressure, ft
 h = Head of liquid above
 main circulating loop, ft
 Subscript 1 = Blanket
 Subscript 2 = Core
 Values in parenthesis are those with
 no core corrosion sample holder

Figure 1

Core and Blanket Pressures
 at
 Core Flow Rate = 400 gpm
 Blanket Flow Rate = 250 gpm

Legend:

P = Pressurizer pressure, ft
 h = Head of liquid above
 main circulating loop, ft

Subscript 1 = Blanket

Subscript 2 = Core

Values in Parenthesis are those with no
 corrosion sample holder

Figure 2

Core and Blanket Pressures
 at

Core Flow Rate = 400 gpm

Blanket Flow Rate = 350 gpm

Figure 3
Mixing Resulting from Interconnecting
Chemical Processing Lines

Core Flow Rate = 400 gpm
Blanket Flow Rate = 250 gpm

Figure 5

Flow through Line Connecting
Corrosion Sample Access Holes

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