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Astronuclear

WANL-TME-543

September 30, 1963

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TEST SERIES D 2

MEASUREMENT OF LOSS COEFFICIENT
FOR THE BERYLLIUM REFLECTOR ASSEMBLY FLOW TESTS

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SPECIAL REVIEW FINAL DETERMINATION	Reviewed	Class.	Date
	DBW	4	5-582
Class: <u>1A</u>			

Approved:

Supervisor, Fluid Flow Test & Analysis

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INFORMATION CATEGORY

~~Confidential - R. D.~~

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INTRODUCTION

Cooling of the beryllium reflector is effected by hydrogen flowing through a series of passages covering the entire length of the reflector. The hydrogen is introduced through holes in the lower support ring, flows through the reflector and is exhausted through holes in the upper support ring.

The purpose of this memo is to summarize the results of the flow tests on a segment of the beryllium reflector assembly using hydrogen as the fluid medium instead of air as reported previously*.

The areas which were investigated were:

1. The effect of the hole size and geometry on pressure loss coefficients for the dome end and nozzle end support rings.
2. The effect of inlet and exhaust configuration on the pressure drop across the reflector.
3. The pressure distribution and flow patterns in the thin plena between the support ring and the reflector.

TEST APPARATUS AND INSTRUMENTATION

The test fixture is shown on Figure 1 and 2. The entire assembly was completely immersed in a liquid nitrogen dewar. The test fixture was installed in a flow loop having a normal flow capacity of 0.2 pps of hydrogen. A regenerative three pass heat exchanger was used to cool the incoming gas with the effluent gas as well as liquid nitrogen. Suitable control valves were provided in the loop to insure the proper pressure levels and mass flows in the model.

* Reference WANL-TME-333, dated May 25, 1963.

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A "Cryotrol^R" maintained the nitrogen liquid level in the dewar within 1" of high limit for complete immersion. Its sensing probe actuating a solenoid liquid valve supplying nitrogen from two 200 liter portable dewars connected in parallel. Two Guardsman^R controls insured that only liquid nitrogen was supplied to the system. Automatic closure of the valve occurred when gas replaced liquid nitrogen.

A 60,000 cubic foot hydrogen tube trailer was connected to a 720 pound per hour cold flow loop incorporating a three pass finned tube heat exchanger, one pass of which was connected to the liquid nitrogen supply line previously mentioned. The amount of liquid nitrogen supplied to the heat exchanger being controlled by a Fisher diaphragm air operated regulator valve which in turn was controlled by a Foxboro "Dynalog" using as sensing probes copper-constantan thermocouples at different locations on the test model and in the heat exchanger. These temperature sensors governed the air signal to the Fisher valve and accomplished the desired temperature control.

The flow loop was also provided with a bank of helium bottles used for complete purging of the system before and after each test. Supply lines for both hydrogen and helium gases were remotely operated from the control room.

Inlet pressure was controlled by a remotely operated pressure reducing valve. Outlet pressure was similarly maintained by a flow valve also operated from the control room. The inlet flow of hydrogen was connected to the middle pass of the heat exchanger, the gas being cooled down by the liquid nitrogen in the outermost pass, after which the gas entered the liquid nitrogen immersed test model. The outlet of the test model was connected to the innermost pass of the heat exchanger where the gas was brought back to ambient temperature after absorbing heat from the inlet flow of hydrogen. The entire flow in the system was measured through a precalibrated ASME sonic flow orifice. The gas was burned at the end of a flared stack.

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Hydrogen was introduced in the inlet plenum through two stainless steel tubes. From the inlet plenum the flow passes through holes in the support ring, Figure 3A, into the thin space between the inlet support ring and the reflector before entering the reflector cooling holes. At the exhaust end of the reflector all cooling holes exhaust into a thin space between the reflector and the outlet support ring before passing through the holes in the outlet support ring, Figure 3B, and then to the outlet plenum. This test fixture simulates a 2.5 degree segment of the entire reflector.

The lower plenum, where pressure P_1 is maintained, is assembled to a simulated inlet support ring which has fifteen holes through which complete flow passes. The thin inlet space between the inlet support ring and the reflector is simulated by 1/8" thick spacer plate used between the simulated inlet support ring and the main body of the fixture while the thin outlet space between the reflector and the outlet support ring is simulated by 1/16" thick spacer plate used between the main body of the fixture and the simulated outlet support ring, Figure 4. The plenum, the simulated support ring and plate are properly orientated and fastened to the main body of the fixture which has four tubes simulating the cooling holes in the reflector segment. Similar components are also assembled at the outlet of the fixture.

Fourteen pressure taps were placed at different locations as indicated and were connected to pressure and differential gauges. Both pressures and differential pressures could be read at all points and between all points respectively.

The inlet pressure was read at P_1 in the inlet plenum. The pressure in the support ring space was averaged between taps P_{2a} and P_{2b} and pressure differential read between them and P_1 . Four P_3 readings were taken; namely, P_{3a} , P_{3b} , P_{3c} , and P_{3d} near the inlet end of the four tubes simulating the holes in reflector segments. These four readings were alternately taken with their respective differential pressures relative to P_{2a} and P_{4c} . A duplicate arrangement was used for the outlet end; namely, P_{4a} , P_{4b} , P_{4c} and P_{4d} at the outlet end of the four tubes. Their respective pressures were read and their differential pressures taken with respect to the pressure P_{5a} in the outlet space of the support ring. Figure 5 shows inlet and outlet configuration of the simulated reflector.

P_6 indicated the pressure in the outlet plenum. Flow through the model was measured by an ASME type calibrated orifice. These tests were conducted with present reactor design arrangements as follows:

Inlet Support Plate Holes	15 at .085" dia. (.342" thick)
Inlet Plenum Height	.125"
Inlet Radius	1/8"
Outlet Radius	1/8"
Outlet Plenum Height	1/16"
Outlet Support Plate Holes	42 at .0625" dia. (.375 " thick)

These tests were conducted with the following parameters:

Inlet Pressure	750 psig
Inlet Temperature	140° - 365°R
Mass Flow	.02 to .2 pps
Outlet Pressure	630 to 745 psig

DATA REDUCTION

From temperature and pressure readings the following calculations were made:

Mass Flow

$$W = .00962 \frac{P_7}{\sqrt{T}}$$

where W = mass flow (lb/sec)
 P_7 = flow pressure at inlet of orifice (psia)
 T = temperature at orifice (°R)

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Loss Coefficient

$$C = \frac{.8293 P_{ave} \Delta P_{ave} N^2 D^4}{T W^2}$$

where P_{ave} = average pressure at inlet to flow component (psia)
 T = average of T_{inlet} and T_{outlet} ($^{\circ}R$)
 D = hole diameter (inches)
 N = number of holes
 ΔP_{ave} = pressure drop (psi)

Reynolds Number

$$\frac{48 W}{N \pi D \mu}$$

where μ = absolute viscosity $\left(\frac{lb}{ft \cdot sec} \right)$

Friction Factor

$$f = \frac{D}{L} C$$

where L = length of tube (inches)

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DISCUSSION

Figure 6 presents loss coefficient for the holes in the inlet support ring (C_{1-2}) as a function of Reynolds number based on hole diameter (15 holes, .085 inch diameter). While there is fair agreement of the maximum value of the loss coefficient at very high Reynolds number for hydrogen ($C_{1-2} = 0.90$) and air ($C_{1-2} = 1.20$)⁽¹⁾ the agreement is poor at low Reynolds. No concrete explanation can be advanced at this time to account for the difference. There is a possibility that the discrepancy is associated with inlet flow development (holes in simulated inlet support ring having $L/D = 4.02$). Reference information on establishing velocity profile⁽²⁾ in tubes (L/D required for establishing velocity profile is usually in the range of $0.02 - 0.06 Re$) have used air. Another possible source of discrepancy may be due to the fact that the pressure taps at station 2_a and 2_b were relocated. Test repetition and re-examination is required in this area.

Figure 7 presents loss coefficient for the inlet to the reflector (C_{2-3}) as a function of Reynolds number based on tube diameter (4 holes, .180 inch inside diameter). This loss coefficient is in good agreement with air data previously reported in Reference (1).

Figure 8 presents total loss coefficient across the holes in the inlet support ring and the inlet to the reflector (C_{1-3}) versus Reynolds number based on hole diameter at the inlet of the reflector (4 holes, .180 inch diameter). Figure 8 is presented for the convenience of the design groups.

Figure 9 presents friction factor (f_{3-4}) for the four tubes which simulate the reflector for typical tests. This is in agreement with air test and with curves obtained by Nikuradse⁽³⁾.

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1. WANL-TME-333.
 2. Hunsacker, J. C. and Rightmire, B. G., "Engineering Application of Fluid Mechanics", Pg. 123. McGraw-Hill Book Company, Inc., 1947.
 3. Hunsacker, J. C. and Rightmire, B. G., "Engineering Application of Fluid Mechanics", Pgs. 126-127. McGraw-Hill Book Company, Inc., 1947.

Figure 10 presents loss coefficient for the outlet of the simulated reflector (C_{4-5}) versus Reynolds number based on tube diameter (4 holes, .180 inch inside diameter). In agreement with air data, although somewhat higher, this figure shows a pressure recovery and consequently the loss coefficient is negative.

Figure 11 presents loss coefficient (C_{5-6}) for the simulated outlet support ring as a function of Reynolds number based on hole diameter (42 holes, .0625 inch diameter). Here again as in the case of loss coefficient for the inlet support ring (C_{1-2}) no complete explanation is available for this report and more experimental tests are recommended. The pressure taps at station 5_a and 5_b were relocated for the hydrogen test.

Figure 12 presents total loss coefficient across the outlet of the reflector and the holes in the outlet support ring (C_{4-6}) versus Reynolds number based on hole diameter at the outlet of the reflector (4 holes, .180 inch diameter). As in the case of Figure 8 for loss coefficient (C_{1-3}) calculations are based on total of readings of differential gauges ΔP_{4-5} and ΔP_{5-6} .

CONCLUSIONS AND RECOMMENDATIONS

These tests were made at maximum flows for the new high flow loop really taxing the overall performance. Due to high flow and limited supply of hydrogen, these tests had to be of very short duration (20 minutes per tube trailer); therefore, limiting the time for equilibrium to less than 3 minutes. At least 45 seconds per run were required to ensure good quality of photographs of 12 pressure gauges and 21 differential pressure gauges. The photographs were easily read and not problems were incurred in the reduction of this data. Major difficulties were encountered in obtaining good flow of the coolant (liquid nitrogen) because of "off the shelf" control valve malfunctions.

In view of the foregoing, we make the following recommendations:

1. Rerun selective tests at both ambient and cryogenic temperature.
2. Improve refrigerant control and investigate possibility of larger supply of liquid nitrogen.

Figure 1

Reflector Assembly

Figure 2

Reflector Assembly Showing Location of Pressure Taps

Figure 3B Simulated Outlet Support Ring

Figure 3A Simulated Inlet Support Ring

Figure 4. Spacer Plate

Figure 5 Reflector Inlet and Outlet Configuration (1/8" Radius)

FIGURE 7
 Loss Coefficient
 For Inlet to the Reflector vs Reynolds Number
 (Based on Tube Inside Diameter)

FIGURE 9
Friction Factor
For Tubes Simulating Reflector vs Reynolds Number
(Based on Tube Inside Diameter)

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FIGURE 12
Loss Coefficient
For Holes in Outlet Support Ring and Reflector vs Reynolds Number
(Based on Tube inside Diameter)