PATHFINDER ATOMIC POWER PLANT COOLANT DISTRIBUTION TESTS

Final Report

By

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November 15, 1959

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PATHFINDER ATOMIC POWER PLANT

FINAL REPORT

COOLANT DISTRIBUTION TESTS

by

J. Wilson and R. Styles

Submitted to

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NORTHERN STATES POWER COMPANY

and

CENTRAL UTILITIES ATOMIC POWER ASSOCIATES

Under

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by

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ABSTRACT

Tests were made to determine the head loss coefficient through the inlet plenum of the Pathfinder reactor and to determine the flow distribution among the fuel element nozzles for various operating conditions -- with all three pumps operating at the same flow rate and with any combination of only two pumps operating at the same flow rate. A quarter-scale wooden model was used for the tests. Air was used as the fluid. The loss coefficient was determined to be 1.8 ± 0.3 . The velocities of flow through the fuel element nozzles were determined to be within ± 5 per cent of average flow when all pumps are operating and within ± 10 per cent of average flow when only two pumps are operating.

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1. INTRODUCTION

Recirculation pumps feed coolant to the inlet plenum of the Pathfinder reactor. The coolant flows around the superheater manifold and enters the inlet nozzles of the ninety-six boiler fuel elements. Three recirculation pumps are used to feed the plenum, but the cases where any one of the pumps may be temporarily out of service is also of interest.

Tests were made 1) to determine the head loss coefficient through the inlet plenum and 2) to determine the flow distribution to the inlet nozzles of the boiler fuel elements for the four possible test conditions, i.e. when three pumps are operating at equal flow rates and when any combination of only two pumps are operating at equal flow rates.

2. EQUIPMENT

The inlet plenum and superheater manifold were simulated with a quarter-scale wooden model. Air was used as the working fluid. Simple ducts and three blowers, arranged in an open system, were used to simulate the pump loops. A plan view of the equipment is shown in Figure 1; a photograph of the equipment is given in Figure 2.

The inlet nozzles of the boiler fuel elements were simulated with four, thin, grid plates designated A, B, C, and D. Each of the grid plates contained ninety-six holes of equal size arranged in the same pattern as are the inlet nozzles in the reactor. The diameter of the holes in the different plates were $3/8$, $11/16$, $3/4$, and 1 inch, respectively.

Air was supplied by three centrifugal blowers with 4-7/8-inch square discharges. A square-to-round adapter was used to connect the blowers to 5-foot lengths of 5-inch diameter pipe that in turn were connected to the inlet plenum. Two of the pipes, as shown in Figure 1, contained 90-degree elbows. The flow was controlled by blocking off the inlet screens of the blowers with tape and by changing the blower speeds. When one blower was not operating, its inlet was completely blocked with tape to eliminate backflow from the other two blowers.

Three static pressure taps were located in the model one inch below the grid plate as shown in Figures 1 and 3. The taps were carefully installed so that burrs, which would cause inaccurate readings, would not be formed. These three taps were connected together to obtain an average reading.

Pitot tubes, adjustable so that a traverse could be made (Figure 4), were used to measure the velocity and pressure heads in the three inlet pipes. Static and total pressure from the tubes were applied to a differential manometer for measuring velocity head. Static pressure was also applied to a manometer for measuring pressure head.

A single pitot tube with a special centering fixture was used to measure velocities through the grid plate orifices. Ordinary U-tube water manometers were used to measure pressure and velocity heads above 2 inches of water, and an Ellison 0- to 2-inch inclined manometer graduated in 0.01-inch sub-divisions was used to measure all velocity heads below 2 inches of water. The location of these test points is shown in Figure 3.

In the test, no attempt was made to duplicate the Reynolds number

of the inlet pipes of the reactor (2×10^4). It was assumed that air flow in the model would be sufficiently separated and turbulent to preclude viscosity effects, and the loss coefficient and flow distribution were therefore expected to be independent of the Reynolds number. The air velocities were chosen so as not to produce significant compressibility effects, and the Reynolds numbers, depending on the grid plate and air velocities used, varied from 0.5×10^5 to 1.7×10^5 . The validity of these assumptions was investigated with respect to specific test results and is discussed in Section 4.

3. PROCEDURE

3.1. Head Loss Coefficient. The total head loss through the inlet plenum, H_L , in both the model and the reactor is given by the expression,

$$H_L = \frac{KV_1^2}{2g}, \quad (1)$$

where,

V_1 = the velocity at the inlet pipes

K = the head loss coefficient

g = acceleration of gravity

The total head loss is also given by Bernoulli's equation,

$$\frac{P_1}{\gamma} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + Z_2 + H_L. \quad (2)$$

Values for V_1 and P_1 were obtained in the inlet pipes about three pipe diameters upstream from the inlet, and P_2 was measured by the three taps

one inch below the grid plate. V_2 was calculated at this point from the flow and area below the grid plate, and the head loss coefficient could then be calculated from Eq. (1). Z is the static head in feet of fluid and γ is the specific weight of the fluid. The Z terms were eliminated from Eq. (2) in calculations since they were not significant.

3.2. Flow Distribution. Inlet Plenum. The flow distribution along the surfaces within the inlet plenum was observed by spraying the inner surface of the model with a solution of lamp black and transformer oil. During the test, the lamp black is moved by the air leaving an easily recognized flow pattern on the surface. Photographs of these patterns were taken.

Grid Plate Orifices. Flow distribution is affected by the pressure drop ratio, P_d -- the ratio of the pressure head drop across the grid plate, P_{2-3} , to the total head loss through the inlet plenum, H_L . This ratio is given by the expression,

$$P_d = \frac{\Delta P_{2-3}}{H_L \gamma} \quad (3)$$

To ensure that the flow distribution patterns would be applicable, the model was required to duplicate the pressure drop ratio of the reactor. The calculated pressure drop in the reactor fuel element, P_{2-3} , was 13.2 psi (38.4 feet of water at 489°F), and the calculated velocity head at the inlet, V_1 , was 5.87 feet of water. The head loss coefficient for the quarter-scale model was determined by the procedure given in Section 3.1., and the coefficient for the reactor was assumed to be the same. This

value was then used to calculate the pressure drop ratio for the reactor.

Pressure drop ratios for each of the grid plates were calculated and plotted as a function of the orifice diameter. The grid plate (hole size) that produced a pressure drop ratio in the model equal to that obtained in the reactor was then chosen for the tests.

After a grid plate was selected, the velocity at each hole in the grid plate was measured and recorded on a chart showing the location of each hole. These charts were then used to plot velocity distribution maps.

4. RESULTS

4.1. Head Loss Coefficient. Values for the head loss coefficient obtained with the various grid plates and at various flow rates vary considerably more than expected. Analysis of the test results verifies the initial assumption that the loss coefficient is independent of the Reynolds number. It was found, however, that the loss coefficient varies with a parameter, ϕ , which represents a difference in the flow rates of the blowers. The parameter is given as a per cent of the average flow by the expression,

$$\phi = \frac{Q_m - Q_{avg}}{Q_{avg}} \times 100, \quad (4)$$

where,

Q_m = the flow from any one blower that differs from Q_{avg} to the greatest extent (higher or lower)

Q_{avg} = the average flow from the three blowers.

In most cases the difference was caused by a lower flow in pipe 1.

This parameter was calculated only for the cases when all three blowers were in operation. The head loss coefficient was then plotted as

a function of ϕ in Figure 5.

One possible explanation for the variations in the head loss coefficient is that compressibility effects were produced in the model due to the use of air as the working fluid. Tests run at very low velocities, however, resulted in similar variations in the loss coefficient and therefore indicate no compressibility effects in the model itself.

A definite tone of about 300 cps was developed by the blowers when operated at 3000 rpm (the natural frequency of the inlet pipes was about 300 cps). Tests were run at different blower speeds in an attempt to eliminate this tone. The tests were made with air flows of from 540 to 1300 cfm with blower speeds of from 2500 to 3050 rpm. A test was also made with a blower speed of 1340 rpm. In all of these tests ϕ ranged from 1.5 to 38 per cent, and the loss coefficient appeared to be a function of ϕ only.

Another possible explanation for the variation in the loss coefficient is that the flow pattern is changed as ϕ varies. This could reduce separation losses and consequently cause the loss coefficient to vary. Assuming that this more probable explanation is correct, model similarity is maintained, and a loss coefficient for the reactor may be found.

Since all pumps in the reactor system operate at equal flow rates under normal conditions, ϕ for the reactor should be less than 5 per cent. All values for head loss coefficient, K , obtained in tests where ϕ is

less than 5 per cent should then be valid. The values are plotted against the Reynolds number in Figure 6. A head loss coefficient of 1.8 ± 0.3 was obtained and is considered valid for the reactor. A mean value of 1.8 was used to determine the pressure drop ratio of the reactor.

4.2. Flow Distribution. Inlet Plenum. Two representative photographs of the flow distribution in the inlet plenum are shown in Figure 7. The patterns show considerable flow separation, which indicates that the flow distribution and loss coefficient are independent of Reynolds number as assumed.

Grid Plate Inlet Orifices. To further ensure that the flow distribution was independent of the Reynolds number, a velocity distribution ratio, $V_{\min}/V_{\max}$ was obtained for the various grid plates under various conditions. $V_{\min}$ is the average of the three lowest velocities through the grid plate orifice for a given test, and $V_{\max}$ is the average of the three highest velocities. The ratio is plotted as a function of the Reynolds number in Figure 8, and no appreciable variation appears.

The pressure drop ratios of grid plates A, B, C, and D, calculated with Eq. (3), are plotted as a function of the size of the hole in Figure 9. Since the mean head loss coefficient is 1.8, the pressure drop ratio for the reactor as calculated from Eq. (3) is 3.6. A hole size of 11/16 inch diameter (Grid Plate B) is therefore indicated for further testing.

Flow distribution patterns for Grid B for the four test conditions are shown in Figures 10 through 13. The general trend of these patterns

show a region of low flow near the center and regions of high flow at several points on the outer perimeter. The general magnitudes of these two extremes with three blowers operating are about 5 per cent above and below the average flow calculated by the continuity equation. In tests with two blowers operating, the pattern becomes less symmetrical, and velocities 10 per cent above and below the average are obtained.

The patterns for grid plates A, C, and D are generally the same, except that the magnitude of the extreme values changes. The effect of a change in orifice size on the velocity distribution is as expected. A reduction of orifice diameter restricts the flow and induces a higher static pressure under the grid plate. The flow then tends to distribute itself more evenly between orifices. By increasing the orifice diameter, an opposite effect is noted.

5. CONCLUSIONS

Test results substantiate the initial assumptions of the experiment, i.e. that the flow distribution and head loss coefficient are independent of the Reynolds number. The head loss coefficient, however, varies with a parameter, ϕ , which represents the greatest variation between the flow from one blower and the average flow from three blowers. A loss coefficient of 1.8 ± 0.3 is obtained by plotting values obtained in tests where ϕ is less than 5 per cent. This value is considered valid for the reactor.

The flow through the grid plate orifices for the test condition with three blowers operating varies 5 per cent above and below the calculated average flow. When only two blowers are operated, the flow varies from 5 per cent above to 10 per cent below the calculated average and from 10 per cent below to 5 per cent above the calculated average, depending on which blower is not running. Since the test properly simulated reactor operating conditions, this approximate coolant flow distribution may be expected in the reactor.

NOMENCLATURE

D = Inlet pipe diameter (ft)

g = Acceleration of gravity (32.2 ft/sec²)

H_L = Total head loss through inlet plenum (feet of air or water)

K = Head loss coefficient

P_d = Pressure drop ratio

P = Pressure differential (psf, psi)

Q = Fluid flow (cfs)

R = Reynolds number = $\frac{VD}{\nu}$

V = Velocity (fps)

Z = Static head (feet of air or water)

ν = Kinematic viscosity (ft²/sec)

γ = Specific weight of fluid (lbs/ft³)

ϕ = Flow rate parameter

Quarter-Scale Model Test Setup. The numbers 1, 2, and 3 indicate pitot tubes. The letters A, B, and C indicate static pressure taps. (A-C Dwg. 43-201-658)

Fig. 1

Quarter-Scale Model Test Setup. Centrifugal blowers (top right) supply air to the model. The experiment was monitored by static manometers (bottom left) and differential manometers (bottom right). A pitot tube with a special centering fixture was used to measure velocity head at the grid plate orifices (NP Photo 025-16, 023-32).

Fig. 2

Location of Test Points. Three static pressure taps ganged together are mounted one inch below the grid plate. The average velocity, V_2 , below the grid plate was calculated for each test. (A-C Dwg. 43-024-011).

Pitot Tube Traverse. The pitot tubes mounted upstream from the inlet plenum were adjustable so that a traverse could be made. The pipe cross-section was divided into four annular rings. Readings were taken at the indicated points. (A-C Dwg. 43-024-019).

Figs. 3 & 4

Loss coefficient vs. ϕ . Loss coefficient through the inlet plenum varies with a parameter, ϕ , which represents a variation in flow rates from the various blowers. (A-C Dwg. 43-024-013).

Loss Coefficient vs Reynolds Number. The values for the loss coefficient are those obtained in tests where ϕ was less than 5 percent (A-C Dwg. 43-024-012).

Figs. 5 & 6

Flow Distribution Patterns. These representative photographs of the surfaces of the inlet plenum show the separation anticipated (NP Photos 003-12, 003-14).

Fig. 7

Velocity Ratio vs Reynolds Number. The ratio of the average of the three lowest velocities to the average of the three highest velocities is plotted for the various grid plates. (A-C Dwg. 43-024-020)

Pressure Drop Ratio vs Orifice Diameter. The pressure drop ratio for the four grid plates was plotted. The grid plate that best simulates the inlet orifices in the reactor was then obtained from the curve. (A-C Dwg. 43-024-018).

Figs. 8 & 9

TEST D-1

Flow Distribution Pattern with Three Blowers Operating.
The contour numbers indicate the percent of average velocity.
Flow is 1031 cfm; δ is 2.3 percent. (A-C Dwg. 43-024-017).

Fig. 10

Flow Distribution Pattern with Two Blowers Operating. The contour numbers indicate the percent of calculated average velocity. (A-C Dwgs. 43-024-016, -014, -010).

TEST D-2

Flow = 959 cfm

TEST D-3

Flow = 866 cfm

TEST D-4

Flow = 863 cfm

Figs. 11, 12, 13