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TO: K. W. Foster* 786-44 HQ-2

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SUBJECT: Experimental Measurements of the Suction Head Required by the Hallam Prototype Free Surface Sodium Pump

CONTENTS:

I	STATEMENT OF PROBLEM	PAGE 1
II	SUMMARY OF RESULTS AND RECOMMENDATIONS	PAGE 1
III	METHOD USED, DESCRIPTION OF EQUIPMENT, SAMPLE CALCULATIONS . . .	PAGE 3
IV	REFERENCES AND APPENDICES	PAGE 6

I STATEMENT OF PROBLEM

Experimental measurements were required to determine the net positive suction head (NPSH) required by the Hallam Prototype Free-Surface Pump in order to maintain circulation of sodium over the flow range of interest. This information can be utilized to determine if cost reductions are possible for future pumps of this type by ascertaining the margin of safety by which this pump was over-designed.

II. SUMMARY

The values of NPSH required at various fluid flow rates by the Allis-Chalmers free surface pump are shown in Figure 1. The pump was designed on the basis of a specification (Reference 1) which indicated that an NPSH corresponding to 25 feet of sodium was available at the suction nozzle of the pump, when circulating 7200 gpm of sodium at 945°F. The test data (Figure 1) indicate that an NPSH corresponding to 22 feet of sodium was required at the design flow rate. This value is identical to that predicted by the correlation given in Reference 2 which relates pump specific speed to the cavitation constant. Curves obtained with water (Reference 3) of required NPSH vs suction eye velocity indicate that an NPSH corresponding to 21.7 feet of sodium is required. Thus, it may be seen that the present methods for predicting required NPSH are quite accurate and that the Allis-Chalmers pump was designed with a reasonable margin of safety of slightly over 10%.

148 002

PUMP PERFORMANCE AT VARIOUS SUCTION STATIC HEADS AND NPSH REQUIREMENTS

Figure 1

ATOMICS INTERNATIONAL

A Division of North American Aviation, Inc.

NO 6569
DATE July 25, 1961
PAGE 3 OF 10

III. METHOD USED

A series of hydraulic tests were performed using an Allis-Chalmers free-surface sodium pump that had been purchased for the Hallam pump development program. The pump, described in Reference 2, was operated at design speed of 1100 rpm and sodium was circulated at temperatures between 1000 and 1080°F while obtaining NPSH data. During heating and cooling of the loop, additional data on head vs capacity were obtained at temperatures of 760 to 850°F.

The test loop used for these tests was made of Type 304 stainless steel and consisted of 12-in. schedule-20 pipe, a throttle valve, an expansion tank and a variety of service lines. The space above the free surface of sodium in the pump case was connected via a heated vent line to the top of the loop expansion tank; thus, the pressures in the pump casing and the expansion tank were always the same.

Sodium flow rates were measured using an electromagnetic flow meter, and the pressures at the pump suction and discharge were indicated by conventional Bourdon-tube gages attached to specially developed pressure transmitters. Chromel-alumel thermocouples were used to indicate sodium temperature. The pump shaft speed was measured with a frequency meter attached to a tachometer generator. Pump-motor power was indicated by a kilowatt meter. A vacuum pump was connected to a vent line at the floor plate of the pump to establish and maintain various values of absolute pressures in the pump case and expansion tank; the resulting pressures were read with a mercury manometer.

The test procedure was to establish the absolute pressure of the system when the sodium at 1000° to 1080°F was flowing at a rate of approximately 6000 gpm. Readings were then taken of the pump suction and discharge pressure, pump shaft speed, motor power consumption, and flow rate and temperature of the sodium. The throttle valve was then opened slightly and all readings again were taken at the higher flow rate. These steps were repeated, at constant system pressure, until an indication of reduction in total head greater than 5% was obtained. When this cutoff point was reached, the flow again was reduced to 6000 gallons per minute and the system pressure reset to a lower value with the vacuum pump. This procedure was repeated until data had been obtained at four different cover-gas pressures and yielded the data

ATOMICS INTERNATIONAL

A Division of North American Aviation, Inc.

NO. 6569
DATE July 25, 1961
PAGE 4 OF 10

plotted in Figure 1. The procedure for calculating the points on these curves is shown in the Appendix.

Additional data on pump performance was obtained at a sodium temperature between 760 to 850°F and these data are plotted in Figure 2. The procedure for computing the head-capacity curve and the efficiency curve is also illustrated in the Appendix.

DISCUSSION

To keep liquids from boiling at the entrance to the impeller of a centrifugal pump, a sufficient static head above the vapor pressure of the fluid being pumped must be provided to overcome friction losses, etc. This static head above vapor pressure is called NPSH or net positive suction head. It is defined as the gage reading in feet taken on the suction nozzle referred to the pump centerline, minus the vapor pressure in feet corresponding to the temperature of the liquid, plus the velocity head at this point.

In designing a pump installation and purchasing a pump there are two types of suction head or NPSH to be considered (Reference 5). One is the available suction head of the system and the other is the required suction head of the pump to be placed in the system. The former is specified by the plant designer and is based upon the condition of the liquid to be handled, pump location, piping configuration, etc; the latter is established by the pump manufacturer, and is usually based upon test results obtained with the pump. It is necessary that the available head of the system be equal to or greater than the required suction head in order to avoid cavitation difficulties.

The available head specified for the HNPF prototype free-surface pump was 25 feet of sodium. The manufacturer had supplied head-capacity data obtained with water but had not determined the required suction head to avoid cavitation difficulties. This test was performed to obtain such information using sodium at 1000 to 1080°F. It was found that a head corresponding to 22 feet of sodium was required to avoid cavitation difficulties.

The value of NPSH required by the pump is defined, for the purposes of this report, as the value obtained at the point where the head versus capacity curve drops approximately 5% below the designed level. These points (see Figure 1) occurred at flow rates of 6600, 7600, and

148 005

PUMP PERFORMANCE AT SHAFT SPEED OF 1100 RPM

A/C WATER TEST DATA		
X	X	X
0	0	0
SODIUM AT ~ 500°F		003840
SODIUM AT ~ 500°F		003839

Figure 2

148 006

ATOMICS INTERNATIONAL

A Division of North American Aviation, Inc.

NO. 6569
DATE July 25, 1961
PAGE 6 OF 10

8000 gpm for the particular cover-gas pressures selected. Figure 3 was prepared to aid in obtaining values for pump suction head by interpolation. The values of NPSH were calculated using the procedure shown in the Appendix using pump suction pressures estimated from Figure 3.

A correlation has been prepared (Reference 2) that relates the specific speed of a pump to a cavitation constant. Based on this method the calculated NPSH required for this pump was 22 feet at 7200 gpm whereas the observed value also was 22.0 feet (Figure 1). Pump manufacturers have standard curves for use in estimating NPSH requirements. One such curve, shown in Reference 3, indicates that an NPSH corresponding to 21.7 feet of sodium should be required for this pump when the flow equals 7200 gpm.

The ability of the pressure transmitters to provide accurate data for these tests represents a significant improvement over the apparatus formerly available for this purpose. During the course of the tests readings as low as 21 in. Hg were indicated by the pump suction gage and pressures to 88 psig were read from the pump discharge gage. The head-capacity curves shown in Figure 2 were run before and after the NPSH tests to demonstrate that the pressure transmitters were working properly. The excellent agreement between the data obtained with water and that obtained with sodium may be seen in Figure 2.

IV. REFERENCES

1. AI Specification 7518-S78104.
2. A. J. Stepanoff, "Centrifugal and Axial Flow Pumps," Wiley - New York, 1944, Page 267.
3. V. Lobanoff, "What is this NPSH?" Oil and Gas Journal 56 (February 24, 1958) Pages 121-124.
4. NAA-SR-MEMO No. 4336, "Performance Test of HNPF Prototype Free Surface Pump," R. W. Atz.
5. A. H. Church, "Centrifugal Pumps and Blowers," Wiley - New York, 1944, Pages 74-81.

Original data for this report are recorded in Laboratory Notebook,
pages 003838 - 003841.

148 007

EFFECT OF SUCTION STATIC HEAD UPON VARIATION IN PUMP SUCTION PRESSURE

TDR No. 6569
Page 7 of 10

PUMP SUCTION PRESSURE - FT. OF SODIUM

KE 10 X 10 TO THE 1/2 INCH 359-11
KEUFFEL & ESSER CO. MADE IN U.S.A.

ATOMICS INTERNATIONAL

A Division of North American Aviation, Inc.

NO. 6569
DATE July 25, 1961
PAGE 8 OF 10

APPENDIX

I. Sample Calculation for NPSH

Using values for a flow of 6600 gallons/minute with a gas pressure of 28 cm of Hg below atmospheric.

Laboratory data:

Sodium temperature = 1080°F
Sodium flow = 6600 gallons/minute
Pump suction pressure = 18.0 in. Hg
Pump discharge pressure = 45.5 psig
Pump speed = 1100 rpm

1. Convert gas pressure (cm Hg) to feet of Na @ 1080°F

$$P_{\text{gas}} \text{ ft Na} = \left[\frac{(76.0 - P_{\text{atm}})}{2.54 \text{ cm/in.}} \right] \text{ cm} \times \frac{1 \text{ ft}}{12 \text{ in.}} \times \frac{\rho_{\text{Hg}}}{\rho_{\text{Na}}}$$

$$= \left[\frac{76.0 - 28}{2.54} \right] \frac{1}{12} \times \frac{13.6}{0.808} = 26.5 \text{ ft Na at } 1080^\circ\text{F}$$

where $P_{\text{atm}} = 28 \text{ cm}$ and $\rho_{\text{Hg}} = 13.6$; $\rho_{\text{Na at } 1080^\circ\text{F}} = 0.808$

2. The suction static head becomes 26.5 ft + 3.9 ft = 30.4 ft where 3.9 ft is the elevation of the free surface of the sodium in the expansion tank above the centerline of the pump suction nozzle.

3. Convert pump suction pressure from inches Hg to feet of sodium.

$$P_{\text{suct}} \text{ ft Na} = (29.92 - P_{\text{suct}}) \text{ in. Hg} \times \frac{1 \text{ ft}}{12 \text{ in.}} \times \frac{\rho_{\text{Hg}}}{\rho_{\text{Na}}}$$

$$= (29.92 - 18.0) \text{ in. Hg} \times \frac{1 \text{ ft}}{12 \text{ in.}} \times \frac{13.6}{0.808} = 16.75 \text{ ft Na at } 1080^\circ\text{F}$$

4. The vapor pressure at 1080°F equals 10 mm Hg

$$P_{\text{vapor}} \text{ ft Na} = 10 \text{ mm Hg} \times \frac{1 \text{ in.}}{25.4 \text{ mm}} \times \frac{1 \text{ ft}}{12 \text{ in.}} \times \frac{\rho_{\text{Hg}}}{\rho_{\text{Na}}}$$

$$= \frac{10}{25.4} \times \frac{1}{12} \times \frac{13.6}{0.808} = 0.552 \text{ ft Na}$$

5. Velocity head when $Q = 6600 \text{ gallons/minute}$. Twelve-in. Schedule 20 pipe has cross-sectional area of 117.9/144 = 0.819 ft².

Velocity head (ft Na)

$$= \frac{V^2}{2g} = \frac{Q \times \frac{1 \text{ ft}^3}{7.48 \text{ gallon}} \times \frac{1 \text{ min}}{60 \text{ sec}} \times \frac{1}{0.819 \text{ ft}^2}}{2 \times 32.2 \text{ ft/sec}^2}$$

148 008

ATOMICS INTERNATIONAL

A Division of North American Aviation, Inc.

NO. 6569
DATE July 25, 1961
PAGE 10 OF 10

2. Input to variable speed drive, HP

Motor efficiency at 320 HP input = 90.4%

$$\text{HP}_{\text{input}} = 320 \times \frac{90.4}{100} = 289 \text{ HP}$$

3. Efficiency of the variable speed drive = $\frac{\text{speed of pump}}{\text{speed of motor}} \times 100$

Motor speed at 289 output HP, equals 1187 rpm.

$$\text{Drive efficiency} = \frac{1100}{1187} \times 100 = 92.8\%$$

4. Input HP to pump equals $289 \times \frac{92.8}{100} = 268 \text{ HP}$

$$\text{Pump efficiency (\%)} = \frac{\text{HP output}}{\text{HP input}} \times 100$$

$$\frac{212}{268} \times 100 = 79.1\%$$

148 011