ENGINEERING RESEARCH INSTITUTE
THE UNIVERSITY OF MICHIGAN
ANN ARBOR

# CONTINUOUS FLOW FLUID TUNNEL CAVITATION-EROSION FACILITY

PROGRESS REPORT NO. 3

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## 1.0 ABSTRACT

References 1 and 2 proposed a blowdown-type, continuous operation, automatically reversing fluid tunnel for the study of cavitation-erosion effects with fluids other than water at conditions of elevated temperature and high velocity.

Of particular concern because of the present application to nuclear powerplants are liquid metals. This report evaluates the possibility of the construction of a continuous flow fluid tunnel, powered by a sump-type centrifugal pump for liquid metals ranging from bismuth to sodium. Maximum operating temperature is set at 1000°F and maximum velocity in a cavitating venturi at 50 feet per second for bismuth and 100 feet per second for sodium. The operating behavior of such a facility is examined and the research program discussed.

The equipment cost for the facility is estimated to be $11,100.

## 2.0 INTRODUCTION

The necessity and desirability of a cavitation-erosion facility capable of handling various fluids other than ordinary water were reviewed in References 1 and 2. Of particular concern, because of the present-day application to nuclear powerplants, were liquid metals.

An automatically reversing, continuous operation blowdown-type facility, capable of handling a variety of fluids under extreme velocity and temperature conditions was proposed.

Now, a preliminary facility, utilizing a continuous flow fluid tunnel, powered by a sump-type centrifugal pump, and capable of providing more moderate conditions of velocity and temperature than would have been possible with the blowdown facility, is suggested. Particular emphasis is placed upon the liquid metals. The operating conditions would be sufficiently severe to encompass a great many of the practical applications, and to show the magnitude of the problem for at least all the liquid metal applications.

The fluids which have been considered are:

1. Sodium or NaK

2. Bismuth, lead-bismuth, or mercury

The maximum attainable velocity and temperature conditions in the throat of a cavitating venturi with these fluids and utilizing the pumping equipment herein proposed are:

1. For sodium (or NaK): 100 feet per second at 1000°F

2. For bismuth (or other heavy metals): 50 feet per second at 1000°F.

The maximum estimated operating conditions for the proposed blowdown facility were 1500°F, 300 feet per second for sodium, and 1200°F, 75 feet per second for bismuth (References 2 and 3).

The estimated capital cost for the presently suggested facility is $11,100. Of this total, approximately $7500 would apply to equipment which would be common to the blowdown facility.

## 3.0 DESCRIPTION OF PROPOSED FACILITY

### 3.1 Previously Proposed Blowdown Facility

References 1 and 2 proposed the construction of an automatically reversing, continuous operation, blowdown facility capable of providing cavitating operation at high velocity and temperature with a variety of fluids in an axially-symmetrical venturi section. The fluids of primary interest were the liquid metals which are presently under consideration as coolants and/or fissionable material solvents for nuclear powerplants. However, operation with other fluids of interest as rocket propellants, jet engine fuels, chemical process fluids, etc. would be possible with minimum modification of the equipment. The blowdown-type of facility, powered by inert gas, was chosen in order to avoid the difficulties inherent in a pump capable of handling the various fluids of interest under the applicable conditions of pressure and temperature.

Operation was to be continuous with the test fluid forced repeatedly between two high pressure tanks through a test section. Reversal of the fluid flow was to be accomplished through the action of valves in the powering inert gas system which would be activated by the liquid levels in the high pressure tanks. The flow duration in a single direction was to be sufficient to allow steady-state to be achieved (a minimum of 30 seconds was specified). Venturi throat diameters ranging from a maximum of 1 inch to a minimum of 1/4 inch were planned to investigate the possibility of a scale effect if velocities and pressures were held constant. It was planned to initiate the program with a transparent test section in order to determine the behavior of the equipment. Sonic detection was to be utilized to establish the existence and, at least qualitatively, the nature of the cavitation in the transparent test section with water, and also perhaps with low temperature liquid metal. It was then planned to utilize the sonic behavior as a bridge between the tests with a transparent test section and those for which a metallic test section would be necessitated by the nature of the fluid and/or the operating temperature. It was also planned to measure the flow rate with a second venturi (with reduced area ratio) or orifice, in conjunction with level or pressure indicating apparatus, and the throat pressure directly with an instrument available from the Callery Chemical Company. Since the determination of the degree of damage sustained by the test section under various conditions of fluid and operating parameters was as much an objective of the program as a further study into the basic nature of the cavitation phenomenon in fluids other than water, some measurement and determination of damage was necessary. The possibility of drastic shortening of required overall test duration through the use of irradiated test sections was considered as well as the possibility of visual observation upon disassembly of the equipment.

## 3.2 Proposed Continuous Flow Preliminary Facility

The blowdown-type facility was chosen originally since it seemed suitable, without the introduction of components of doubtful feasibility, for operation with a variety of fluids under extreme conditions. However, if the fluid choice and the operating conditions were to be somewhat restricted, it would become possible to construct a continuous flow fluid tunnel facility powered by a readily obtainable sump-type centrifugal pump. Under these conditions, a considerable portion of the expensive equipment would be eliminated. The instrumentation would be similar so that the investment in this portion of the equipment could be utilized eventually in a blowdown facility if such were desired. The preliminary facility, however, would serve to disclose a great deal of valuable data regarding the nature of the phenomenon and the seriousness of the related problems. If it appeared desirable at a later data to increase the severity of the operating conditions and proceed with a blowdown facility, then the experience gained would be of extreme value in the final design of such a facility. If, on the other hand, it appeared possible to answer all pertinent questions with the preliminary facility, the program would be complete at this point.

To allow the utilization of a readily obtainable, reasonably economical pump, it is necessary that a sump-type be considered wherein a free surface of the test fluid is maintained beneath an inert gas blanket. A stuffing box or rotating seal assembly is necessary to contain the inert gas. To simplify the sealing problem it is necessary that the inert gas blanket be maintained at a pressure only slightly in excess of atmospheric. In this way, inward leakage of air and hence oxidation of the test fluid is absolutely prevented, and the loss of inert gas is kept to a minimum. Schematically a pump of the proposed type would appear as shown in Figure 1. Pumps of this type are commercially available in suitable sizes at reasonable cost.

The operating conditions for the facility are limited by

1. the head and/or pressure attainable from a commercial single stage centrifugal sump-type pump capable of handling high temperature fluids.

2. the flow rate attainable from such a pump.

3. the maximum allowable operating temperature of such a pump.

4. the allowable suction specific speed for the pump, since suction pressure is fixed by the requirement of the inert gas pressure exceeding atmosphere only slightly.

5. minimum throat velocity, since it is necessary to diffuse the fluid from the cavitating pressure in the venturi throat up to suction pressure.

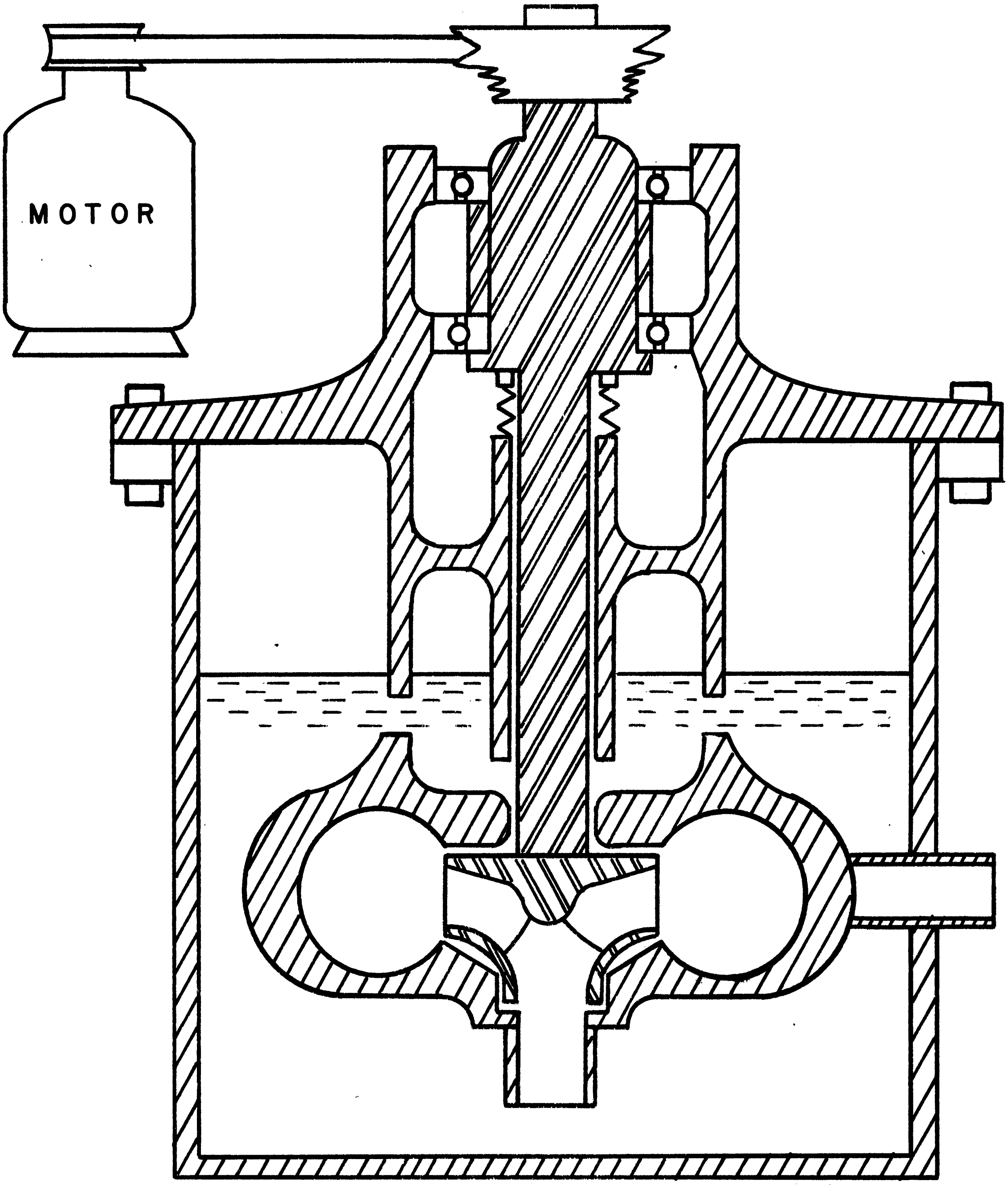


FIG. I

LIQUID METAL PUMP & DRIVE VERTICAL OVERHUNG SHAFT INERT GAS BLANKET-MOTOR DRIVE.

A preliminary survey has disclosed that a pump manufactured by the Berkeley Pump Company of Berkeley, California, capable of pumping molten bismuth at 1000°F at a design point flow rate of 40 GPM against a head of 45 feet of fluid at 1800 RPM, seems most suitable. This pump is a vertical, sump-type unit similar to that shown in Figure 1 with a Vee-belt drive allowing various pump speeds from a constant speed motor. A firm quote of $1000 for this unit has been obtained.

The preliminary facility design has been based upon the Berkeley pump. The test fluids considered were liquid bismuth (or lead-bismuth, or mercury) and sodium (or NaK). Maximum allowable temperature for the pump is 1000°F. It is conceivable that various other fluids of interest could also be utilized as the research program continued. An initial facility shake-down with ordinary water and a transparent test section is planned.

The design speed of the pump is 1800 rpm. However, checks of critical speed, bearing loads, and stresses of critical components have indicated that an operating speed of 3600 rpm should be feasible for fluids with a specific gravity of the order of unity. For fluids such as bismuth, where the specific gravity is approximately 10, the pressures become excessive at the higher speed, so that a strengthened casing would probably be required. Consequently, operation based on speeds of 1800 rpm and lower for the heavy fluids and 3600 rpm and lower for the light fluids has been considered.

The proposed facility is as shown schematically in Figure 2. The system comprises a closed loop of piping of minimum length, only sufficient to provide an adequate straight run ahead of both the cavitating and the flow measuring venturi. A total piping length of approximately 15 feet is necessary. Consistent with the pressure, temperature, and flow rate requirements, 1-1/2 inch, Schedule 80, stainless steel pipe has been selected.

Two throttling valves have been included in the system, one after the pump discharge ahead of the cavitating venturi and the other before pump suction and after both venturis. Assuming a fixed pump speed (as determined by the motor speed and the pulley ratio), a valve between pump discharge and cavitating venturi is necessary to achieve vapor pressure conditions in the venturi throat. The second valve is then necessary to reduce the pressure from the diffuser section of the venturi to that of pump suction which is fixed by the inert gas-sealant system requirement. Cavitation under reduced velocity conditions can be achieved either by more severe throttling of the primary valve or by reducing pump speed. From the viewpoints of pump off-design radial thrust load, power requirements, and extraneous fluid noises, reducing pump speed rather than additional throttling seems desirable. This can be achieved in steps through the provision of a suitable set of stepped pulleys. Small adjustments necessary to achieve the proper cavitating operation at these various speeds can be made with the valves.

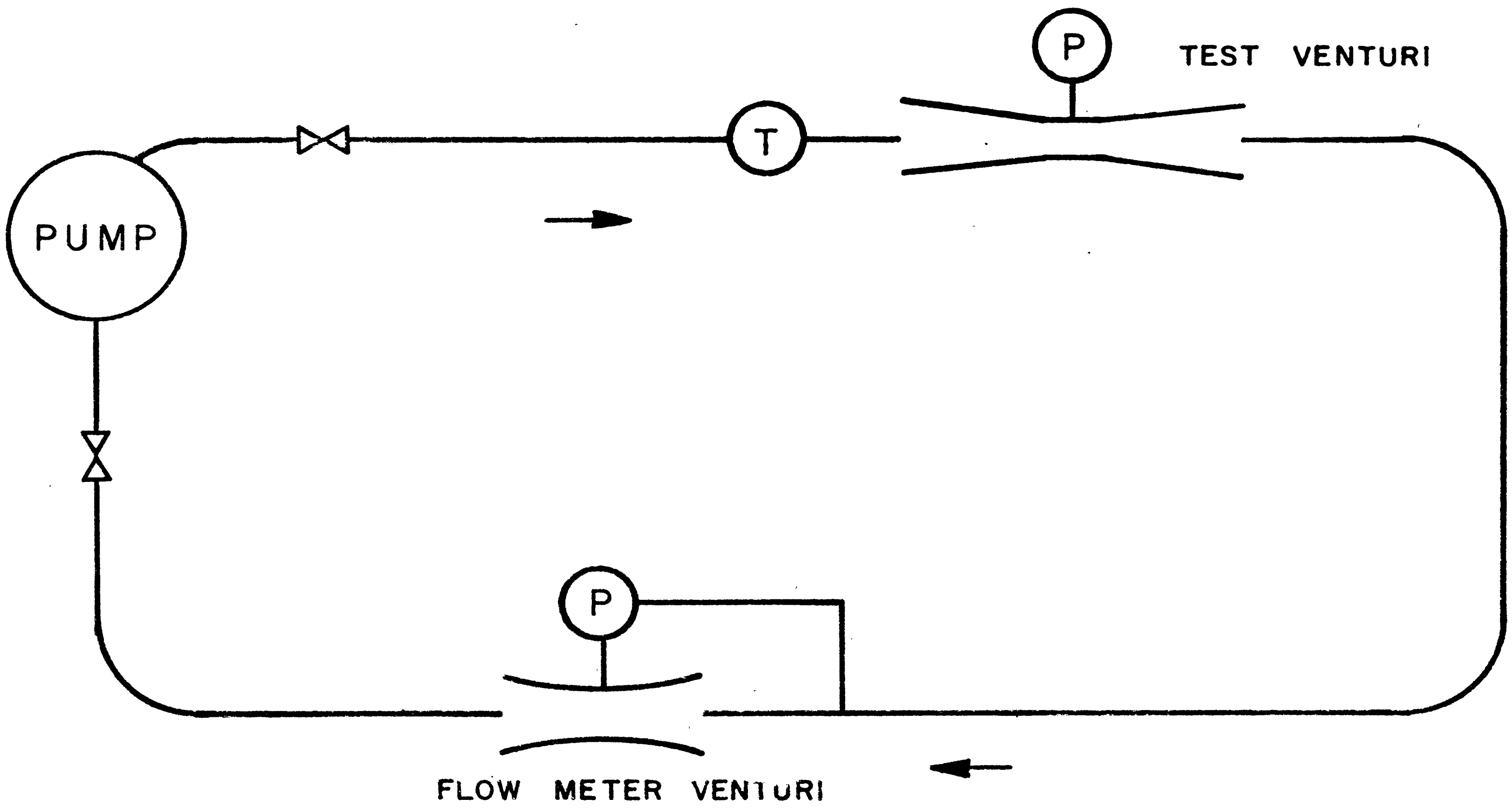


FIG. 2 FACILITY SCHEMATIC

Under the condition of fixed suction pressure (equal to inert gas pressure plus submergence), it will be necessary to adjust both valves to achieve suitable operation.

Figure 3 shows suitable operating conditions for attaining with bismuth cavitating throat velocities of 50, 40, 30, and 20 feet per second. The pump flow, head, speed, and the primary (i.e., upstream) valve drop are shown. Under the conditions of estimated hydraulic losses in the loop, it is noted that the minimum velocity from which it is possible to diffuse from throat pressure to pump suction pressure is about 22 feet per second. This assumes that the venturi and the pump suction are on the same level. However, it appears possible to elevate the venturi section and thus obviate this lower limitation. Such an arrangement would have the advantage of allowing a gravity drain of the system to the pump sump tank which would also serve as storage tank.

Figure 4 shows for bismuth the head loss to be assumed in the downstream valve to reduce the pressure from venturi discharge to pump suction. Also indicated is the drop which would be provided by a fixed restriction at this point suitably adjusted for the maximum flow. It is noted that such a fixed restriction would be too severe at all reduced flows and thus an adjustable valve is required.

Figures 5 and 6 give similar data for the sodium system, utilizing the same piping and venturis. It is noted that in this case, with a maximum pump speed of 3600 rpm, a maximum throat velocity of 100 feet per second can be achieved. Here the minimum velocity, fixed by the positive gage pressure requirement in the pump sump, is approximately 40 feet per second. This can be reduced only slightly by a small elevation of the venturi, since the density of the fluid is less than that of bismuth by a factor in excess of 10.

Figures 7 and 8 list the density and viscosity for sodium and bismuth as functions of temperature.

Tables I and II list the velocities, flow rates, pressure, horsepowers, speeds, and suction specific speeds for bismuth and sodium respectively under the various operating conditions. It is noted that all values are reasonable. The maximum operating conditions for bismuth and sodium respectively are 50 feet per second, 1000°F, and 100 feet per second, 1000°F. These compare with 75 feet per second, 1200°F, and 300 feet per second, 1500°F, for the blowdown facility.

The previously discussed operating points have all been based upon a venturi throat diameter of .5625 inches. In order to determine the possible existence of a scale effect, it may be desirable to operate with smaller as well as larger throat sections, at velocities (for the larger throats) less than the maximum. Such tests would require off-design pump operation. However, it would not be necessary that they be conducted under maximum head conditions or for long durations.

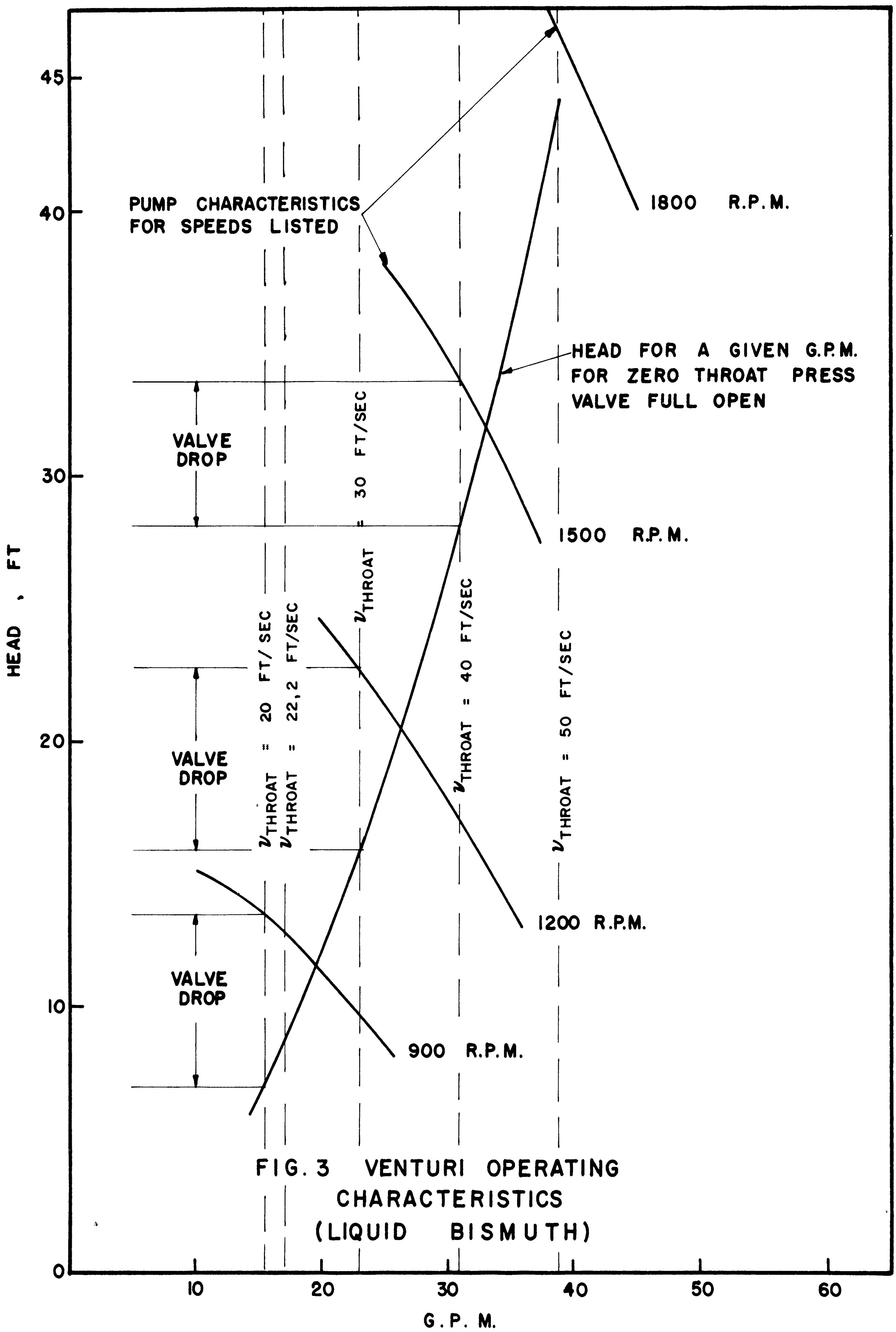


FIG. 3 VENTURI OPERATING CHARACTERISTICS (LIQUID BISMUTH)

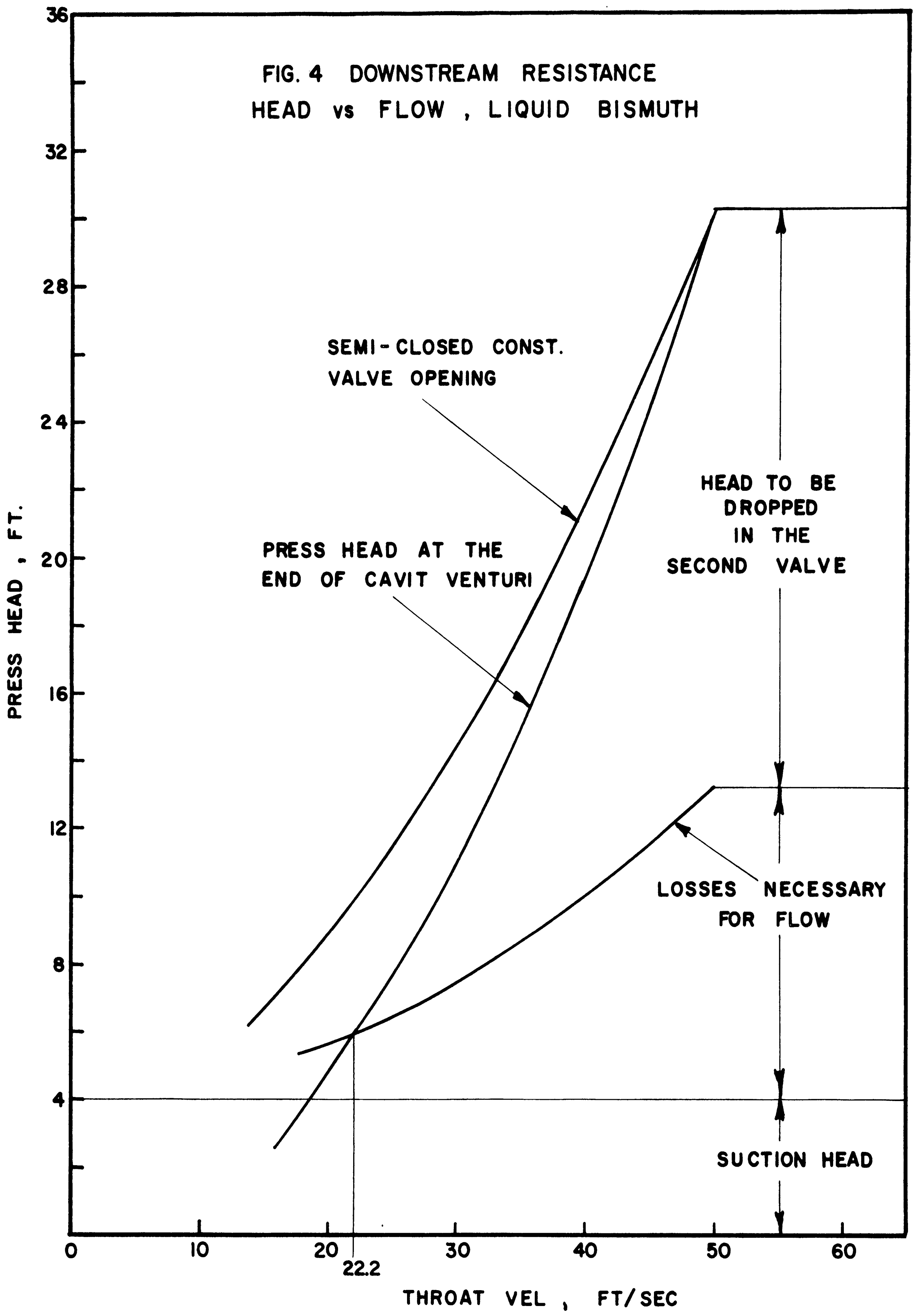
FIG. 4 DOWNSTREAM RESISTANCE
HEAD vs FLOW, LIQUID BISMUTH
SEMI-CLOSED CONST. VALVE OPENING
PRESS HEAD AT THE END OF CAVIT VENTURI
HEAD TO BE DROPPED IN THE SECOND VALVE
LOSSES NECESSARY FOR FLOW
SUCTION HEAD
PRESS HEAD, FT.
THROAT VEL, FT/SEC
36
32
28
24
20
16
12
8
4
0
10
20
22.2
30
40
50
60

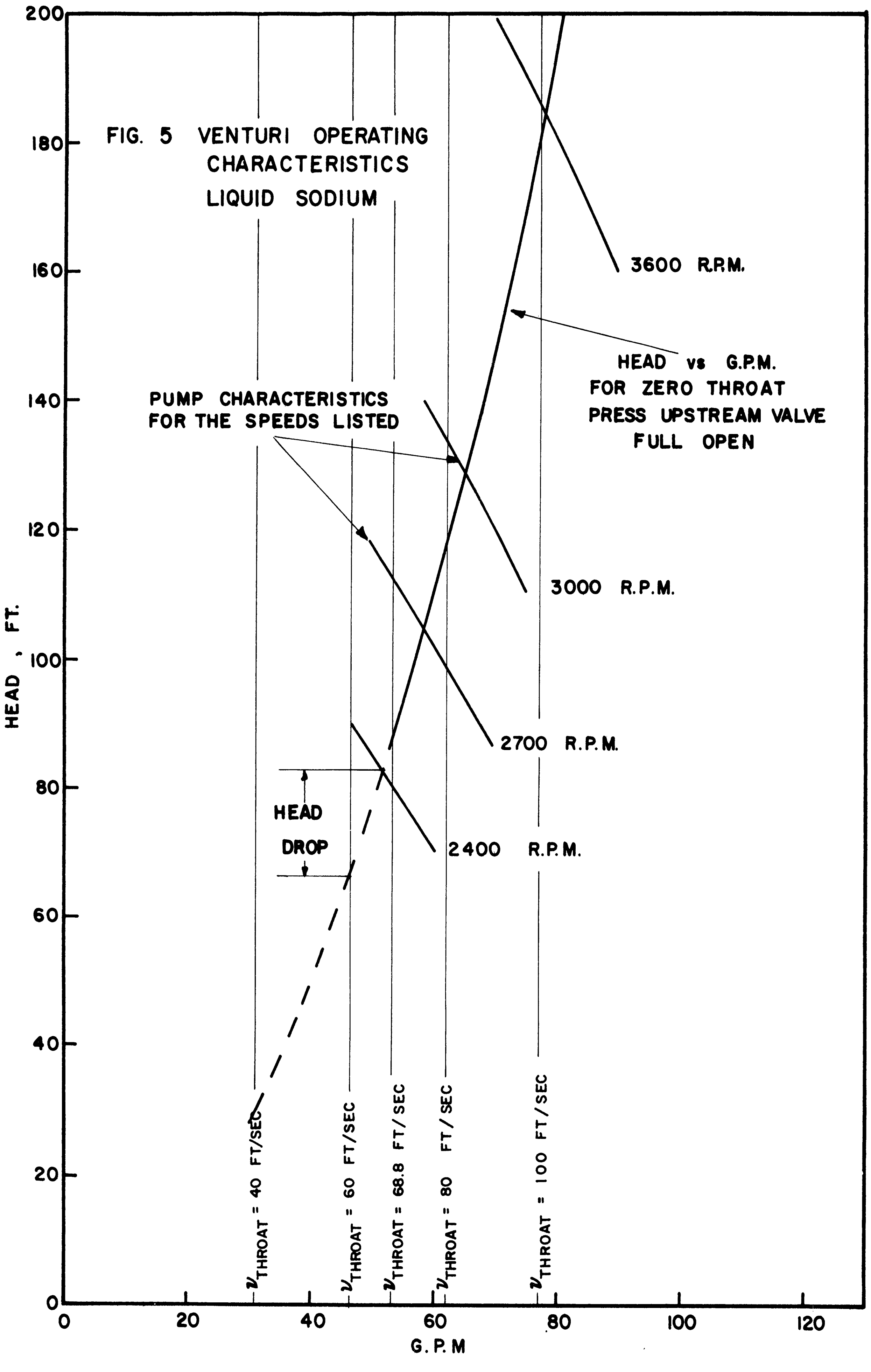
FIG. 5 VENTURI OPERATING CHARACTERISTICS LIQUID SODIUM
3600 R.P.M.
HEAD vs G.P.M. FOR ZERO THROAT PRESS UPSTREAM VALVE FULL OPEN
PUMP CHARACTERISTICS FOR THE SPEEDS LISTED
3000 R.P.M.
2700 R.P.M.
2400 R.P.M.
HEAD DROP
HEAD , FT.
G. P. M
$v_{THROAT}$ = 40 FT/SEC
$v_{THROAT}$ = 60 FT/SEC
$v_{THROAT}$ = 68.8 FT/SEC
$v_{THROAT}$ = 80 FT/SEC
$v_{THROAT}$ = 100 FT/SEC
0
20
40
60
80
100
120
140
160
180
200

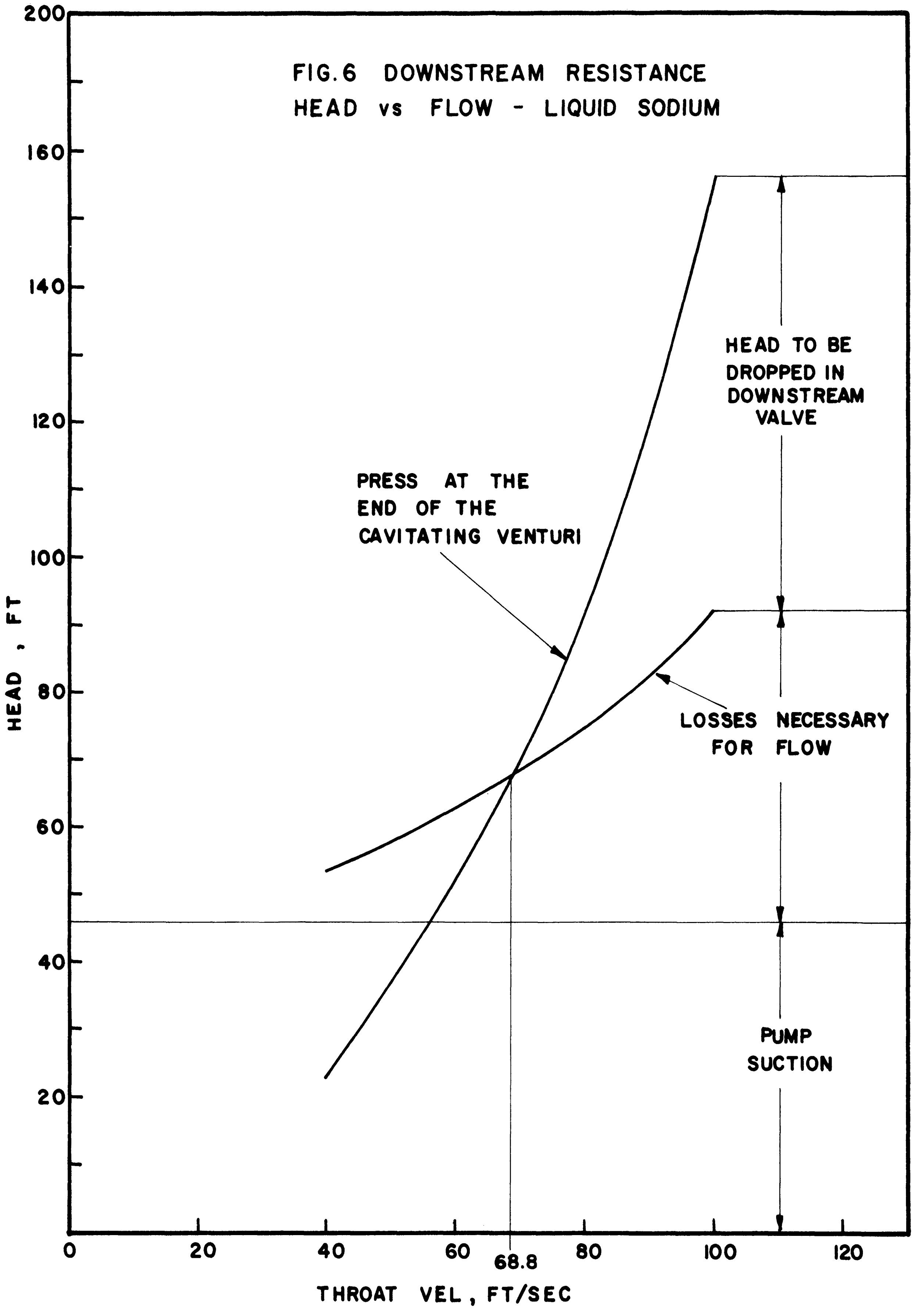
FIG. 6 DOWNSTREAM RESISTANCE
HEAD vs FLOW - LIQUID SODIUM
200
160
140
120
100
80
60
40
20
HEAD , FT
HEAD TO BE
DROPPED IN
DOWNSTREAM
VALVE
PRESS AT THE
END OF THE
CAVITATING VENTURI
LOSSES NECESSARY
FOR FLOW
PUMP
SUCTION
0
20
40
60
68.8
80
100
120
THROAT VEL, FT/SEC

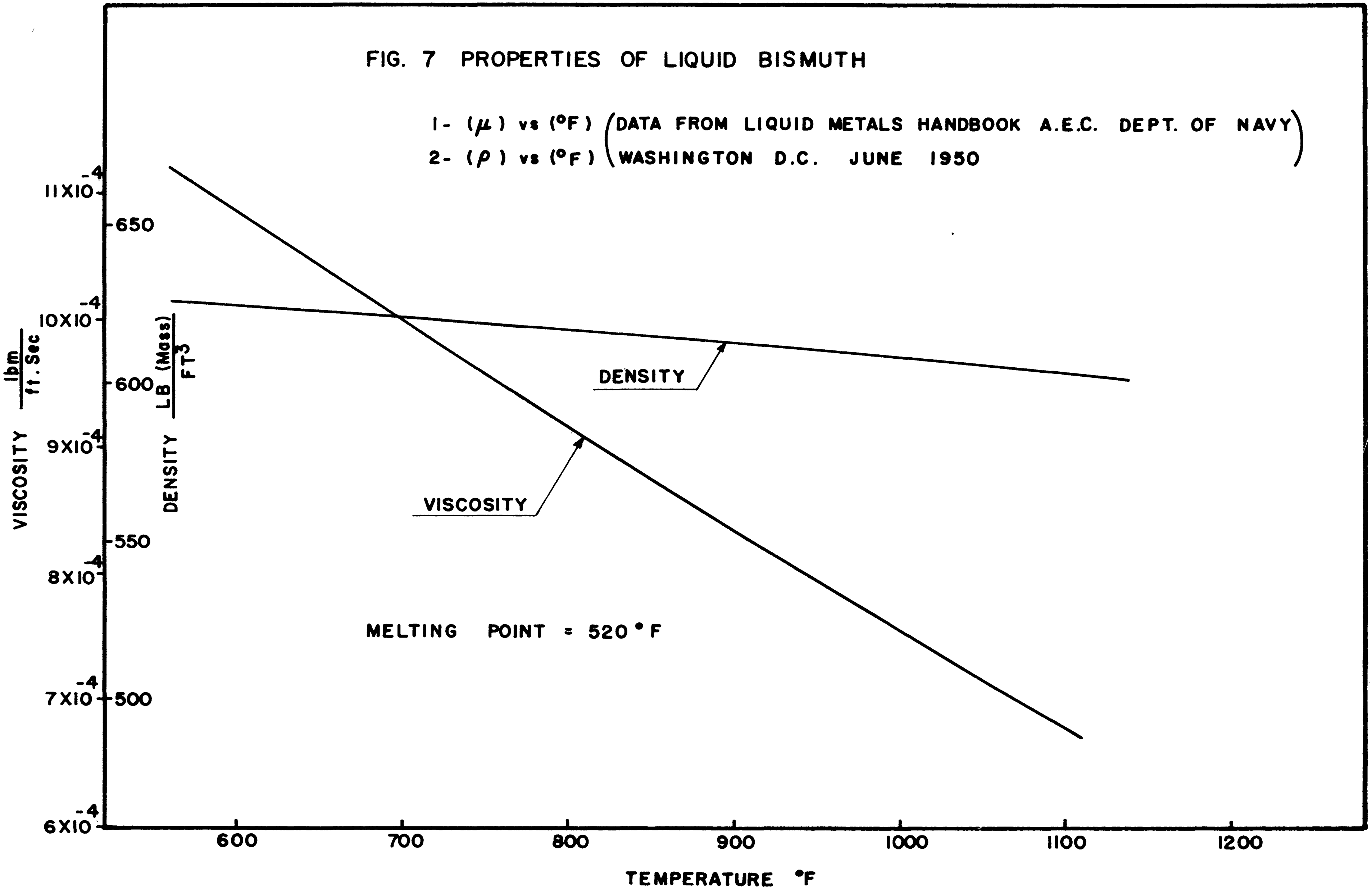


FIG. 7 PROPERTIES OF LIQUID BISMUTH

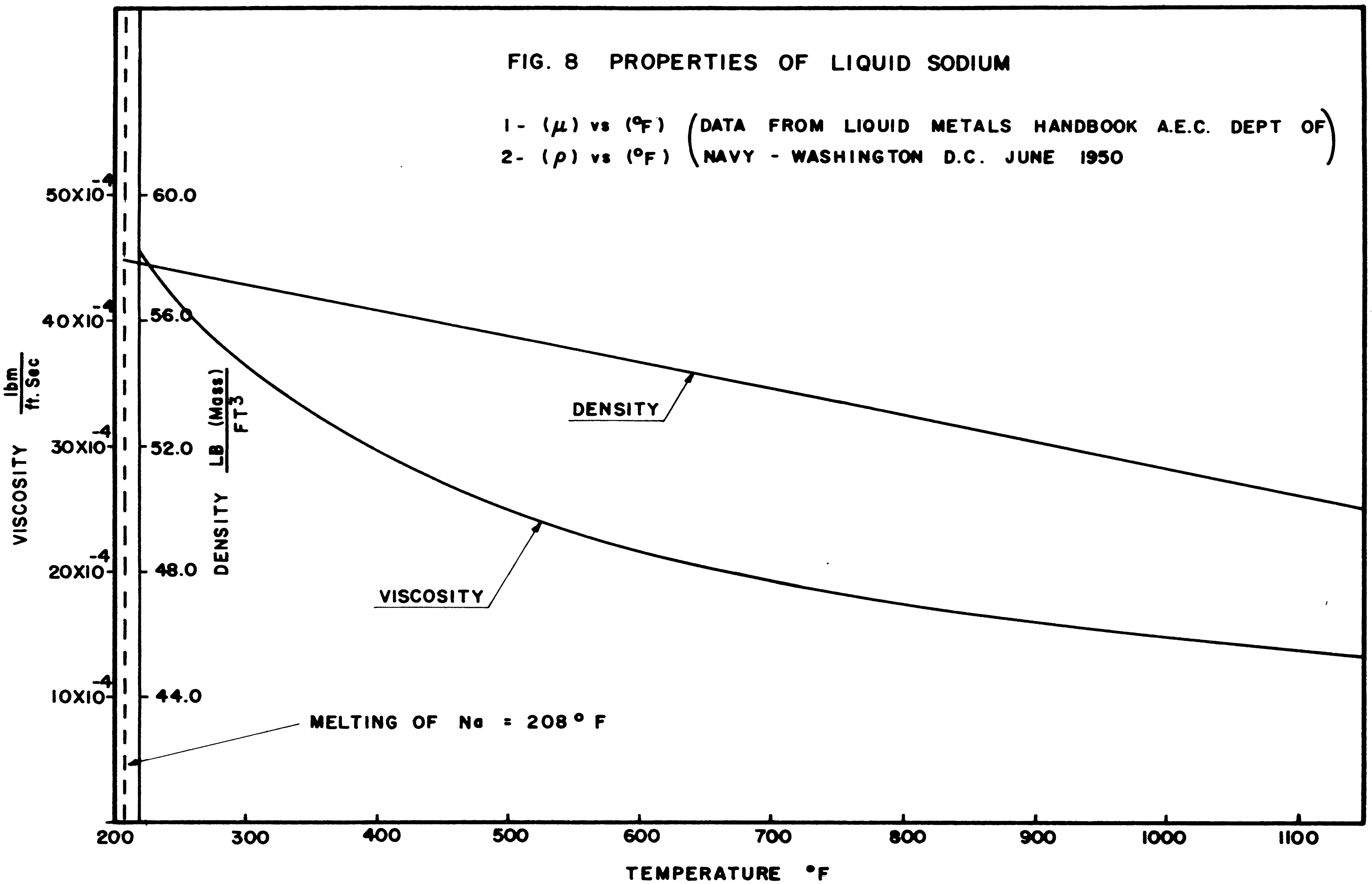


FIG. 8 PROPERTIES OF LIQUID SODIUM

TABLE I

BISMUTH OPERATING CHARACTERISTICS

| Venturi Velocity $V_T$ ft/sec | Pipeline Velocity $V_p$ ft/sec | Pump Disch. Q GPM | Pump Head H ft | Pump Speed N RPM | Pump Disch. Press. $p_d$ psia | Venturi Inlet Press. $p_{vi}$ psia | Venturi Exit Press. $p_{ve}$ psia | Pump Suction Press. $p_s$ psia | Suction Specific Speed Ns (Approx) | Ideal Pump Power Input Pi HP | Overall Pump Eff. η % | Motor Output Pm HP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 50 | 7.0 | 38.6 | 46.70 | 1800 | 200.0 | 180.0 | 128.0 | 16.9 | 4000 | 7.28 | 33.0 | 21.84 |
| 40 | 5.6 | 30.9 | 33.75 | 1500 | 143.0 | 115.0 | 82.0 | 16.9 | 3000 | 4.20 | 33.0 | 12.60 |
| 30 | 4.2 | 23.2 | 22.75 | 1200 | 96.5 | 65.0 | 46.0 | 16.9 | 2000 | 2.80 | 33.0 | 8.40 |
| 25 | | 19.5 | 11.5 | 900 | 48.6 | - | - | - | - | 2.24 | 33.0 | 4.48 |

<u>Note</u>: The figures for the row of throat velocity in venturi of 25 ft/sec are derived from Figure 3.

TABLE II

SODIUM OPERATING CHARACTERISTICS

| Venturi Velocity | Pipeline Velocity | Pump Disch. | Pump Head | Pump Speed | Pump Disch. Press. | Venturi Inlet Press. | Venturi Exit Press. | Pump Suction Press. | Suction Specific Speed | Ideal Pump Power Input | Overall Pump Eff. | Motor Output |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $V_T$ | $V_p$ | Q | H | N | $p_d$ | $p_{vi}$ | $p_{ve}$ | $p_s$ | Ns | Pi | $\eta$ | Pm |
| ft/sec | ft/sec | GPM | ft | RPM | psia | psia | psia | psia | (Approx) | HP | % | HP |
| 100 | 14.25 | 77.4 | 186 | 3600 | 67.5 | 63.8 | 55.0 | 16.7 | 1800 | .305 | 33.0 | .915 |
| 80 | 11.41 | 62.0 | 118 | 3000 | 42.8 | 41.2 | 33.2 | 16.7 | 1350 | .155 | 33.0 | .465 |
| 70 | | 54.5 | 92.0 | 2700 | 33.2 | - | - | 16.7 | 1125 | .106 | 33.0 | .318 |

Note: The figures for the row of throat velocity in venturi of 70 ft/sec are derived from Figure 5.

Heating of the loop would be accomplished by wrapping of the equipment with electrical heating wire. Pump work would be a considerable contribution to the heating so that in some cases it might be necessary to provide a finned cooling section on the pipe. In any case, the heating elements would be necessary to melt the charge at the start of operation.

The valves would be of the bellows-sealed type so that zero leakage would be achieved. Suitable valves are manufactured by several concerns and quotations have been obtained.

The instrumentation for pressure, temperature, and flow measurement would be as described in References 1 and 2 and would be adaptable to an eventual blowdown facility if such were eventually desired. The sonic equipment would also be as described in these references. It would probably be necessary to utilize suitable filters to remove relatively low frequency noise originating in the pump and in the fluid turbulence.

## 4.0 RESEARCH PROGRAM

The research program generally would be similar to that described in References 1, 2, and 3 except that the test fluids would be limited to ordinary water, molten bismuth (or lead-bismuth or mercury), and sodium (or NaK). The program would be initiated with an equipment shakedown using ordinary water and a transparent test section. This preliminary phase would be useful in calibrating the flow and pressure instrumentation, generally testing out the equipment, and determining the type of cavitation generated by the facility. The sound pattern created by such cavitation could be observed and perhaps correlated to some extent with the other parameters as well as the visual appearance.

The second phase of the program would be conducted with one of the liquid metals. It might be desirable to utilize mercury as a first step at low temperature in the transparent test section. This would serve to provide some visual indication along with the flow, pressure, and sonic measurements.

The succeeding phases would encompass the other liquid metals of interest in steel test sections at elevated temperature. Damage results would be noted visually at disassembly or perhaps detected more rapidly by means of irradiated test sections and down-stream monitoring.

At the conclusion of the liquid metal test phases it would be possible to judge the desirability of proceeding with more severe test conditions. In the case of an affirmative decision it would be necessary to determine the relative advantages of the procurement of a higher performance pump or of proceeding to the construction of the previously proposed blowdown-type facility.

## 5.0 ESTIMATED EQUIPMENT COSTS

The estimated costs of equipment follow:

| | ITEM | SPECIFICATION | ESTIMATED COST |
|---|---|---|---|
| 1. | Test Sections (steel) | 3 sections (Fig. 2, 3, 4 of Reference 2) | $1000 |
| 2. | Test Section (glass) | 2 sections | 400 |
| 3. | Liquid Metal Valves for Main Loop | 1-1/2 inch, bellows seal 2 required | 1500 |
| 4. | Filling Equipment and Valves | | 400 |
| 5. | Electrical Heating Wire and Controls, Thermal Insulation | | 300 |
| 6. | Flow Meter | Venturi and pressure measuring instrumentation | 1500 |
| 7. | Throat Pressure Gage | Callery Chemical unit | 1300 |
| 8. | Inert Gas System | | 100 |
| 9. | Sonic Equipment | Amplifier, pick-up, sound box | 1000 |
| 10. | Liquid Metal Pump | Berkeley sump-type pump | 1000 |
| 11. | Sump Tank | | 200 |
| 12. | Drive Motor | 25 hp, 3600 rpm, a.c. with pulley drive | 500 |
| 13. | Loop Piping | Sch. 80, 316 SS, 1-1/2 inch 20 ft. plus elbows, etc. | 50 |
| | | TOTAL | $9250 |
| | | TOTAL (with contingency 20%) | 11,100 |

Items 1) through 9) encompass items identical with those required for the blowdown facility.

The estimated equipment cost for the blowdown facility (Reference 3) was $25,000. Neither estimate has included the cost of the test fluid itself. Where this is appreciable, as with mercury or bismuth, it has been determined that it may be returned at the conclusion of the tests with very little depreciation.

## 6.0 BIBLIOGRAPHY


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